Innovative Solutions for Synchronizer Systems

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Abstract:
Modern transmission concepts require increased efforts to achieve improvements in comfort and efficiency in line with reduced cost. Synchronizer systems are the central element for a change of ratio in stepped transmissions. The trend toward transmissions with optimized efficiency and improved comfort at the same time requires aligned high-capacity synchronizer systems.

HOERBIGER is the leading specialist for synchronizers in MTs, AMTs, DCTs and Transfer Cases. The product portfolio comprises all installation sizes for use in cars, trucks and tractors.

HOERBIGER is developing innovative solutions for synchronizer systems as well as for components based on its comprehensive application and production know-how, which offers technical and commercial benefits to the transmission manufacturer.

In the first section, this paper presents the design of the new synchronizer system and explains its advantages proven in tests.

Today’s transmissions more or less exclusively use Borg-Warner-type synchronizers. A key feature is the blocking teeth at the blocker ring. The blocking teeth transmit the shifting force from the sleeve to the friction system, and at the same time prevent the sleeve from shifting through as long as a differential speed is present. The necessary blocking safety requires a compromise in terms of shift quality. In some cases, segmented splines are used to optimize the engagement of the sleeve independently of the blocking geometry.

The newly developed HOERBIGER synchronizer system is characterized by the absence of blocking teeth at the blocker ring. This offers critical free space for the design, which can also be used for improved shift quality and reduced manufacturing costs. In addition, it was possible to achieve further advantages regarding efficiency and noise reduction.
In the second section, new components are presented using the in-house know-how on forming technology and friction lining technology.

Due to the consequent use of sheet metal forming as the manufacturing process, it became possible to also achieve design solutions on the hub that resulted in further cost reduction opportunities.

By combining the HOERBIGER Sinter Friction Lining technology with a sophisticated forming process, it was possible to create a new blocker ring, which offers good performance for a wide range of applications.

For the execution of the necessary development work from design to simulation and validation in transmissions and vehicles, HOERBIGER was able to employ its long-lasting expertise and its wide range of development and testing tools.

For the manufacture of components for the new synchronizer system and the innovative components, HOERBIGER uses its leading competencies in the fields of forming technology and friction technology, in conjunction with state-of-the-art machining and heat treatment.

1. Introduction

Synchronizers have a long history and were developed around the world by engineers in an effort to satisfy the desire for higher performance, greater shifting comfort, and lower manufacturing costs. The Borg-Warner design with blocking teeth has become established as the prevailing design. The lining technology still encompasses a wide variety of materials, including brass, molybdenum, sinter and carbon. Manufacturing technologies employed include forging, sintering, and increasingly metal forming technology. In conjunction with state-of-the-art lining technologies, the latter has resulted in considerable improvements in performance over the past few years, while reducing manufacturing costs at the same time.

After the manufacturing technology for synchronizers has been revolutionized, innovative designs are required to achieve further progress in regard to functionality and cost. With the Smart Key Synchronizer (SKS), HOERBIGER has unveiled a new synchronizer design principle, which is suited to crucially contribute to the viability of this system component. In particular, the SKS will also be excellently suited for use in automated transmissions, such as AMTs and DCTs.
2. Principle and design of the SKS

To begin, figure 1 explains the principle of the SKS. In the conventional blocking synchronizer according to the Borg-Warner principle, the blocker ring performs both the blocking of the sleeve and the speed synchronization. The detent is used only to position the blocker ring during the indexing phase. The shifting force is transmitted from the sleeve to the blocker ring by way of the blocking teeth.

In the SKS, the function of the blocker ring is limited to the speed synchronization and the positioning of the SKS blocker unit. The new SKS blocker unit assumes the blocking function.

The design arrangement of the elements in the synchronizer system is apparent from figure 2.
Figure 2: Design arrangement of the Smart Key Synchronizer (SKS)

The SKS blocker unit comprising an indexing key, a blocking key, and a spring is located in the area of the previous indexing unit. The blocker ring is coupled to the SKS blocker unit by way of its recesses. The blocking key is additionally guided laterally in the sleeve.

Figure 3: Arrangement of the SKS blocker unit
The spring pushes the blocking key of the SKS blocker unit into the detent groove of the sleeve. During shifting, the sleeve is moved axially in the direction of the gear to be engaged and in the process carries the SKS blocker unit along, thereby pressing it against the blocker ring. The applied axial force produces a friction torque between the blocker ring and gear wheel cone, which results in a rotation of the blocker ring relative to the hub. The rotation of the blocker ring also produces a rotation of the indexing key relative to the blocking key guided in the sleeve. As a result, the blocking key is pushed radially outward by bevels into the detent groove of the sleeve, blocking it from further axial movement.

Now, the shifting force can be transmitted from the sleeve to the blocker ring by way of the SKS blocker unit. After the rotational speed differential has been reduced, the friction torque in the cone collapses and the blocker ring can be turned back into the center position. This releases the blocking of the sleeve, and the sleeve can be moved axially and engage in the clutch gearing.

3. Benefits of the SKS compared to conventional synchronizers

The principle of the SKS offers several benefits with respect to function, production, and cost.

The elimination of the blocking teeth at the blocker ring makes it possible to design the pointing of the sleeve teeth systematically for the engagement with the clutch teeth. The pointing angle can be optimized independently of the blocking function.

The back tapering in the sleeve can be configured shorter, thereby increasing the guide length to the hub.

The outer teeth of the hub can be widened, which improves both the load-bearing capacity and the shifting quality.

The blocking function in the SKS blocker unit can be set independently of the blocker ring.

Figure 4: Benefits of the SKS
Particularly in combination with the HOERBIGER sintered lining, the blocker ring can be produced cost-effectively by way of metal forming technology. For single and multi-cone synchronizers, non-variable components can be used. As part of the development and testing phases, additional benefits were discovered, which are not immediately apparent:

Figure 5: Ring coupling to prevent rattling

Coupling the blocker rings by way of the SKS blocker unit results in significantly reduced rattling tendency - a benefit that is of tremendous importance especially for transmissions without double-mass flywheel.

Another advantage of the coupling is the reduction in drag losses in the synchronizer. Guiding the opposing blocker rings by way of the indexing key reduces their tendency toward wobbling, which can cause drag losses and also wear. This effect can be further intensified by a small back taping at the coupling site.

Figure 6: Comparison of the introduction of force between Borg-Warner design and SKS
Furthermore, the modified introduction of the axial force results in a more uniform application across the width of the blocker ring, which contributes to increased performance capability. Analyses conducted by [2] with respect to the influence of the ring inversion when the axial force is introduced by way of the blocking teeth have demonstrated that the stress of the friction lining can be evened out if the rigidity of the ring is increased. This also reduces wear.

4. Testing program of the SKS

HOERBIGER extensively tested the SKS in component, transmission, and vehicle tests. For this purpose, HOERBIGER employs modern testing technology and methodology for the assessment of functional reliability and shifting quality. In the vehicle, the shifting quality is measured with the RICARDO GSQA measuring system. Comparative measurements were conducted, which analyzed transmissions with standard synchronizers and the SKS. The measurements were carried out according to a standardized method and allow the evaluation of individual criteria for the assessment of the shifting quality.

![Image of criteria for the assessment of the shifting quality](attachment:criteria.png)

Figure 7: Criteria for the assessment of the shifting quality

Both warm and cold runs were performed, and the shifts were statistically evaluated for different criteria. A central criterion was the second load peak, which characterizes the engagement of the sleeve in the clutch gearing.
Figure 8: Shift quality measurement in the vehicle - impulse of 2nd load peak upshifts

Figure 9: Shift quality measurement in the vehicle - impulse of 2nd pressure peak downshifts
Compared to a production transmission using a conventional synchronizer, the analyses showed that the SKS significantly improves the pressure point behavior, in particular also for a cold transmission.

To begin with, the test bench tests were used to check the design configuration with respect to blocking safety. The results were used to validate the design of the SKS blocker unit and prepare guidelines for computation.

![Figure 10: Transmission test bench](image)

Durability was tested both on the HOERBIGER μ-comp synchronizer test bench and in the complete transmission. Special emphasis was placed on the components of the SKS blocker unit. The SKS blocker unit is used to transmit the entire shifting force from the sleeve to the blocker ring. In addition to selecting the suitable material combination, a crucial factor for wear resistance is also the design configuration of the contact geometry inside the SKS blocker unit as well as that between the blocking key and sleeve.

Table 1: Selection of μ-comp test program

<table>
<thead>
<tr>
<th>Prüfprogramm</th>
<th>Mehrstufenpressungstest</th>
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<tbody>
<tr>
<td>Stufe</td>
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<tr>
<td>Pressung</td>
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<tr>
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<td>Gesamtzyklen</td>
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</table>
It was possible to demonstrate that the configuration is reliable with respect to function and wear. At the end of the endurance tests, the components of the SKS blocker unit shown in figure 11 exhibited no critical signs of wear.

![Figure 11: Components of the SKS blocker unit after the service life test](image)

The wear measurements at the blocker ring likewise confirmed the more uniform stress on the friction lining as a result of the improved force application onto the blocker ring.

| Table 2: Results from μ-comp tests |

<table>
<thead>
<tr>
<th>Versuch</th>
<th>Schaltungen</th>
<th>mittlerer Reibwert</th>
<th>mittleres Verhältnis μ3/μ1</th>
<th>Spaltmaß neu [mm]</th>
<th>Spaltmaß gelaufen [mm]</th>
<th>Spaltmaß- verschleiß [mm]</th>
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</tbody>
</table>
5. Application possibilities of the SKS

In manual transmissions, the entire transmission or each individual synchroniser systems can be equipped with the SKS, however mixed installations in any one synchroniser system are not possible. With respect to function, the benefits in manual transmissions include improved shifting quality, especially for single-cone synchronizers, increased performance capability, and reduced rattling noise and lower losses.

In automated transmissions, such as AMTs and DCTs, a strong blocking function can be provided by the SKS, without making the engagement of the sleeve in the clutch gearing more difficult. In this way, it is possible to select the blocking position more quickly, and the previous shifting through is reliably prevented, even in the case of highly dynamic gear shifts.

Single / double / triple modular system

By replacing or adding components, the base elements of the SKS can be used to configure a double or triple cone synchronizer.

Ideal, the multiple cone synchronizers have a non-coupled configuration. In general, this is possible as the engagement teeth are implemented independently of the lock-up torque.

![SKS modular system](image)

Figure 13: SKS modular system

In certain cases, however, it may also be necessary to lower the blocking release forces. This applies if in a DCT, equipped with a wet clutch, the drag torque in the cold transmission prevents blocking release. In this case, an additional coupling may be introduced. Ideally, the
rings are coupled by modified indexing keys. This also maintains the principle of non-variable parts. The unlocking forces are then reduced by a modified groove geometry in the sleeve.

6. Innovative components

The forming technology enables the cost-effective production of components in mass production processes. The design of the products must be adapted to the cold forming requirements in order to avoid additional steps, such as machining or joining technologies. This means that the cold forming process should produce parts in their final geometry, only adding a deburring and heat treatment process.

The investment in equipment and tooling is rather high, which calls for high volume and/or standardization.

6.1 Formed synchronizer hub

Having begun the forming of synchronizer rings, HOERBIGER is now also looking into the components of the hub / sleeve assembly. This paper presents a first look into HOERBIGER’s development of a formed synchronizer hub. The design takes into account the above-mentioned requirements and implements the geometry of a hub formed out of sheet metal. The segmented spline elements at the outer and inner diameters are excellent examples of a systematic implementation of a process-optimized design.

Nevertheless, the hub must function in the transmission. Initial tests showed that the selected approach is working and the durability and also shiftability are comparable to existing hubs produced with powder metal technology. The development is still ongoing and first prototypes for customer projects are scheduled to be available by the middle of 2010.

6.2 Formed Blocker Ring Coated

The manufacture of single-cone blocker rings with carbon or sinter friction linings today is characterized by the following steps.

First, a blocker ring without friction lining has to be produced. The technologies employed include forging, sintering or forming.
Secondly, a lining blank has to be cut, and thirdly the blank has to be assembled into the cone of the blocker ring by welding or bonding. Inserting the friction lining is a costly process and requires utmost care in order to avoid problems of delamination.

The HOERBIGER approach toward improving the production process for single-cone blocker rings is to develop a sequence of forming steps, which allow a ring to be formed together with a sintered friction lining. A key factor for success is to perform a minimum of forming in the area in which the friction lining is applied.

To begin with, the HOERBIGER sinter friction lining is applied to a stamped sheet metal ring at an area which later will be the cone. Then these parts are formed in several steps, which is shown in principle in figure 14.

![Sequence of forming steps diagram](image)

Figure 14: sequence of forming steps

The feasibility of the process has been proven by several tests performed on the HOERBIGER µcomp test bench. The friction coefficients and the durability results demonstrate the huge potential of this new production technology.

The development is still ongoing and initial prototypes for customer projects are scheduled to be available by the middle of 2010.

7. Summary
By developing the SKS Smart Key Synchronizer, HOERBIGER succeeded in implementing a comprehensive innovation of the Borg-Warner design, which had been proven for decades. Due to the redesign of the blocking function, it has become possible to lower the manufacturing costs for the entire system and at the same time achieve functional advantages during shifting.

The SKS principle allows optimal use of the HOERBIGER manufacturing technologies for the production of synchronizer rings with sintered linings. Based on this, a systematic non-variable parts strategy can be implemented, which allows the customer to respond to varying requirements, without having to completely redesign peripheral parts.

For applications in semi-automatic transmissions, especially DCTs, the SKS offers considerable advantages due to the high functional reliability and independent engagement geometry.

A look into the advanced engineering projects of HOEBIGER shows the consistent advancement in metal forming technology, which will also make it possible in the future to cost-effectively produce hubs and single-cone rings with friction linings.