Dog Clutch Without Angular Backlash

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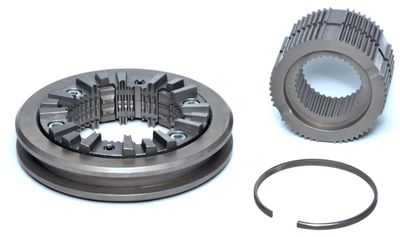

INTRODUCTION

For shifting gears mechanically in passenger car gearboxes, two design options are most widely used – a synchronizer or dog clutch (see Figure 2).

Dog clutches without synchronization are not widely used in passenger car gearboxes. One of the reasons is the angular backlash in the engaged state which is caused by the commonly used shape of the dogs with negative angle of the sides – see Figure 1 a). The backlash is necessary for successful engagement of these dogs. Using positive angle of the sides as in Figure 1 c) would be favorable for minimizing the angular backlash. However, the axial force arising on the sides of the dogs when transmitting torque in this case points out of the mesh – which leads to unwanted disengagement.

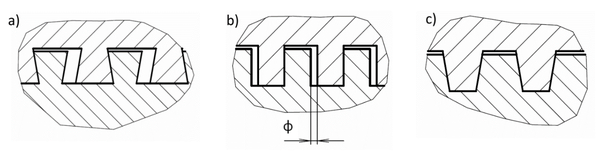

Figure 1: Types of face dog dogs regarding to the side angle of the dogs

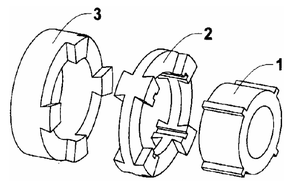

Figure 2: General face dog clutch design
1 – hub; 2 – sliding gear; 3 – shifted gear

The dog clutch is a suitable candidate to replace the synchronizer, especially in the case of using external synchronization by an electric motor – possible in electric and hybrid-electric vehicles. In the default configuration, dog clutches cannot offer the same qualities as the synchronizer, but the dimension and weight savings are significant.

Standard dog clutches are not able to disengage under load. This places limitations such as in the case of AUDI/Porsche 2-speed EV gearbox where disengagement of the dog clutch may not be possible for certain conditions and functionality of the gearbox is therefore limited.

OBJECTIVES

1. **Design a gearshift mechanism based on the dog clutch:**
   - Angular backlash in the engaged state is minimized.
   - Disengaging is possible even under load.

   The positive angle of the sides of the dogs may be necessary to comply with these requirements. Furthermore, the dog clutch must be competitive with other mass-produced dog clutches and must therefore meet the other standard dog clutch properties.
2. **Verify the gearshift mechanism experimentally** using a physical prototype and a suitable test bench. Testing will focus on the gearshifts and torque transmission, especially:
   - Functionality.
   - Service life.
   - NVH and comfort.

SOLUTION

Dog clutch with blocking mechanism was developed. Key features:

- Positive angles of the dog's sides regarding to Figure 1 c)
- One blocking ring to secure the clutch in all operating positions (engaged/neutral)
- Able to disengage anytime
- Purely mechanical device

Uniqueness of the design was confirmed:

- Patent 'Řadicí spojka' – Czech Office of Industrial Property
- Utility model 'Schaltungskupplung' – German Patent and Trademark Office

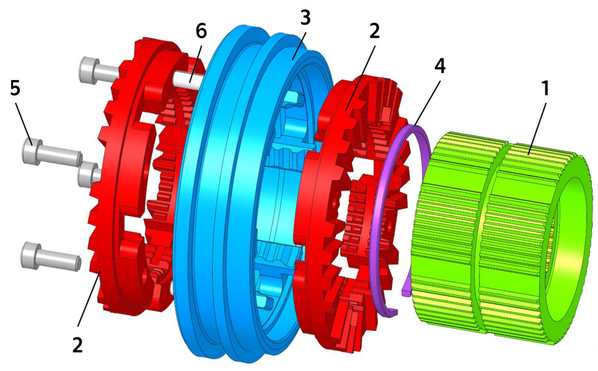

Figure 3: Dog clutch with blocking mechanism design

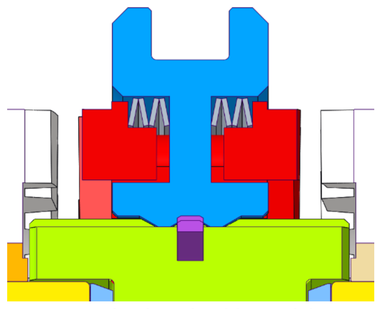

Figure 4: Dog clutch with additional disc springs

It consists of hub (1) fixed to the gearbox shaft, sliding gear (2) which can move axially to engage selected gear, gearshift sleeve (3) to control the sliding gear movement and blocking ring (4) to secure the sliding gear in desired positions (see Figure 3). Sliding gear is divided into two halves connected by screws (5) and pins (6) because of assembly reasons. No modifications of the standard gear selector mechanism are needed. Adaptation for sequential shifting was developed using additional disc springs between the sliding gear and gearshift sleeve.

In the engaged state, the whole axial force acting on the dogs of the sliding gear is secured by the blocking ring. For the gearshift process, an axial gap of defined size between the sliding gear and gearshift sleeve is crucial. When the engagement or disengagement starts, the gearshift fork always slides the gearshift sleeve first. The gearshift sleeve compresses the blocking ring. As the process continues, the gap between the sleeve and sliding dog is reduced to zero and the sleeve pushes the sliding gear in the desired direction – it is no longer blocked by the ring.

VERIFICATION

Prototypes were made (Figure 5) for testing in the Škoda MQ200 five speed mechanical gearbox as a replacement of synchronizers for 1st to 4th gear.

Figure 5: Prototypes of the dog clutch

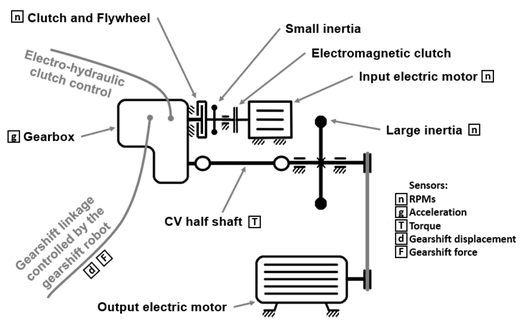

Figure 6: Updated test bench schematics

The testing was mostly performed at the test bench initially designed for testing of standard gearshift mechanisms. Therefore, many modifications and upgrades were necessary prior to the testing. Most importantly, external synchronization using an electric motor was added to the input shaft together with a controllable friction clutch system for further research of the behavior during gearshift. A completely new control system in LabVIEW was created. The updated layout of the test bench can be seen in Figure 6.

Functionality was tested in the first place. Before assembly into the gearbox, the scales were used to measure the gearshift force necessary for compressing the blocking ring (Figure 7). Afterwards, the prototypes were assembled into the gearbox and the gearshifts were monitored and evaluated using a video probe at low angular speeds (Figure 8). Then the testing continued for standard operation conditions with focus on the clutch behavior, gearshift times etc.

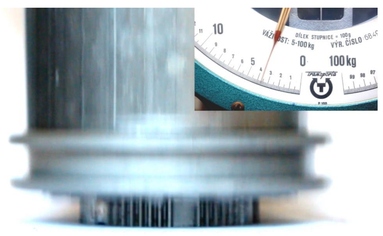

Figure 7: Gearshift force measurement

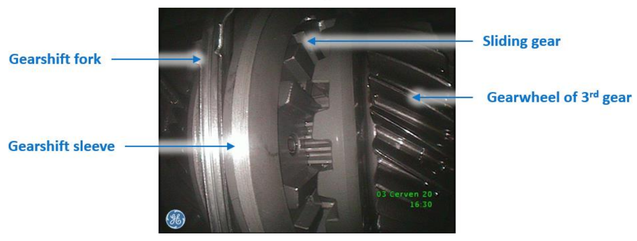

Figure 8: Gearshift verification using video inspection probe

Figure 9 shows typical gearshift (3rd gear, mismatch speed 30 min^{-1}):

- 0.96 s – The curves of displacement and gearshift force start to rise, the gearshift started.
- 1.02 s – A sharp drop in force, the ring is compressed, the sliding gear can continue moving. Shortly after, the force starts rising again together with input RPM and output torque as the gearshift dogs come into contact.
- 1.08 s – The engagement process is finished, further increase in the displacement is caused only by the gearshift pressure still building up.
- 1.17 s – The control program evaluated the gearshift as successful, the gearshift force drops again, the tension in the gear selector mechanism is released, the displacement decreases slightly, gearshift duration was roughly 60 ms.

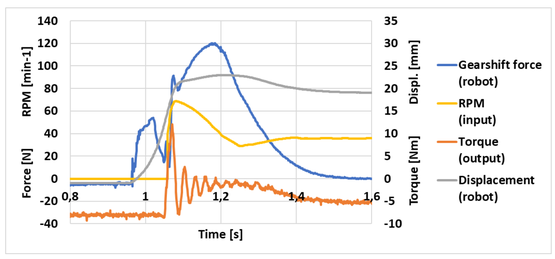

Figure 9: Shifting 3rd gear; mismatch speed 30 min^{-1}

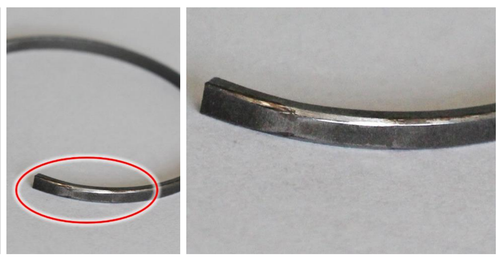

Figure 10: Ring after successful service life test – detail

Service life tests were focused on the blocking ring – the most critical component of the clutch subjected to cyclic bending stress. After 720,000 cycles, there was no plastic deformation of the ring, the outer diameter still complied with the dimension required in production drawing. The most visible wear was located at the outer diameter, at the edges where the blocking ring is compressed by the gearshift sleeve, near the ends of the C-shape – see Figure 10.

The NVH measurements indicate that the NVH of the dog clutch with blocking mechanism during gearshift should be manageable in real operation, especially for the intended mismatch speed of 100 min^{-1}, where the NVH is comparable or only slightly worse than of the synchronizer.

CONCLUSION AND FUTURE WORK

The new patented dog clutch with blocking mechanism retains all the advantages of a conventional dog clutch and additionally provides the benefits of minimal angular backlash in the engaged state (less than 0.1°) and the ability to disengage anytime, even under load. It is purely mechanical and compatible with standard gear selector mechanisms, including sequential shifting, without additional modifications. Its properties were successfully tested experimentally. In the following steps of the research, it would be suitable to:

- Assemble a gearbox with the dog clutches with blocking mechanism into a vehicle and perform tests that focus on gearshift quality and comfort perceived by the driver.
- Complete the the multi-body simulation program for further optimization of the gearshift comfort through the design of the dogs.
- Optimize the dogs for even greater axial space savings than for the prototypes.
- Conduct a search for possible application in the drivetrains of commercial vehicles or heavy industrial vehicles and machines.

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