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Gearshift systems and synchronization

At the threshold of mechatronics

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Intro-duction

Along with the electrified drive train, conventional combustion technology with manual and automated manual transmissions still will play an important role in the future. This is thanks to the low system costs, high efficiency and robustness of manual transmissions.

In addition, new requirements are being placed on manual transmissions in conjunction with hybridization, stop-start systems and automation (AMT, DCT) (Figure 1):

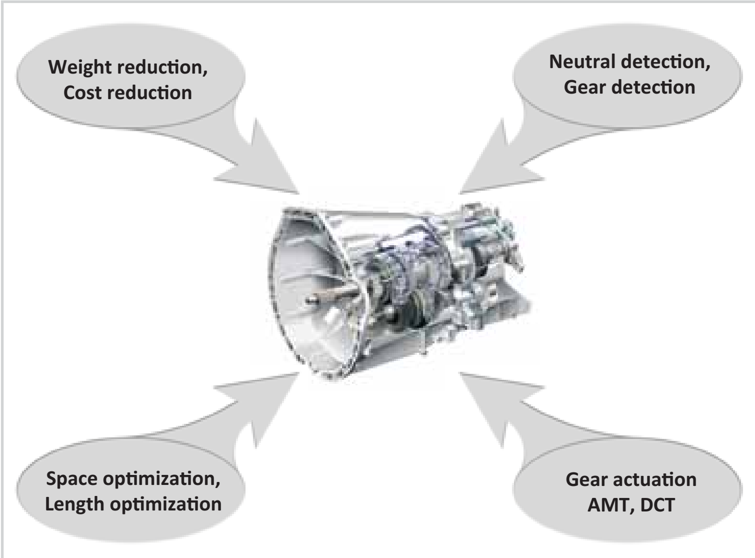

Figure 1 New requirements for manual transmissions

- Neutral detection and gear detection
- Gear actuating elements
- Reducing weight and costs
- Optimizing space and length

Gear shift transmission requirements

INA offers suitable innovative solutions for these new requirements:

Neutral detection and gear detection

- Sensor detent pin as neutral gear sensor
- Sensor bearing with position detection and detent function

Gear actuating elements

- Integrated hydraulic gearshift fork actuator

Reducing weight and costs

- Gearshift forks for gear shift transmissions
- Plastic housing for gearshift systems
- Friction pad system (FPS) for synchronization systems
- Clutch bodies for synchronization systems
- Gearshift sleeves for synchronization systems manufactured by forming

Optimizing space and length

- Flat struts for synchronization systems

Neutral detection and gear detection

Sensor detent pin as neutral gear sensor

In combination with manual transmissions, stop-start systems and mild hybrids require new functions in gearshift systems such as reliable detection of neutral gear.

The neutral detection of first generation often consists of an ADD-ON sensor and a separate Magnet as the target. The sensor in most applications is located on the transmission housing, and the magnet is mounted on the selector shaft. Due to the distance to the sensor and the long selecting stroke

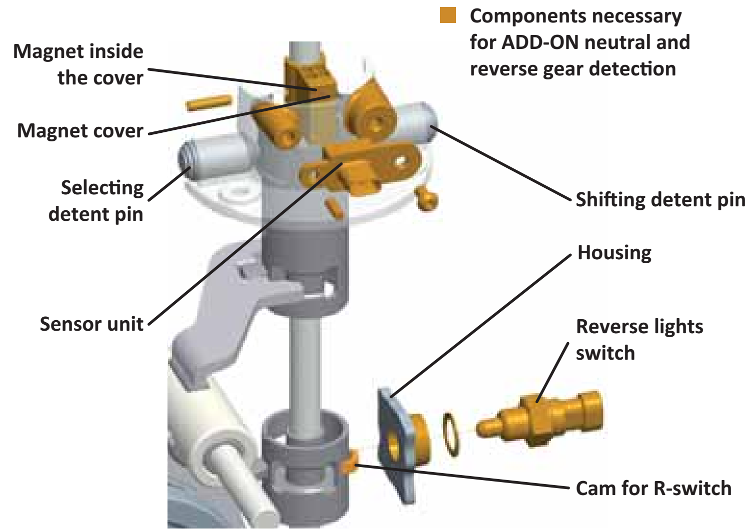

Figure 2 A conventional ADD-ON sensor system of first generation

the magnet has to be designed very large. For protection against damage, contamination and for assembling process a magnet housing is essential.

More often than not a reverse lights switch is still required, which is activated by a cam.

A conventional ADD-ON sensor system of first generation therefore consists of several individual components that are placed in three different locations and require lots of space (Figure 2). The selector shaft and the housing must be machined for assembling of components. Due to many work steps and partly very big and therefore expensive components unnecessary costs are being generated.

An integrated solution, that substitutes all ADD-ON components, is limited to only one installation location, and is more economical to install, is more effective. INA has developed a new sensor system for neutral gear detection – the sensor detent pin (Figure 3). The basic idea involves fitting a sensor for measuring stroke onto the shifting detent pin already mounted in the gearshift system that is actuated during gearshift operations.

The characteristic of the shifting cam profile shows that the detent stroke along the neutral

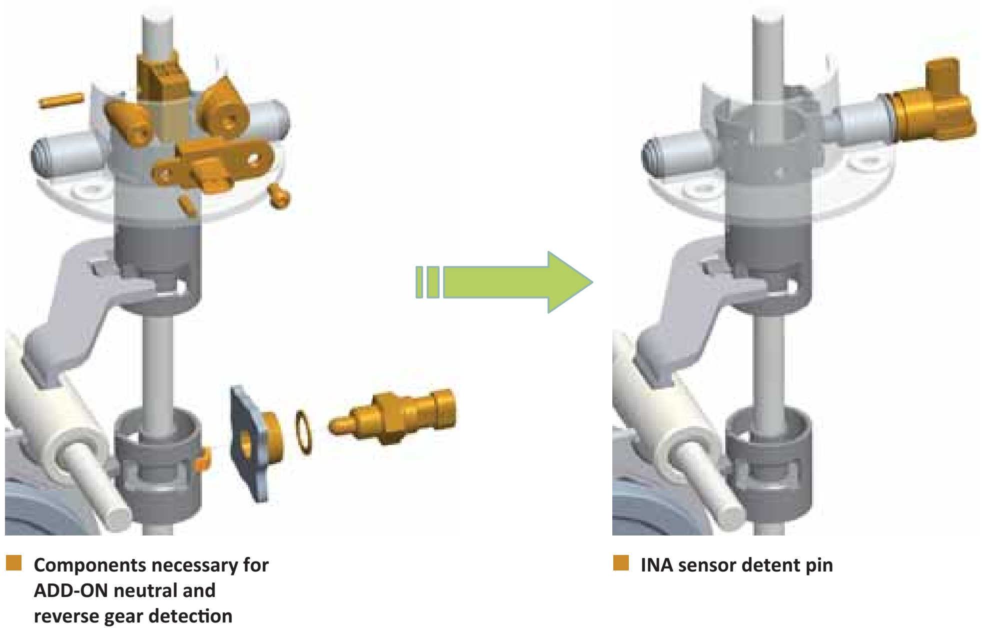

Figure 3 INA sensor detent pin – integration of single components in one unit

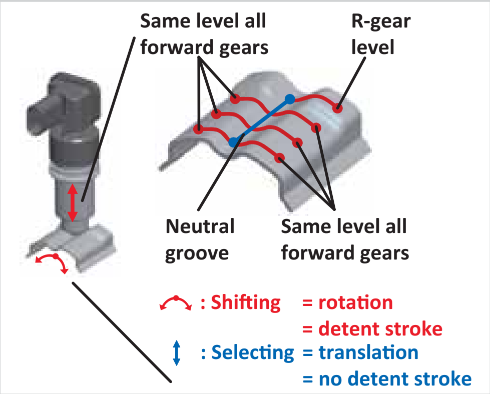

Figure 4 Detent cam profile for INA sensor detent pin

groove does not change so that the signal remains constant (Figure 4). The sensor uses this fact to detect neutral gear within the whole selecting alley. Two additional levels "same level all forward gears" and "R-gear level" are clearly defined and can therefore be detected by the sensor.

Figure 5 shows the setup and function of the INA sensor detent pin. The detent stroke is transferred to the magnet on the linkage pin that is guided in the sensor. The sensor measures the stroke of the magnet during the gearshift progress and generates a defined signal. The sensor unit is supplied with current and the signal is output via the same connector designed according to customer requirements and is usually equipped with three contacts.

Both analog and digital signal can be provided by the sensor. In the case of digital signals, a pulse width modulation signal (PWM) is very common. If redundancy is required, the electronic system can be equipped with two separate Hall effect sensors and two separate signal paths with their own signal output pins in the connector.

In order to create customer-specific requirements for shifting and selection forces, the mode of operation of the shifting and selection detent pins has been combined. In this way the required shift moment characteristic is fulfilled (Figure 6). Here, the shift moment in neutral is only defined by the sensor detent pin. Thus, the sensor detent pin positions the selector shaft in neutral and also detects this position, which is the optimum regarding tolerances.

Conclusion

The sensor detent pin essentially comprises two components – a detent pin and a sensor unit. Both components are based on proven technologies and represent a highly-integrated solution for detection of neutral gear and reverse gear. This solution means that some single components, various fixing elements and manufacturing operations can be omitted. This results in lower system costs in comparison to a conventional ADD-ON sensor system (Figure 2). Volume production of the sensor detent pin will begin in 2010 and it will be available for stop-start applications.

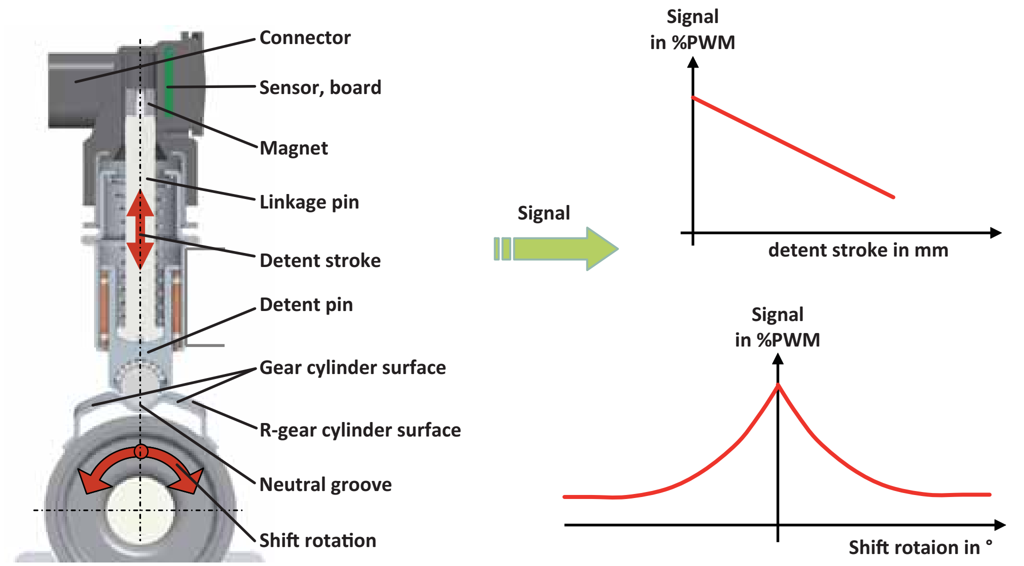

Figure 5 Setup and signal output of INA sensor detent pin

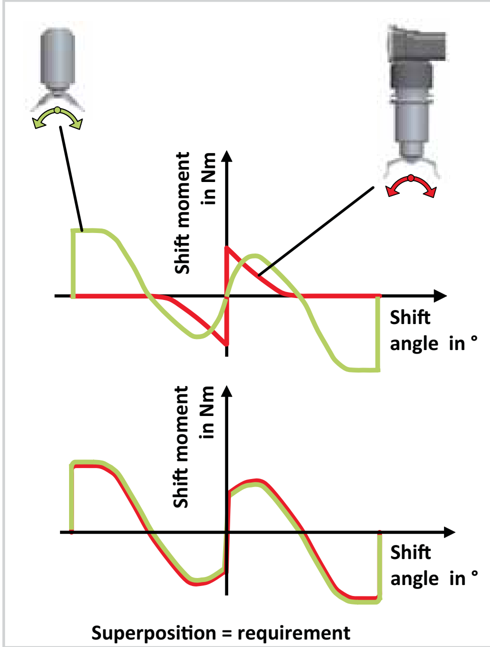

Figure 6 Fulfilling customer requirements in terms of shift moment

Sensor bearing with position detection and detent function

Along with the basic gearshift actuation function, the gearshift forks in current AMTs and DCTs have additional components and functions:

- Bearing support (usually with a ball bearing in transmission housing)
- Detent cam profile
- Components for position detection (Figure 7)

Integrating these functions enables saving of space, costs and reducing of assembly outlay.

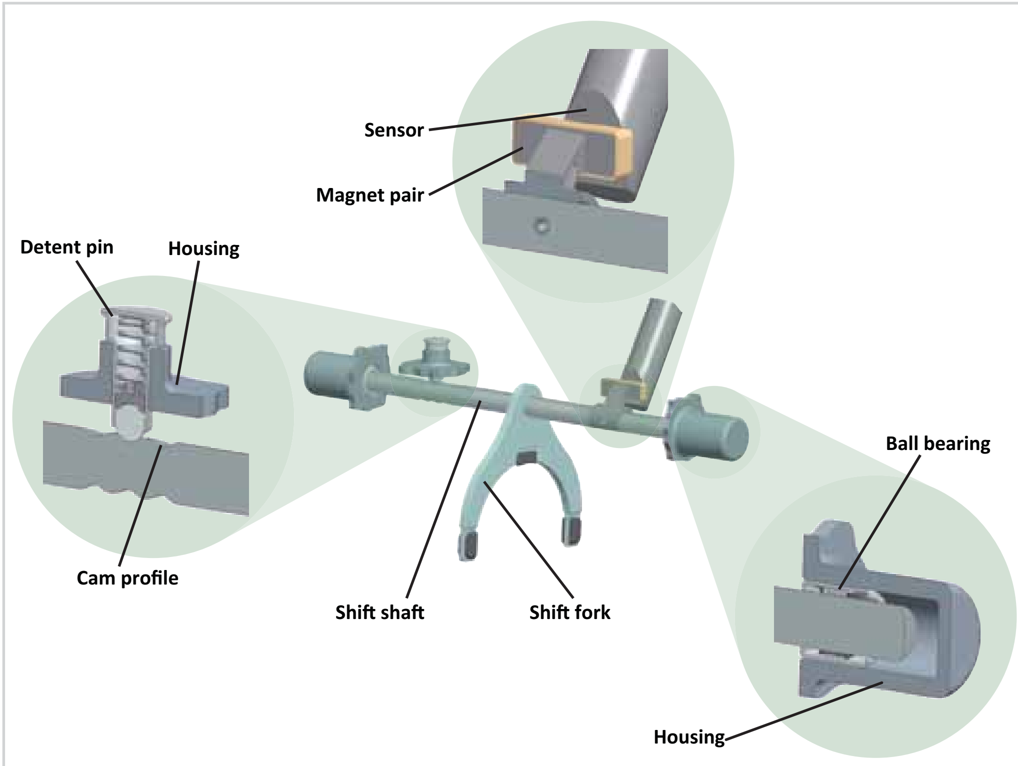

Figure 7 A typical gearshift fork design with bearing supports, detent cam profile and magnet retaining element

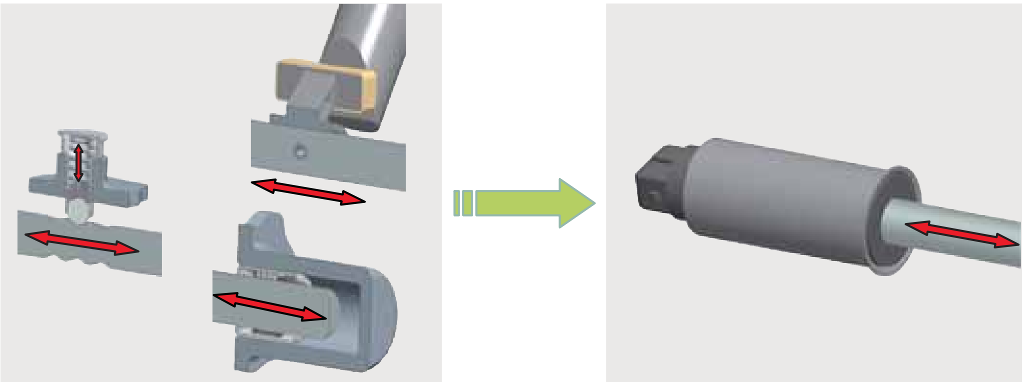

Figure 8 Sensor bearing: Bearing with integrated position sensor and detent function

In conjunction with Continental, INA is developing a sensor bearing with detent function that performs the additional functions and is designed as a module (Figure 8).

The sensor bearing with position detection and detent function (Figure 9) comprises a sleeve – bearing raceway, sensor housing – shift travel measuring system and an inserted detent spring. In conjunction with a detent cam profile at the end of the shift shaft, the spring performs the detent function. The four pairs of ball rollers are arranged at 90° angles to each other and are guided in the pockets of the sensor housing. The sensor housing supports the sensor circuit board and contains an integrated connector with the pins for supplying current and for signal output. The connector can be positioned either inside or outside the transmission. As an output signal a digital or analog signal can be used.

The INA sensor bearing is designed as an integrated solution for DCTs and AMTs. This saves space inside the transmission and enables several, sometimes costly, operations and components to be omitted that are necessary for conventional solutions:

- Detent pin and housing bore
- Magnet with retaining element and cover
- Sensor carrier
- Various assembly operations

However, the level of integration can be increased even further. Four sensor bearings can be combined to create a sensor bearing module (Figure 10).

The four sensor bearing units and the base plate then form a common housing with a common

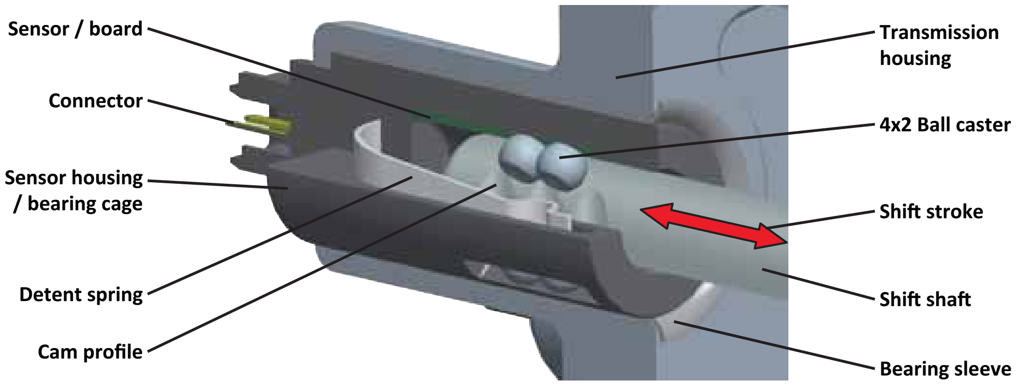

Figure 9 INA sensor bearing: Setup

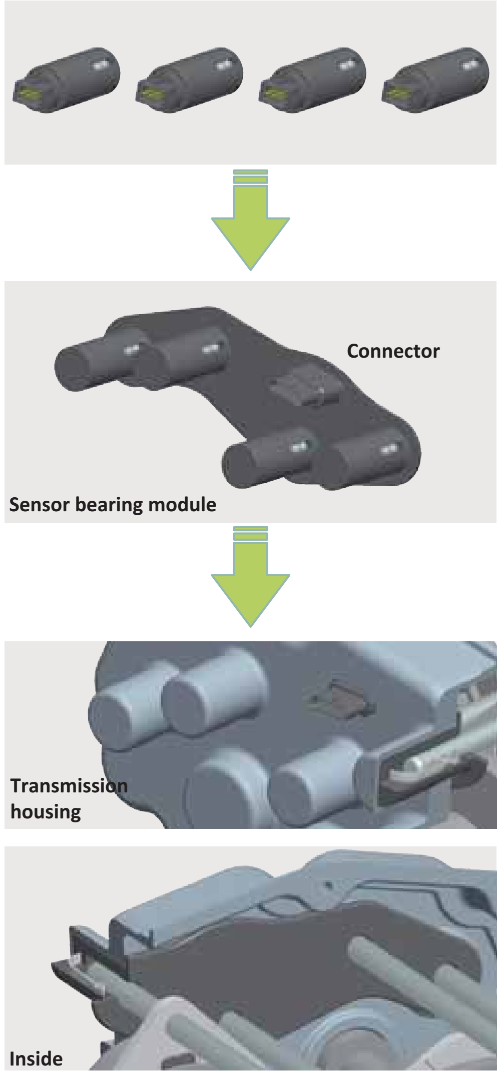

Figure 10 Integration of four sensor bearings in one module

electronic unit. The common connector that replaces four individual connectors is located on the outside in the illustrated example. It can also be used as a direct interface to the control unit on the inside of the transmission. It can be mounted in the transmission in accordance with the customer's requirements.

The sensor module offers additional benefits to those of the sensor bearing solution already mentioned:

- Only one common connector
- Direct connector plug to the control module is possible
- Only one housing
- Only one common electronic unit
- It is not necessary to seal the individual sensor bearings

The sensor bearing and sensor bearing module provide a cost-efficient and space-saving solution to information needs of a modern transmission.

Gear actuating elements

Integrated hydraulic gearshift fork actuator

Several transmission manufacturers are currently developing a series of double clutch transmissions (DCT), which are mostly hydraulic operated. Two different hydraulic systems are used:

- ADD-ON power pack as a separate hydraulic system
- ADD-ON gearshift fork actuators integrated into the transmission housing wall

The space available for the gearshift forks is severely limited in a DCT due to the double clutch. It is therefore advisable to use gearshift forks movable on a fixed shaft. They are not moving inside the housing bores during actuation and therefore require less axial length. In addition, two gearshift forks can be mounted on a common fixed shaft since they can be actuated independently of each other.

INA has developed a gearshift fork actuator especially for DCTs that is integrated into the gearshift fork, and in comparison with the systems mentioned above, it is a cost-efficient alternative with optimized length (Figure 11).

One or two gearshift forks on one shaft are advisable, depending on the design of the transmission. Here, the focus is either on minimizing the number of shafts or simplifying the oil supply. The INA integrated gearshift fork actuator represents a new integration level for hydraulic actuating elements for DCTs.

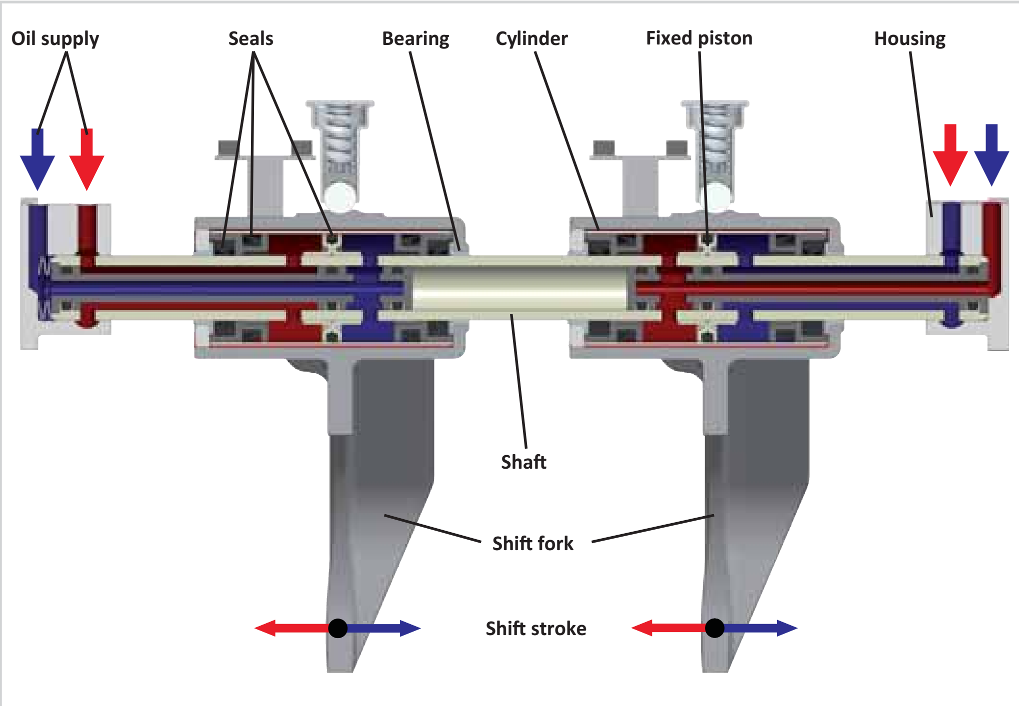

Figure 11 INA integrated hydraulic gearshift fork actuator: Setup

Reducing weight and costs

Gearshift forks for gear shift transmissions

In gear shift transmissions, gearshift forks transfer the gearshift motion to the gearshift sleeve. The gearshift motion is usually introduced via the striker jaw and transferred to the rotating gearshift sleeve through the contact pads.

The varied requirements placed on the design of current gearshift forks can be summarized in certain focal points (Figure 12).

In order to meet these requirements, INA uses various technologies depending on customer specifications and the space available. These technologies are thin sheet metal forming, aluminum die casting, thick sheet metal forming and thick sheet metal fine blanking. Depending on the technology of the individual parts, different joining methods are used such as MAG, TIG and laser welding, press fit, fixing using dowels, riveting or screw mounting.

Thin sheet metal gearshift forks (Figure 13) are designed for relatively low overload gearshift forces

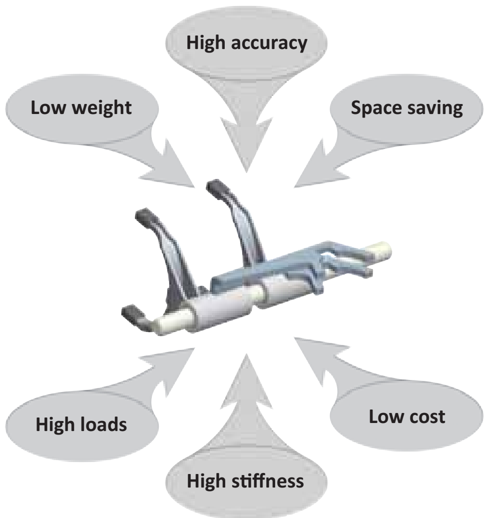

Figure 12 Requirements of gearshift forks

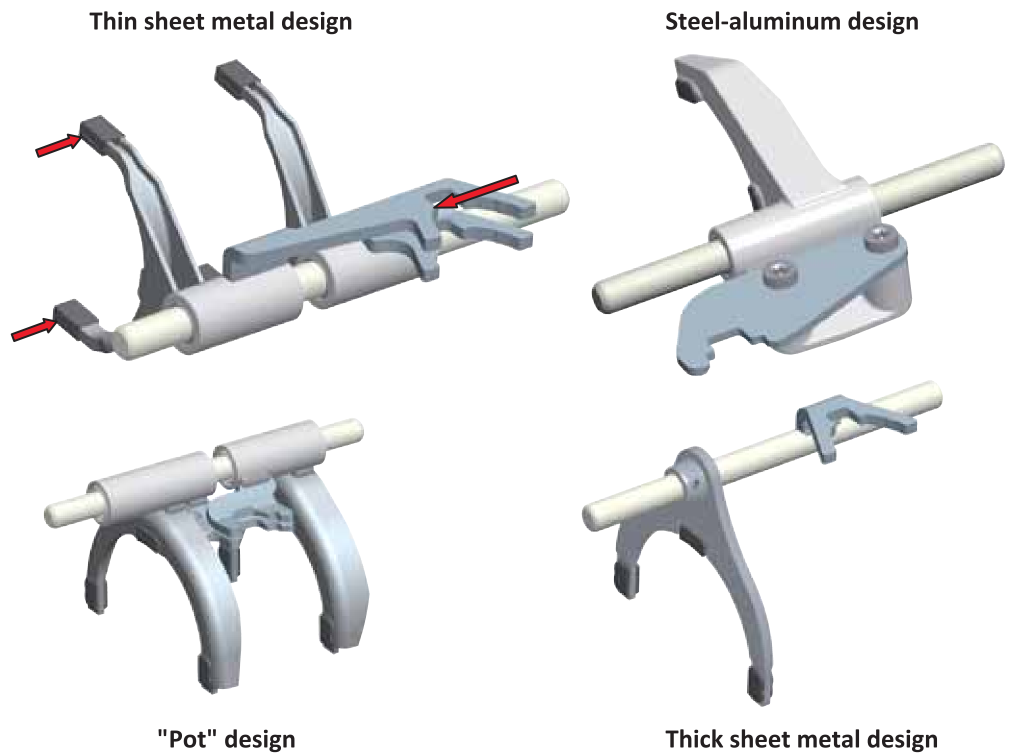

Figure 13 Various gearshift fork technologies depending on requirements

and achieve precision requirements due to the low distortion of laser welding. The injection molded contact pads form the interface to the gearshift sleeve.

Gearshift forks in "pot" design (Figure 13) are suitable for higher loads, which means the relevant welding methods such as MAG and TIG are required. The required accuracy is achieved by reworking the parts by machining and/or pairing of contact pads. The contact pads are joined to the gearshift forks using ultrasonic welding.

Steel-aluminum gearshift forks (Figure 13) comprising a die cast gearshift fork and a flat, precision punched striker jaw are suitable for certain package spaces. Two self-tapping screws secure the striker jaw to the fork with a friction fit. This cost-efficient joining method enables the tolerances to be compensated due to the precise positioning of the striker jaw during screwing process. This makes the complex reworking by machining required for costly die cast steel insert components unnecessary. Volume production of that new technology gearshift forks will begin 2010.

Automated manual transmissions usually require the gearshift fork and shift rod to be designed as one fixed assembly. The shift actuator system is usually located in the housing of the transmission so that the shift rod ends are actuated. Due to the extremely short design of the DCT, the axial space available for the gearshift forks is extremely limited, which often requires a **flat punched thick sheet metal gearshift fork** (Figure 13). The method of fixing the gearshift fork to the shift rod must be selected according to the application.

All gearshift technologies can be supported by both sliding and rolling contact, which must be defined in accordance with the requirements of each individual case. INA's portfolio of gearshift forks offers the adequate gearshift fork technology for each customer requirement.

Plastic housing for gearshift systems

The housing of gearshift systems supports the gearshift components and provides an interface (flange) for mounting onto the transmission. In addition, two levers are fixed on the gearshift system housing to which the Bowden cables for shifting and selecting are connected. The gearshift system must be highly robust since the entire flow of selection and shifting forces is transferred through it. Housings of die cast aluminum have been performing these tasks (Figure 14) reliably for a long time.

Aluminum die casting is characterized by flexible molding, resistance to corrosion, temperature stability and good mechanical strength characteristics. But it requires an essential costly machining that can involve a large share of the price of the housing. Therefore, approaches for saving costs are advisable using alternative materials and omitting the use of rework by machining.

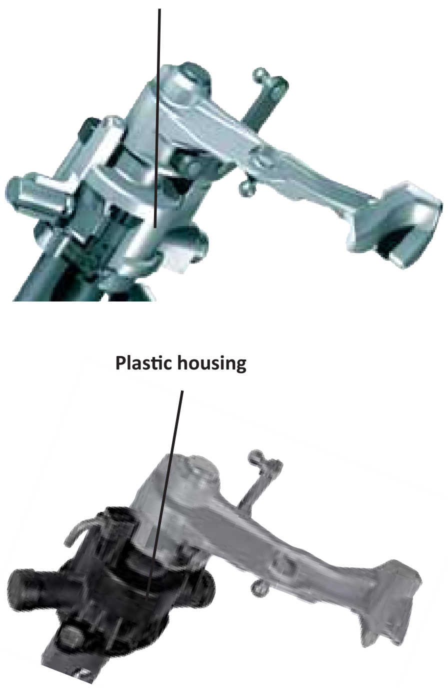

Figure 14 Die cast aluminum and plastic gearshift system housings

The use of plastic is an effective alternative for reducing costs and weight. Plastic housings do not require machining since the interfaces are manufactured at sufficient precision during the injection molding process. The material price of plastic also advocates the use of this material. However, the design of a housing made of plastic must be modified in accordance with the material and manufacturing process characteristics:

- No friction fits (relaxation of the plastic)
- Sealing with sealing rings necessary
- Thermal expansion, the strength of the material at high and low temperatures, moisture intake and aging are to be considered.

INA has developed a gearshift system housing made of plastic. Sample parts from the injection molds were subsequently successfully tested on test rig and in vehicle (Figure 14).

The omission of reworking by machining of the housing (off-tool injection molded finished part) and the lower material price means that using plastic instead of aluminum cuts costs and reduces the weight of the entire gearshift system. The suitability of the plastic housing depends above all on the temperature at the installation location (distance to exhaust system components) and must be checked for every vehicle apart.

Friction pad system (FPS) for synchronization systems

During gearshift operations, synchronization systems are responsible for adjusting the speed of the transmission shaft and gear wheel that are subsequently linked by geometrical locking by the gearshift sleeve.

Originally a single cone system was used. The application of special coatings on friction surfaces has clearly enhanced the performance of the system. A further performance increasing was achieved by using of multi-cone system. The carbon layer system is standing for highest performance allowing omitting of multi-cone solution.

However rings with carbon layer are very expensive to manufacture. After pre-cutting the carbon layers have to be bonded on the rings through a complex process. There are many different carbon materials available on the market, which are manufactured in different ways. But the cost-saving potential of them is relatively low, therefore new solutions are to be developed.

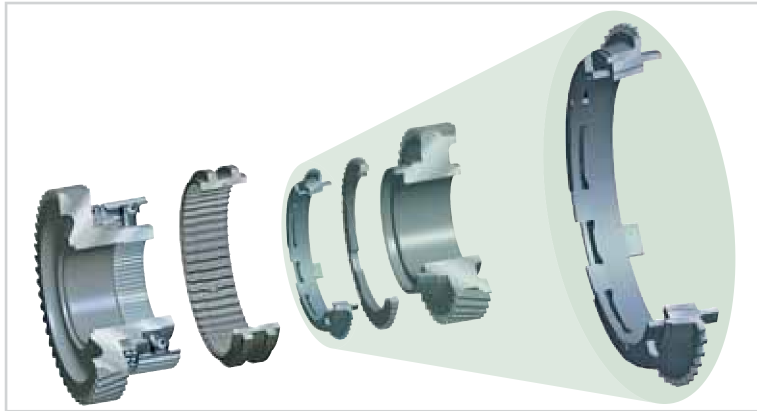

Figure 15 A typical synchronizer package

INA has developed a new system that meets the requirements of modern gear shift transmissions. The friction pad system (FPS) does not require the friction lining to be fixed on the ring and replaces the lining with separate components (Figure 16).

The friction pad system comprises individual pads that are joined to a guide cage and secured from getting lost by stamping. It can efficiently replace conventional synchro rings with or without carbon layers. The pads are secured against loss of components in the slots but can still tilt slightly. This facilitates optimum surface contact during operation. The design of the guide cage (which is similar to that of a needle roller bearing cage) facilitates cost-efficient cage manufacturing processes and pad assembly due to automation.

Via separating the friction and guidance functions the friction pad system achieves several advantages:

- New friction pad materials applicable
- Flexible combinations of friction pairings possible
- Lower installation space requirements compared with conventional systems with similar performance
- No costly adhesive bonding of the lining onto the rings required
- One supplier for the entire module
- One interface for the customer

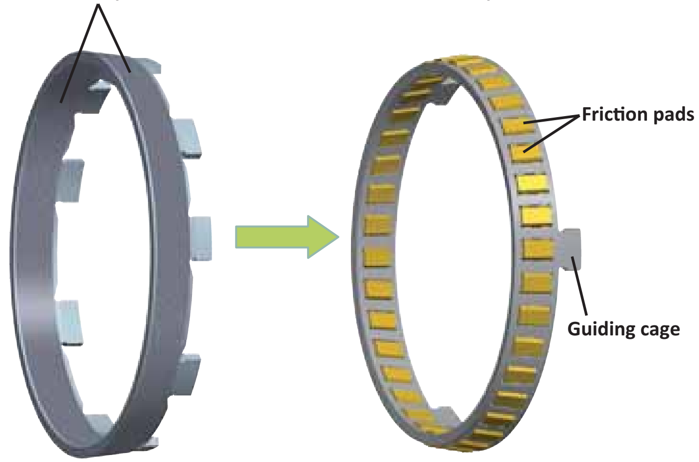

Figure 16 Synchronization ring with carbon layer and FPS

A comparison of the important parameters of the well-known carbon layer system and FPS are shown in Figure 17. The low wear as well as the more favorable friction properties speak in favor of the using the FPS. In addition, the costs of the FPS, which are up to 30 % lower, must be emphasized.

The INA Friction Pad System (FPS) has already been successfully tested and it is already on a par with conventional synchro-

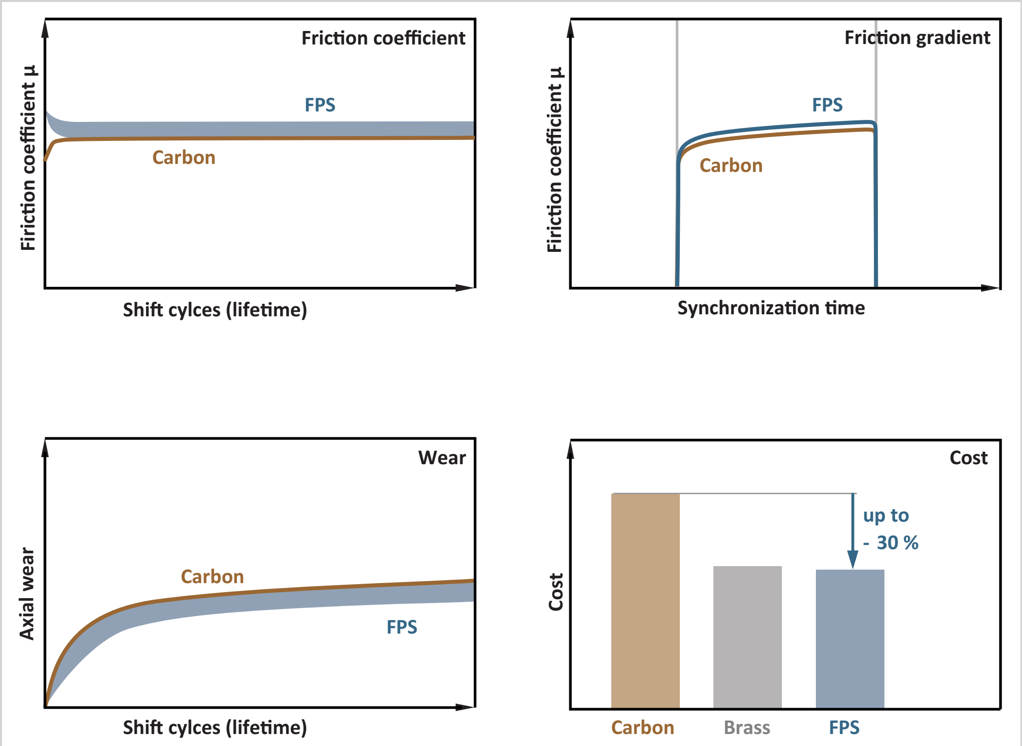

Figure 17 Comparison of carbon layer system with FPS

nization systems. The next stage of development will involve further developing the friction pairings to tap the full potential of the FPS as much as possible.

The mating components of the FPS require a special surface texture that directly influences the performance of the system. This is the reason why all components of the entire friction system must be precisely matched to each other. INA offers optimized inner and outer rings for the FPS that are matched to each other as a system (Figure 18). As a system supplier, by supplying the FPS from one source and due to the clearly-defined responsibilities, INA offers its customers a product optimized in its entirety.

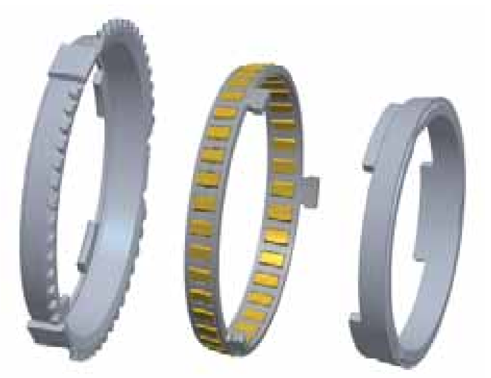

Figure 18 FPS system components – perfectly matched

Clutch bodies for synchronization systems

Special clutch bodies that are rigidly linked with the gear wheel are used in synchronization systems in order to transfer torque (Figure 19). In the last phase of the gearshift operation, the internal teeth of the gearshift sleeve engage in the external teeth of the clutch body thereby linking the transmission shaft with the gear wheel by geometric locking.

Clutch bodies are either produced by machining or sintered, depending on the design. Clutch bodies manufactured by machining are characterized by high machining outlay and therefore

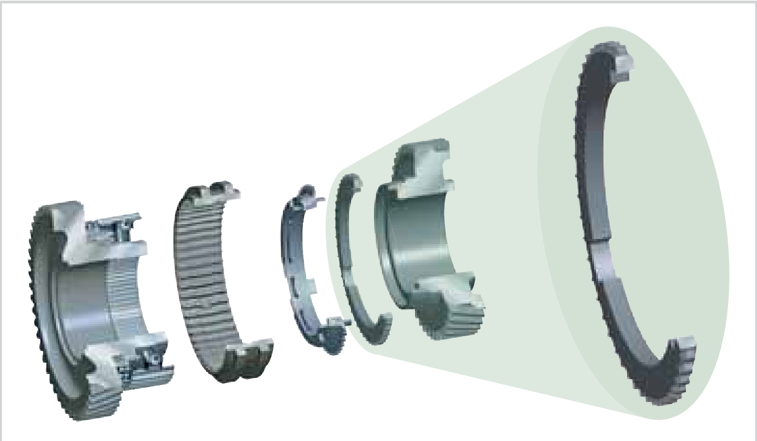

Figure 19 Clutch body in a synchronization package

comparably high costs. Sintered clutch bodies have higher friction and a little less mechanical load carrying capacity due to the sintered material. The surfaces of the teeth manufactured with both technologies are not optimized to the function.

INA manufactures clutch bodies by forming. Depending on the requirements, two designs are used – flat or with integrated inner cone (Figure 20). The following advantages speak in favor of using clutch bodies from INA:

- High mechanical strength due to formed tooth roots
- High quality surfaces due to the forming process

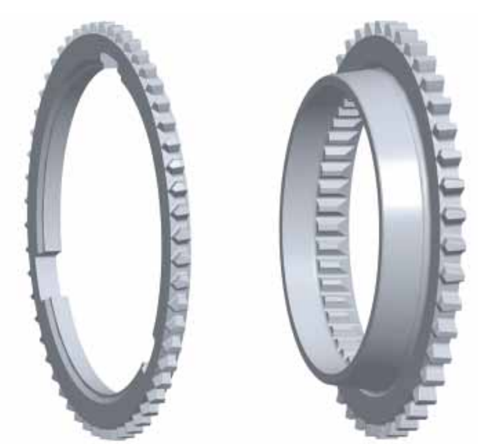

Figure 20 INA clutch body manufactured by forming – flat version (left), version with integrated inner cone (right)

- High, repeatable tooth accuracy due to long tool life
- Cost-efficient technology optimized for large-scale volume production
- Similar performance compared with clutch bodies manufactured by machining

INA clutch bodies can be flexibly adapted to meet customer requirements and can be provided with additional functional surfaces. Along with a lower piece price they have high surface quality and low deviations in actual dimensions thanks to the forming technology, which is oriented on the mass market.

Gearshift sleeves for synchronization systems manufactured by forming

Gearshift sleeves are part of the gearshift system of a gear shift transmission. They trigger presynchronization and subsequently link the transmission shaft to the gear wheel for transferring drive torque (Figure 21). Due to the domination of gear shift transmissions on the European market and a sufficiently large market share worldwide, the gearshift sleeve must be considered as a large-scale volume product.

Today, gearshift sleeves are machined from blanks. The complicated geometry makes the manufacturing methods varied and, above all, highly cost-intensive. In order to meet the requirements as a large-scale volume product an adequate technology for manufacturing of gearshift sleeves must be used. The following targets must be emphasized here:

- No turning, broaching and milling processes
- Reduction of material required
- Increase of tooth quality (surface, roughness)
- Lower component piece price

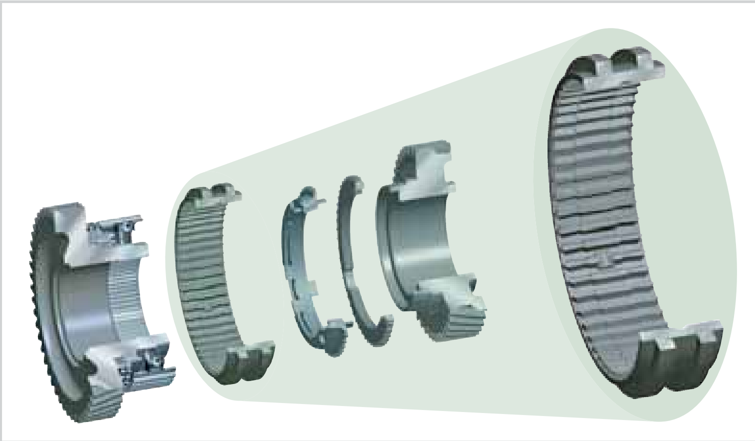

Figure 21 Gearshift sleeve as a part of the gearshift system

INA has available a new forming technology for gearshift sleeve manufacturing that meets the named requirements. The basic idea comprises profiling the body (the ring with internal teeth) from one strip. The subsequent ring forming and joining then build the basis of the INA formed gearshift sleeve (Figure 22). Since the material fibers are not cut but formed during profiling, a heavy-duty ring profile is generated. Due to this manufacturing method, the profiled teeth have a high surface quality since the score marks usually caused by machining are not present.

The groove rings are manufactured in a series of processes, whereby a steel wire with a rectangular cross-section is cut, shaped into a ring and joined. The groove rings are then rigidly linked to the body by means of laser welding (Figure 23). After hardening using a specially-developed process for minimized distortion, the tooth profile has only low deviations in actual dimensions.

Due to the use of forming technology suitable for the mass market and, last but not least, due to the reduced material usage, INA formed gearshift sleeves are low cost and high quality products. They are already in use in several volume production applications.

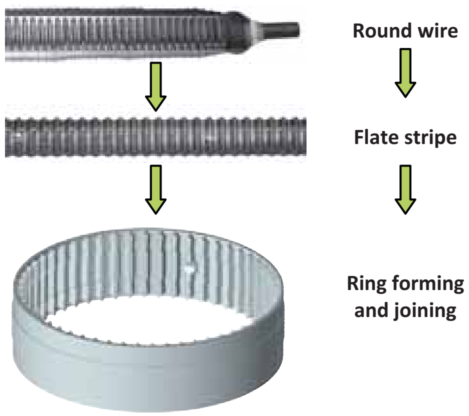

Figure 22 Manufacturing the body

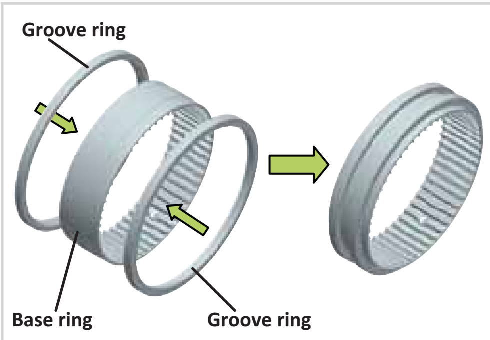

Figure 23 Joining the body with the groove rings

Optimizing space and length

Flat struts for synchronization systems

Axially movable struts are used for presynchronization in shift transmissions (Figure 24). The contact head (often a ball) is preloaded against a slot in the gearshift sleeve and centers the gearshift sleeve in neutral. During the initiation of the shift movement by the gearshift sleeve, the struts generate the actuation force for presynchronization. Three struts are normally used, which are located every 120° in the slots of the selector hub.

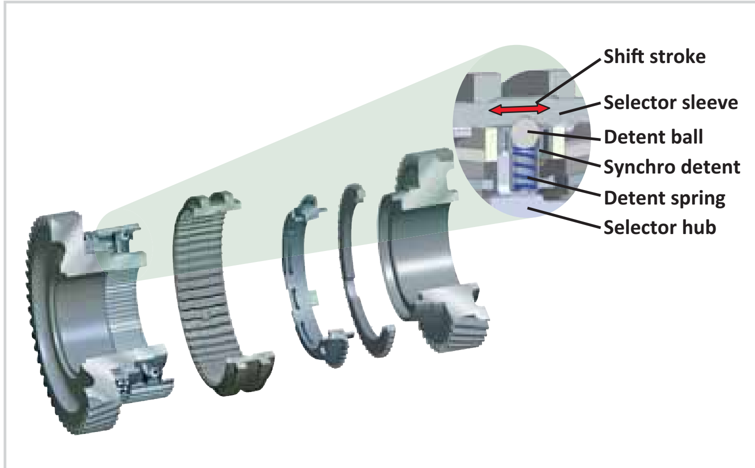

Figure 24 INA struts in a synchronizer package

The struts are available in various single-piece and multi-piece designs. Conventional multi-piece designs comprising separate springs and struts are widely used (Figure 25). The multi-piece design is however being increasingly replaced by the single-piece design.

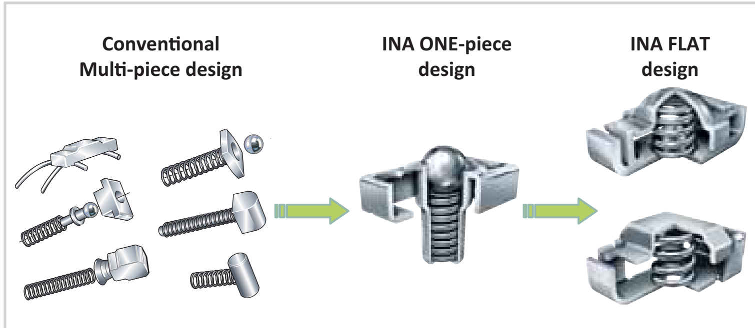

Figure 25 Evolution of struts

The multi-piece designs are characterized by the following features:

- At least two separate components
- High fitting outlay (elements are preloaded, possible loss of parts)
- Often a high overall height:
  - Deep slots required in selector hub
  - High stresses in the residual cross-section of the selector hub

Current front-transverse DCTs have a short design and, compared with manual transmissions, have a significantly higher gearshift frequency. It is for this reason that modern struts must meet the following requirements:

- Modular one-piece design
- Low overall height
- Short axial length (distance between two gear wheels)
- Contribute to reducing system costs
- No radial bores in the selector hub
- Simple to mount

INA ball struts provide a solution to the requirement for one-piece struts (Figure 25). The spring and ball are enclosed in a sheet metal steel housing that prevents the loss of components during mounting. INA ball struts are characterized by simple mounting due to the single-piece design, no bores in the selector hub and the low price.

The transmission can be shortened due to the shallow design of the INA flat strut (Figure 25) since it shortens the distance between two gear wheels. The low overall height is achieved by utilizing the space under the profile for the length of the spring.

INA has developed the so-called "strut-in-sleeve" design (Figure 26). This arrangement facilitates fur-

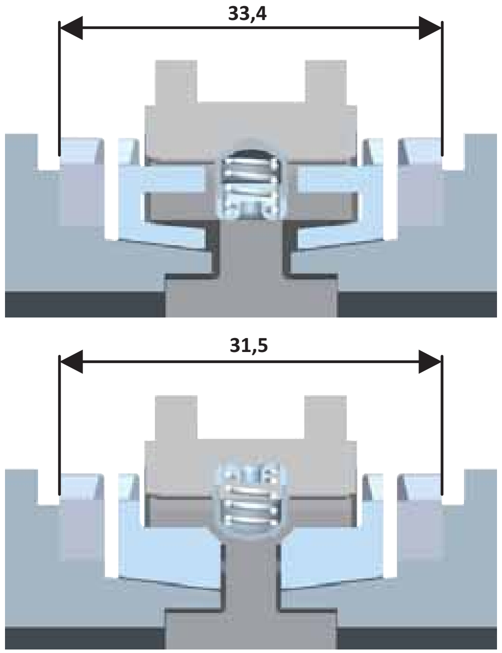

Figure 26 Top: A synchronizer system with a flat strut. Bottom: Reduced length of transmission due to “strut-in-sleeve” design.

ther shortening of the length of the transmission in that the flat strut is fixed in a recess of the gearshift sleeve and moved in the gearshift direction during gearshift operations.

In addition, flat struts enable the depth of the slot in the selector hub to be reduced (Figure 27). Shallower slots reduce the tension in the critical residual cross-section by up to 25 % and facilitate a higher transfer torque of the selector hub with an otherwise unchanged transmission geometry. The risk of fractures in the residual cross-section is therefore also effectively minimized.

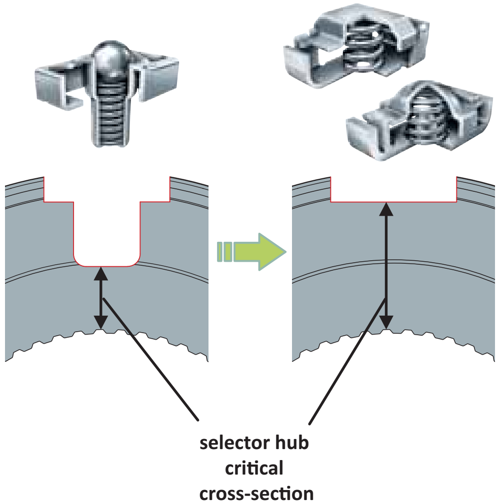

Figure 27 Minimizing stresses in the critical cross-section

Flat struts from INA provide a suitable solution to the requirements placed on these components by contemporary DCTs and AMTs. Their technology is oriented towards large-scale volume production which facilitates the lowering of system costs with reduced installation space and higher system reliability.

Outlook

The Gearshift Systems product line is intensifying its efforts both in optimizing existing products and in entirely new themes in order to meet the market requirements of today and tomorrow. New products and technologies will also in the future be developed in conjunction with customers.

Shifting systems and synchronisers 5

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