Potentials for Efficiency Improvement out of the Synchronizer

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Abstract:

The constantly increasing requirements to reduce motor vehicle CO2 emissions cannot, in the medium term, be met by increased electrification of the driveline alone. Further development and optimization of conventional drivelines thus remain the primary focus. It is highly significant that the trends in engines toward higher torque, in conjunction with downsizing and downspeeding, are not always suitable to allow efficiency improvements in the gearbox. High torques often require large start-up clutches, which consequently influences shift elements and their capacity.

What may result in improved or maintained shifting comfort, can rapidly lead to performance degradation in the transmission. In this context, consideration of efficiencies in the shifting system is increasingly gaining in importance.

This paper will discuss which losses can occur in the synchronizers and their effect on total system efficiency as well as shift quality. The discussion will not be limited to the obvious area of drag torque between the cone friction surfaces, but will also treat the effect of friction in shift operations and the contribution of shift elements to weight and inertia of the rotating gearbox components.

The prerequisite for a reduction of losses is exact measurement in both the transmission and sub-systems. We will present measurement procedures for this as well as typical results. These results represent the basis on which optimizations can be performed and reviewed.

As a developer and manufacturer of entire synchronizer systems, HOERBIGER has the tools required to develop optimal applications with reduced performance degradation. Starting with friction lining technology through the design of friction components to the tuning of all components in the hub system – only optimized interaction of all components can achieve improvements that lead to the desired result.

Further, the vital element of intensive cooperation between the transmission manufacturer and system supplier should not be underestimated - this is critical in exploiting all potentials for improving synchronizer efficiency.

Kurzfassung:
Die ständig steigenden Anforderungen zur Reduzierung des CO2-Ausstoßes von Kraftfahrzeugen lassen sich mittlefristig nicht alleine durch die zunehmende Elektrifizierung des Antriebes erfüllen. Die Weiterentwicklung und Optimierung der konventionellen Antriebe bleibt daher im Fokus. Von großer Bedeutung ist es, dass die motorischen Trends hin zu höheren Drehmomenten in Verbindung mit Downsizing und Downspeeding nicht immer geeignet sind, im Getriebe Wirkungsgradverbesserungen zuzulassen. Die zu übertragenden hohen Drehmomente erfordern oft größere Anfahrkupplungen, was in der Folge auch Einfluß auf die Schaltelemente und deren Kapazität hat.

Was zur Verbesserung oder zur Aufrechterhaltung des Schaltkomforts wichtig ist, kann sehr schnell zur Erhöhung von Verlustleistungen im Getriebe führen. Vor diesem Hintergrund gewinnt auch die Betrachtung der Wirkungsgrade im Schaltsystem zunehmend an Bedeutung.

In diesem Paper wird erläutert, welche Verluste in Synchronisierungen entstehen können und wie sich diese auf den Gesamtwirkungsgrad aber auch die Schaltqualität auswirken können. Die Betrachtung beschränkt sich nicht nur auf den offensichtlichen Bereich der Schleppmomente zwischen den Konusreibflächen sondern beleuchtet auch die Wirkung von Reibung in den Schaltbetätigungen und den Beitrag der Schaltelemente zu Gewicht und Massenträgheitsmoment der rotierenden Getriebeteile.

Voraussetzung für die Reduzierung von Verlusten ist die genaue Messung sowohl im Getriebe als auch an den Teilsystemen. In diesem Paper werden dazu Messverfahren und typische Ergebnisse vorgestellt. Diese Ergebnisse stellen die Basis dar, auf der Optimierungen vorgenommen und überprüft werden können.

HOERBIGER verfügt als Entwickler und Hersteller von kompletten Synchrosystemen über die erfoderlichen Tools zur Entwicklung optimierter Lösungen mit reduzierten Verlustanteilen. Angefangen von der Technologie des Reibbelages über die Gestaltung der Reibkomponenten bis hin zur Abstimmung aller Komponenten im Nabensystem – erst im optimierten Zusammenspiel aller Bauteile können zielführende Verbesserungen erzielt werden.

Nicht zu unterschätzen ist darüberhinaus die intensive Zusammenarbeit zwischen dem Getriebehersteller und dem System-Zulieferer, um alle Potentiale zur Verbesserung des Wirkungsgrades von Synchronisierungen auszuschöpfen.

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1. Introduction

Synchronizers in MTs, AMTs or DCTs are shift elements functioning as a cone friction clutch to equalize the speed between the gear wheel and transmission shaft while providing positive engagement for transmission of the drive torque. In general, losses occur both during gear synchronization as well in non-shifted synchronizers. A distinction must be made between upshifting and downshifting with respect to synchronization. During downshifts, acceleration of the engine-side rotating masses results in performance loss; during a synchronzation time of e.g. 0.2 seconds, the vehicle can be decelerated by about 50 Nm at the shift point. Conversely, during upshifts the engine-side rotating masses are decelerated and the resulting energy is available as driving power during shifting.
However, frictional heat is created which must be conducted away via the oil as dissipation power.

Furthermore, losses that are only briefly effective during shifting will not be considered in detail. More important are energy losses that can influence transmission efficiency over an extended period.

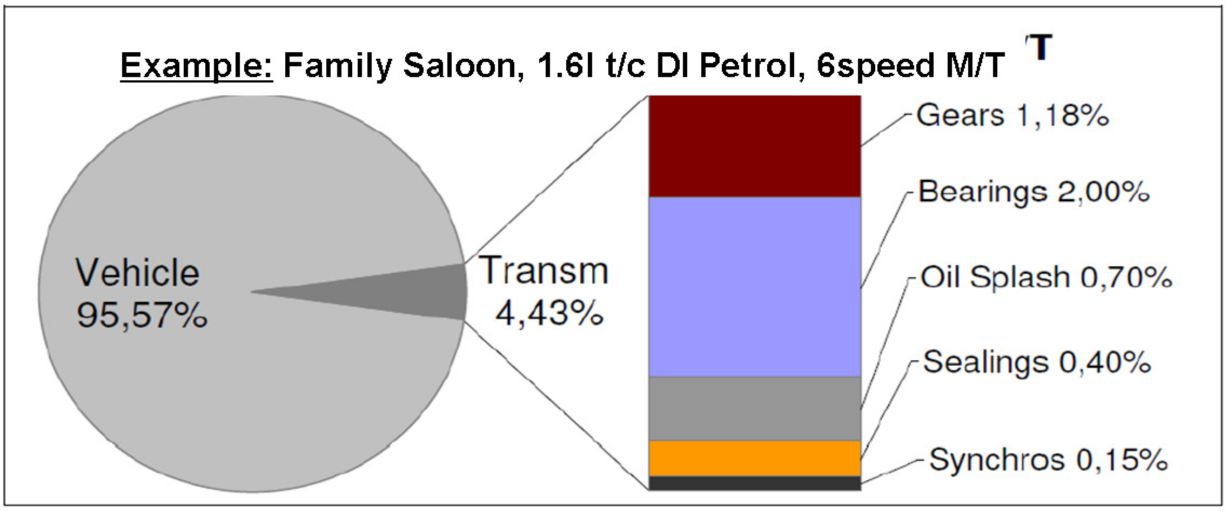
The article under [1] indicated that synchronizer losses, applied to the entire vehicle, amount to about 0.15%. This does not seem like much. However, related to the gearbox, this amounts to 3.3% and should not be ignored, especially since inefficient design can significantly increase the proportion of this loss.

This paper will discuss loss arising from synchronization and its influence within the transmission. Drag losses are particularly significant; they must be metrologically determined in relation to different influences and correspondingly included in the overall analysis.

Based on knowledge of sources of degradation, technical solutions can be developed that can contribute to total efficiency improvement. Solutions already currently in development will be presented, as well as areas of interest in which development is still needed.

2. Losses in the shift system

Shift systems in MTs consist of an external shifting mechanism connecting the driver with the gearbox, and an internal shifting mechanism conducting shifting force to the respective synchronizing mechanism and synchronizer. During shifting, the synchronizer provides speed equalization between the gear wheel and shaft, and once synchronized, provides a positive engagement for torque transmission.



Source: F. Casimir, GETRAG, CTI-Symposium 2011, Berlin

Figure 1: Portion of synchronizer losses

In AMTs and DCTs there is no direct connection to the driver; the shifting force is directed to the internal shifting mechanism electromechanically or hydraulically.

Depending on the shift direction, frictional torque generated in the cone friction clutch for synchronization can provide either driving torque or braking torque. On the whole, resulting losses can be ignored.

Losses in the external and internal shifting mechanisms reduce the force available on the sliding sleeve for shifting. Shifting force loss can be thought of as a 1:1 loss of synchronization capacity. In cold conditions, cable-controlled shifting mechanism efficiency can easily drop to 50%, an essential element of poor shifting quality. Shifting effort increases, shifting through the gears is slowed and scratching can easily occur.

With respect to gearbox efficiency, this degradation can likewise be ignored.

An additional area affecting loss is the contribution of synchronizers to the gearbox weight and rotating masses. Both are factors that play a role in acceleration of transmission shafts and vehicle. However, it is difficult for the supplier to evaluate the resulting influences on total vehicle efficiency. This paper will only present potentials for reducing the mass and moment of inertia.

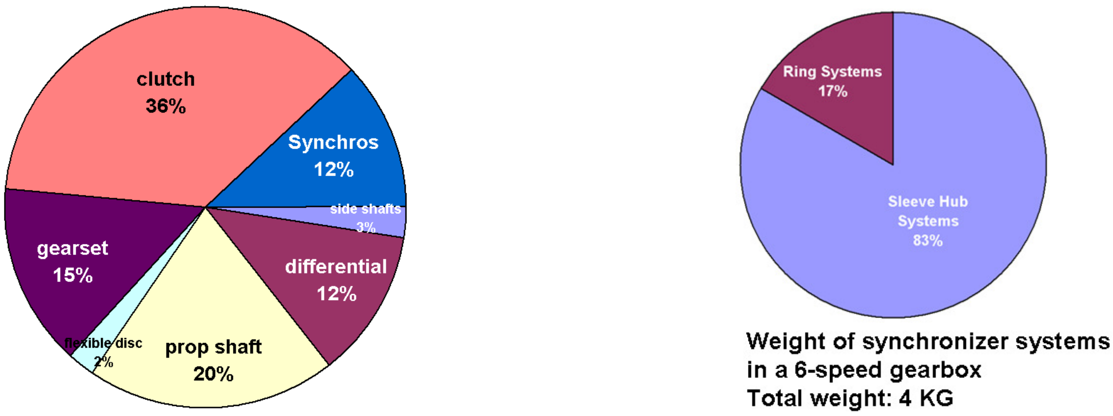


Figure 2: Driveline inertias reflected to input shaft / Weight of synchronizer systems
(3rd gear shifted)

2.1. Drag losses in synchronizers

Drag torque of open cone friction clutches forms the focal point in the determination of synchronizer losses. The synchronizer rings are located between the gear wheel mounted with bearings on the shaft and the hub system joined to the shaft. The number of cones corresponds to the number of gaps between the cones rotating at a differential speed. Depending on their arrangement in the transmission, the gaps are filled with oil to a higher or lesser degree. Additional parameters determining the level of generated drag torque include the oil viscosity, also related to the oil temperature, clearance, differential speed as well as the surface area and frictional surface material.

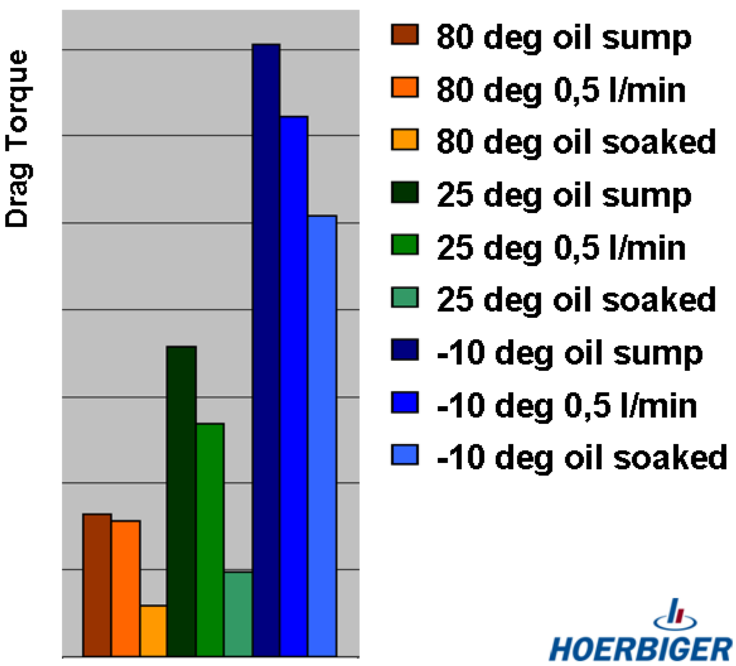


Figure 3: Results of drag torque measurement of a 2-cone friction system

Tests can determine drag losses related to these parameters. In the example shown in Figure 3, various lubrication situations at different oil temperatures in a dual-cone system were examined. It is clear to see that oil temperature-linked viscosity is decisive and leads to significantly higher drag torque even with friction rings wetted only with oil.

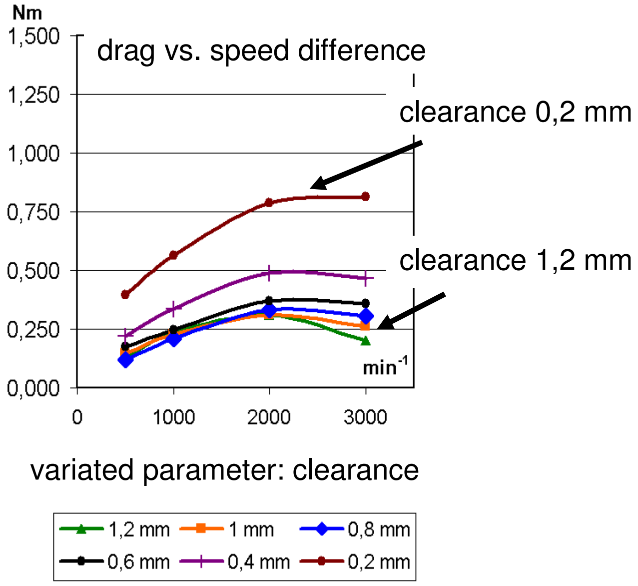
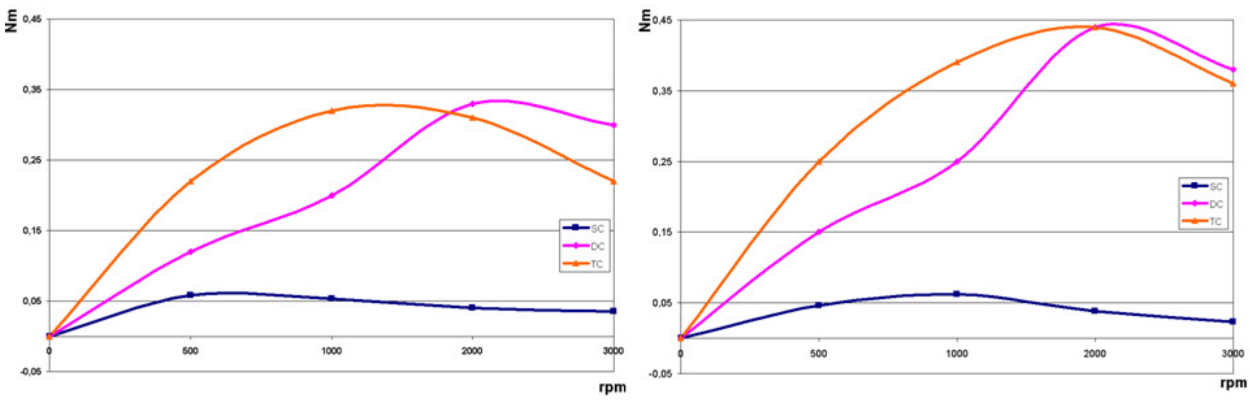


Figure 4: Influence of clearance on drag torque characteristic

An additional essential parameter is the clearance which determines the distance of the cones from each other in an open friction system. Figure 4 clearly shows that drag torque increases significantly when critical clearance is insufficient. If a dual-cone system is designed with the same clearance as a single-cone system, the gap in the dual-cone system is only half as large. The illustration also demonstrates that the drag torque does not increase linearly with the differential speed, but decreases again once a maximum has been reached.



Lining type 1 **Lining type 2**

Figure 5: Comparison of the effects of different friction lining types on drag torque

A comparison of the two diagrams in Figure 5 illustrates the effect of different lining types. The type of material, surface structure and groove geometry result in significant differences. This example compares the characteristics of single-cone, dual-cone and triple-cone systems with the same total clearance. The higher drag torque of the multi-cone systems is determined by the greater number of gaps as well as the reduced distance of the cones from each other with the same total clearance. With smaller gaps, friction lining 2 responds more sensitively and generates greater drag torque than friction lining 1.

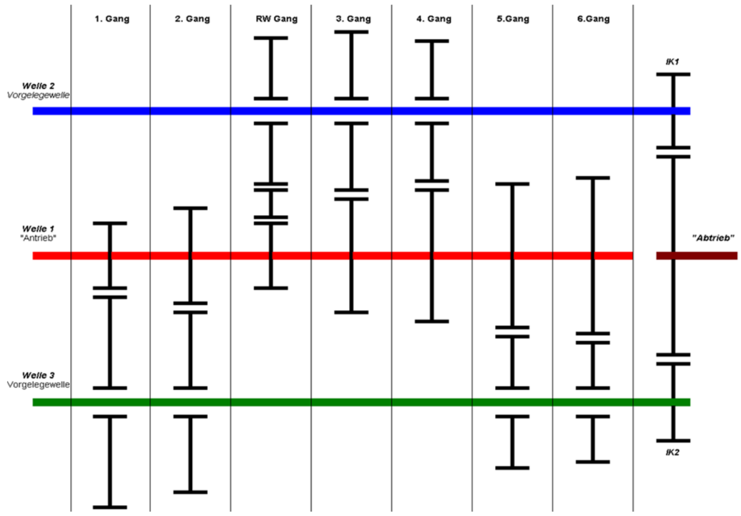


Figure 6: Layout of a 6-speed FWD gearbox

The results of component tests can be used to observe the interaction of all synchronizers in a transmission in various selected gears. Figure 6 shows a layout of a 6-speed FWD gearbox with synchronizers arranged on both main shafts. In this model, measured drag torque curves are provided for each synchronizer. For each selected gear, the drag torque component can now be calculated for the open synchronizers subjected to a differential speed. The sum of individual torques provides the resulting influence on gearbox efficiency related to the input speed.

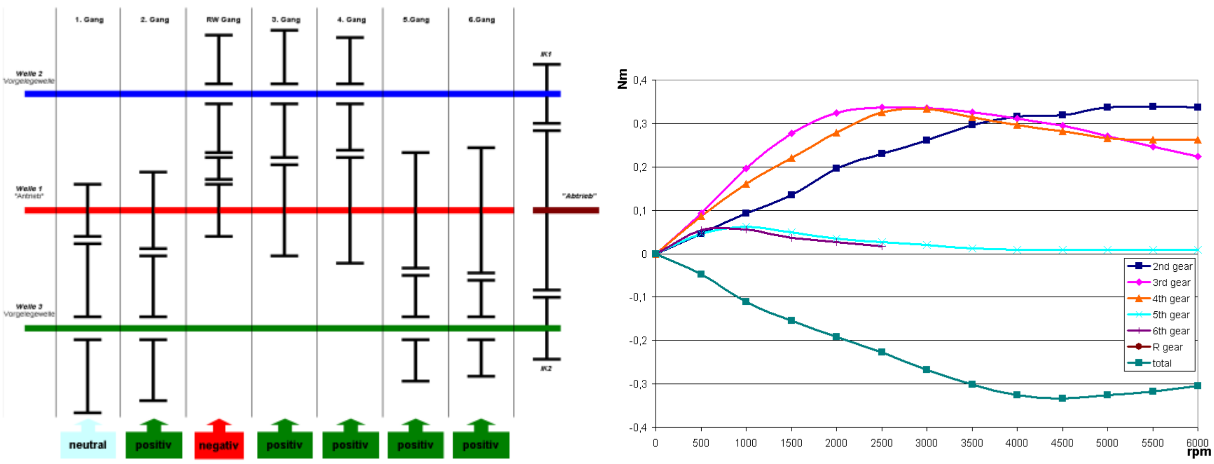


Figure 7: Effect of drag torque in 1st gear

Figure 7 clearly shows that in 1st gear all drag torque of the upper synchronizers is effective in the drive direction and thus does not cause any loss.

There is somewhat of a power split, in that the open synchronizers in which the drive side turns faster than the output side transmit a portion to the total transmission torque. There is only loss related to the lower transmission efficiency compared to the gear wheels; this degradation is discharged as heat.

The diagram in Figure 7 illustrates the effect of individual torques and the total effect on the gearbox. Correspondingly the synchronizers of the upper gears with respect to degradation are of secondary interest. On the other hand, synchronizers of the lower gears as well as reverse gear are highly relevant.

Figure 8 shows the situation for 6th gear for which losses are greatest.

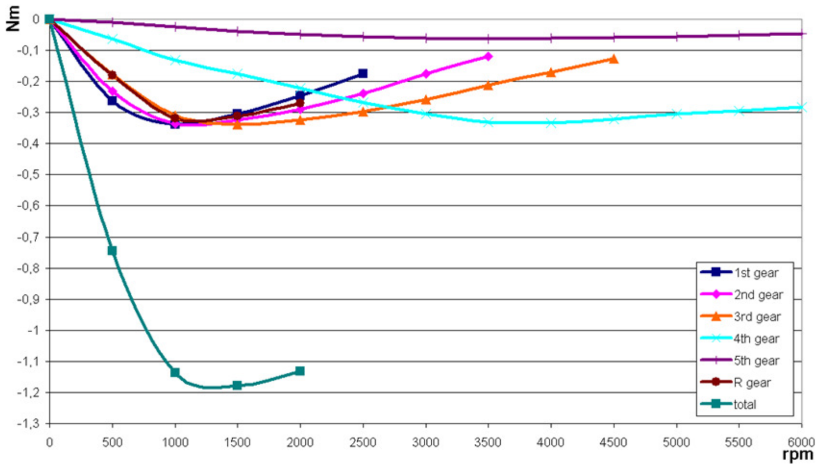


Figure 8: Effect of drag torque in 6th gear

In the lower gears, synchronizers contain several cones which, due to their design, have less clearance per friction surface and thus, on the whole, generate considerably greater losses than single-cone synchronizers. Measures taken in the area will be the most effective. Section 4 will discuss this in more detail.

In this context it is important to note that the effect of drag torque should be evaluated differently when considering its effect on shifting. During synchronization the vehicle is coasting, and the torque from the output is introduced into the gearbox. This means that during a shift from 1 to 2, drag torque effective in the upper gears decelerates the drive-side shafts. This supports upshifting; however when shifting through gears, additional retardation on the drive side can occur, and high 2nd load peaks as well as upshift nibble can arise. Downshifts into the lower gears work against drag torque of the upper synchronizers; this can require higher shifting forces or longer shift times.
Therefore drag torque of the upper gears should also be minimized to improve the shifting quality.

3. Measurement of drag losses in synchronizers

Component tests to measure drag losses in synchronizers were performed on the HOERBIGER µ-comp synchronizer test rig. The rundown curve and drag torque were recorded for each measuring point. The measuring points are summarized in diagrams illustrating the progression of drag torque across the differential speed. (see Figure 9)

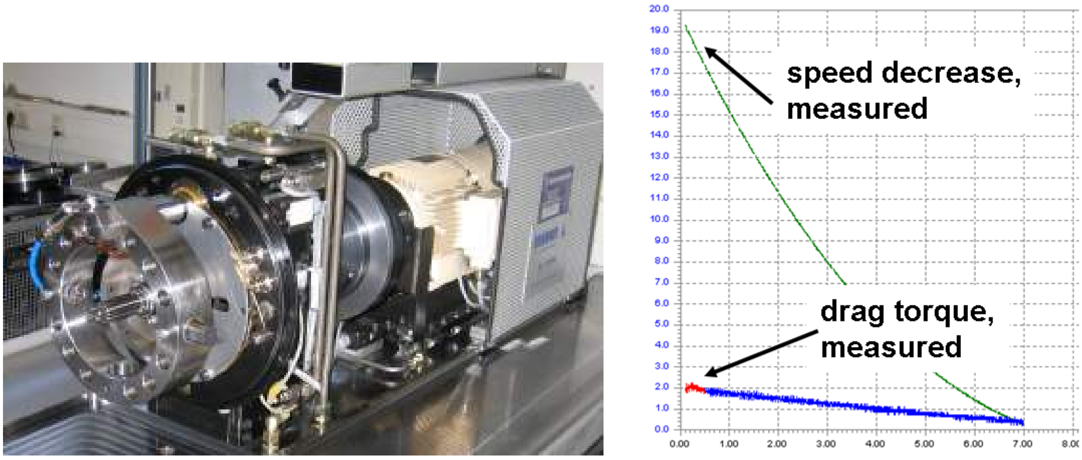


Figure 9: Drag torque measurement on HOERBIGER µ-comp test rig

In addition to synchronizer influences, drag torque curves recorded in complete transmissions also contain losses due to bearings, seals and toothing (without load torque). The gearbox is driven by a torque measuring shaft; there is no load torque on the transmission output. The torque required to propel the drive shaft in various gears is measured. Analogous to the loss calculation in section 2.1, drive torque is the lowest in 1st gear and the greatest in 6th gear.

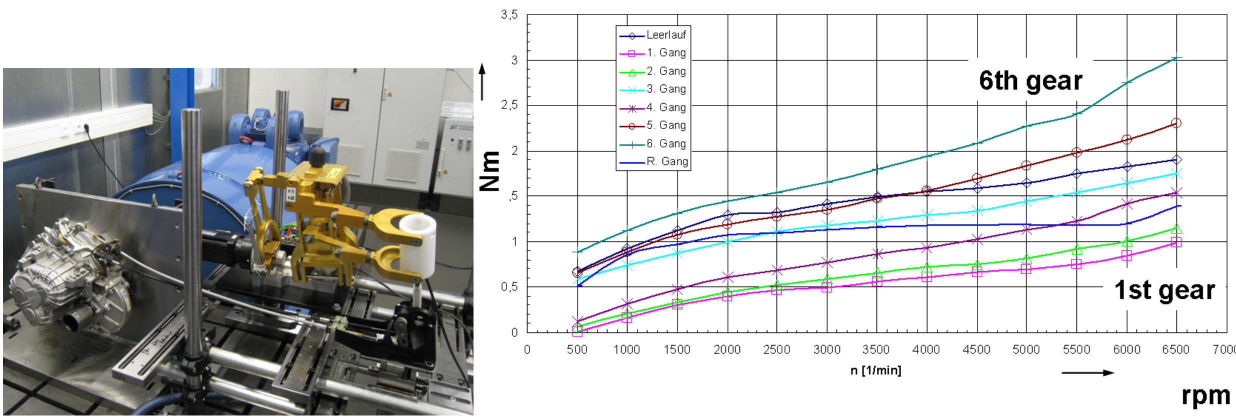


Figure 10: Drag torque measurement on HOERBIGER transmission test rig

4. Design concepts for improved synchronizer systems

Design concepts contributing to loss reduction must relate to loss sources and causal mechanisms described in section 2.

The focus should be the reduction of drag losses in open synchronizers and therefore the highest priority should be the optimization of the lower gears synchronizers. In MTs, the lower gears are generally equipped with multi-cone synchronizers, since their higher synchronization capacity is required to achieve low shifting forces. A reduction of the number of cones would directly result in decreased drag loss; however this requires other means to compensate for the resulting decreased synchronization capacity.
If multi-cone synchronizers are used only to reduce friction surface loads, systems containing single-cone rings with increased load capacity can be used. HOERBIGER offers a broad spectrum of single-cone rings for this with organic or metallic friction linings. Of particular interest in this context is the newly-developed Blocker Ring Evo (BRE) with a sintered friction lining formed with the steel carrier. This achieves extremely high durability in the connection of the lining to the carrier ring, a prerequisite for significant loads and excellent overload protection.

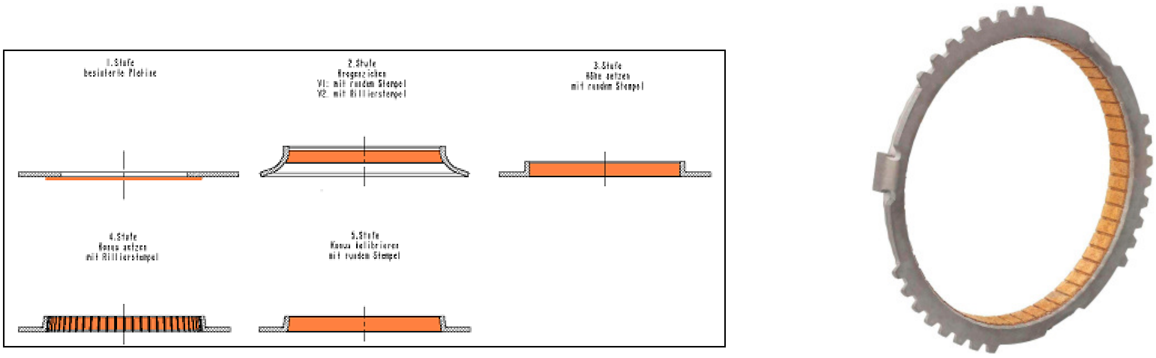


Figure 11: HOERBIGER Blocker Ring Evo BRE

If it is not possible to replace multi-cone systems, it is necessary to provide sufficient clearance in the layout. Since the range of movement of the individual rings increases with enlarged clearance, there is the risk of tumbling and generation of vibration. Problems of this type are characterized by noise; rattling synchronizers also cause increased drag loss. To avoid this, care should be taken to minimize wear in the synchronizer and to ensure that clearance does not become too great during the service life.
As described in section 2, the type of friction lining used also determines the level of drag torque. Since this is particularly an issue in multi-cone systems with narrower gap widths, as many friction surfaces as possible should be provided with sintered friction linings, which generate less wear as well as reduced drag torque.

The HOERBIGER SKS provides an interesting solution - coupling of the synchronizer rings via the blocking units reduces the degree of freedom of the synchronizer rings and measurably contributes to the reduction of rattling. In this system, the sintered friction lining receives an optimal load resulting from the altered force application; this is reflected in extremely limited lining wear. The SKS thus sets the standard with respect to drag torque behavior.

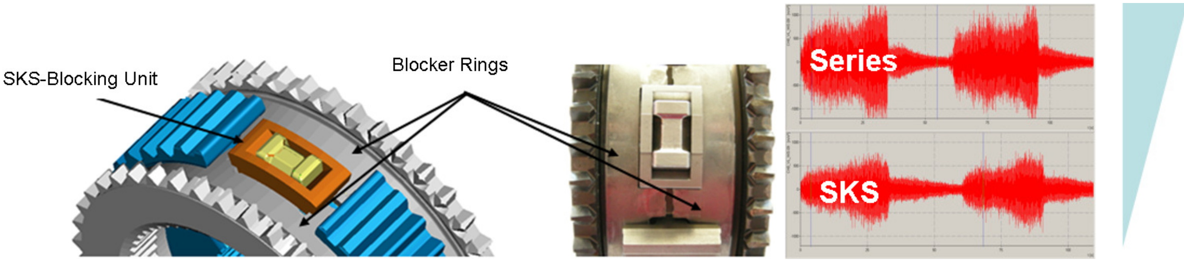


Figure 12: HOERBIGER SKS reduces synchronizer rattle due to coupling of rings

Clearance can also be limited if the sliding sleeve is not positioned centrally on the hub. In this case, clearance is limited on one side; this can result in increased drag torque and even thermal damage to the friction system. Centering the sliding sleeve on the hub remedies this. This can be by means of additional detents or directly integrated into the pre-synchronizer, as is the case with the HOERBIGER SKS.

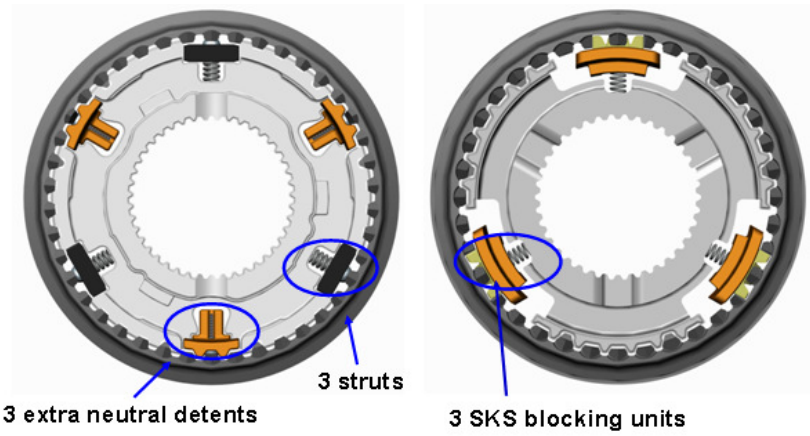
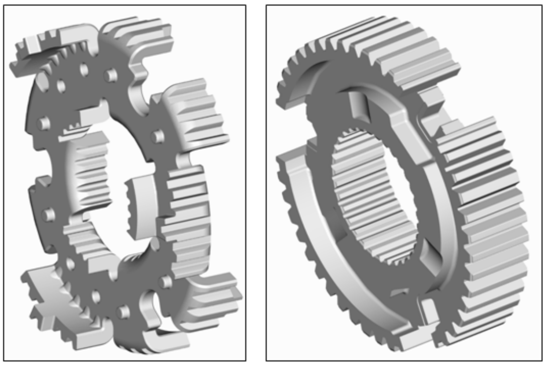


Figure 13: HOERBIGER SKS has centering function integrated in blocking units

As shown in Figure 2, the portion of the sliding sleeve/hub systems accounts for over 80% of the total weight of the synchronizer units. Accordingly, weight reduction measures for these components have the greatest effect. Using the hub as an example, it is clear how metal forming processes can practically cut the weight as well the mass moment of inertia in half.



Comparison	HFH	PM-Hub	Advantage of HFH
weight	165 [g]	317 [g]	- 48 [%]
inertia	172 [$kgmm^2$] 0,000172 [kgm^2]	303 [$kgmm^2$] 0,000303 [kgm^2]	- 43 [%]

Figure 14: **H**OERBIGER **F**ormed **H**ub **HFH** reduces weight and inertia

With this approach, it is particularly important that the supplier and transmission manufacturer work closely together and do more than copy existing applications. Optimal results can be achieved only if the construction of the interfaces to the shaft and gear wheels is included in the solution.

5. Summary

Synchronizers are primary components of MTs and DCTs. Perfect matching of all synchronizer components to each other as well as in the interaction with the interfaces in the gearbox are significant with respect to quality, reliability and costs.
Even primarily considering the function of synchronizers during gear changes, their effect during normal driving operations should be taken into account.
Examinations of drag torque in synchronizers and its effect on the total efficiency of transmissions demonstrate the parameters to be observed during the course of the development process. Starting with the system selection, the layout of clearances and friction linings as well as the positioning and guidance of components are also significant. It has become clear that individual measures do not lead to noticeable improvements, rather, solutions that are tuned to the entire system must be developed.

In addition, the weight component of synchronizers and related inertia contribute to total vehicle fuel consumption. Metal-forming technology likewise offers additional potential for the lightweight construction of components in the power flow.

HOERBIGER development programs pursue the goal of making the entire synchronization system attractive for the future by applying pioneering innovations to achieve an optimum cost-benefit ratio over the system service life.

[1] Leitermann, W.;Casimir, F. Dr..: The Future of Manual Transmissions - optimized Functions, new Features, incremental Customer Benefit, CTI Symposium 2011 Berlin