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Failure of Synchronization In A Manual Gearbox

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***Abstract*: -** The synchronization of each gear will be explained and the problem that can occur if synchronization is not working in the right way. Scratching happens if the synchronization fails. How the sleeve chamfer, the gear piece angle and the tip radius have to be to avoid scratching will be explained. The transmission can then pass all the cold chamber tests with these improvements. Many other counter measurement ideas are described and investigated.

***Keywords*:-** *synchronization, synchronization failure, scratching, angle of synchronization parts, countermeasure scratching, vehicle test, work bench test, cold chamber test*

I. INTRODUCTION

Scratching is one of the biggest problems concerning the synchronization. This effect is hearable in the vehicle. Many ways to avoid this problem are possible, but not all are good enough to solve this item completely or have too many bad influences. It is not accepted by the car manufacturer to reduce the shift ability behavior in the vehicle.

A basic manual gearbox can be said to be a combination of a clutch and a gear set. There are two variations to this type of transmission: synchronized and unsynchronized. The unsynchronized transmission is more robust by nature and can handle higher loads than the synchronized transmission. However, the operator must double-clutch between shifts to match engine and transmission speed manually. Manual gearboxes in modern passenger cars use synchronizers to eliminate the need of double-clutching (Oberland, 2007).

Kirchner integrates the synchronization sequence in different phases of the sliding sleeve when moving from the neutral position in the direction of the target gear, the contact pressure of the balls during the pre synchronizing phase inside of the shift sleeve. The pressure piece is based due to the force between sleeve and detent ball of the synchronizer ring and the friction surfaces when touching. The friction torque during the rotation of the pre-synchronization takes the synchronizer ring in the pockets of the synchronizer body and an axial pushing on the sleeve in the direction of the wheel. Due to frictional locking action of the ratchet teeth it is not possible as long as friction induced by speed differences between synchronizer ring and friction cone at the wheel. During the synchronization phase the frictional torque between the synchronizer ring cones are accelerating or decelerating to synchronize transmission parts to achieve synchronization. By eliminating the relative motion of the friction surfaces it drops to nearly zero at the moment of friction and the synchronizing ring can rotate back from the sliding sleeve (Kirchner, 2007).

The synchronization phases are defined in different ways. (Neudörfer, 2008) has six different phases like overcoming of all free play, then pre synchronization and the third phase is the main synchronization. The next phases are rotation of the synchronizer ring, rotation of the gear teeth and the final phase is to build a positive connection.

According (Ricardo, 2007) the synchronization is divided in 9 steps. The nine phases are disengagement, neutral, neutral detent, pre synchronization, synchronizing, synchronization, blocking release, engagement tooth contact and full engagement.

(Ana Pastor Bedmar, 2013) defines it like this: first phase is the starting free fly and second phase is the starting of angular velocity synchronization area. Third phase is the angular velocity synchronization and fourth phase is when the turning of the synchronizer ring takes place. Fifth phase is the second free fly and sixth phase is the start of the second bump. Seventh phase is the turning of the gear area and eighth phase is the final free fly, then the gear teeth are engaged.

II. SYNCHRONIZATION AND THE PROBLEM

If an acceleration or deceleration of the vehicle is necessary, then the driver must shift from one gear to another gear. In that case a synchronization of the gears is necessary. The synchronization process is shown in the graph below. It starts with the synchronization of the sliding sleeve and the synchronizer ring. The next phase is the unlocking process. Afterwards the untethered flight occurs and the last phase is the meshing phase, where the gear is then completely engaged.

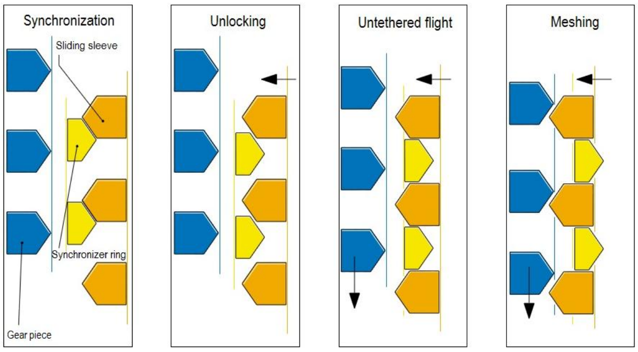

Figure 1: Method for synchronization (INA, 2006).

If the gear can not engage correctly then the teeth will go back and try it again. If it is then also not possible to engage, the teeth will go back and try it again and so on.

III. ANALYSING OF SCRATCHING

The graph below shows four possible positions for the sliding sleeve teeth and the gear piece teeth or the synchronizer ring teeth. The sliding sleeve teeth are always the above one. If the teeth stand like in the graph then two times scratching happens.

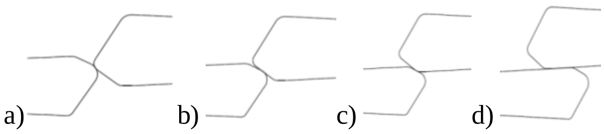

Figure 2: Teeth position during synchronisation

a) The angle of the teeth is too flat and scratching occurs. The teeth of the sliding sleeve will not move completely into the gear piece. The teeth of the sliding sleeve will move back and rotates and move in again and so on. Scratching is hearable in the car.
b) Sliding sleeve teeth angle becomes effective, but the sliding sleeve slope effective length is small. The sliding sleeve teeth can also jump back, rotate and engage again. So scratching is possible.
c) The engage stroke is deep enough, because the sliding sleeve slope effective length is long enough. The reaction force could be received on the slope. No scratching is hearable in the vehicle.
d) The engage stroke is deep and so the engagement could be finished. No scratching occurs.

In the graph below it can be seen that in this example a shift from first gear to second gear was done. If only regarding the red line then it is shown that on the left side of the graph the vehicle is in the first gear and in the middle of the graph the car is in neutral position and on the right side the vehicle is in the second gear. If only considering the shift forces then it is shown in the middle of the graph that scratching happened between the first and second gear. The scratching is also good to see on the input drive shaft and output drive shafts lines. There is in the middle of the graph for a longer time a big difference between the two rotations. The slope of the input shaft rotation in the middle of the graph is always the same and this is also an indication for scratching and a worse synchronization.

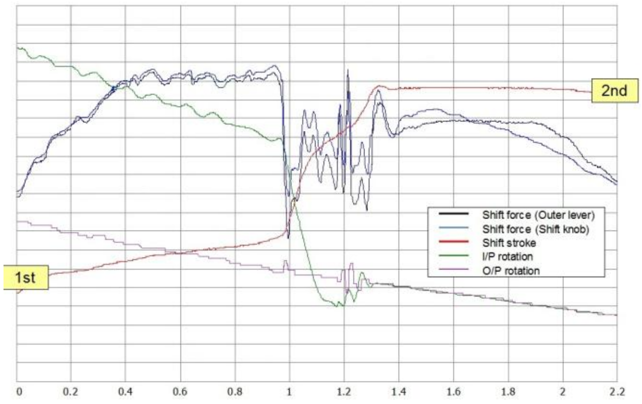

Figure 3: for scratching

This table shows the counter measurement ideas to solve the problem of scratching in a vehicle. Six different counter measurement items are mentioned and were tested in a vehicle or on a workbench.

Purpose	Countermeasure ideas	Negative effect
Reduce the drag torque	Low viscosity oil	Transmission durability
	Reduction of oil amount	
Improvement of engagement	Sliding sleeve chamfers angle reduction	Sliding sleeve chamfer durability
Shorter synchronization starting time and higher synchronization force	Index load increase Key spring load increase	・Shift feeling change ・SNR durability ・SNR biting
	Synchronizer ring oil groove tuning	・SNR durability ・SNR biting
	Reaction force reduce	・Shift feeling change

Figure 4: Countermeasure ideas

The synchronisation at slow speed takes place by the drag torque and not by the synchronization system in the transmission. The synchronization is not working.

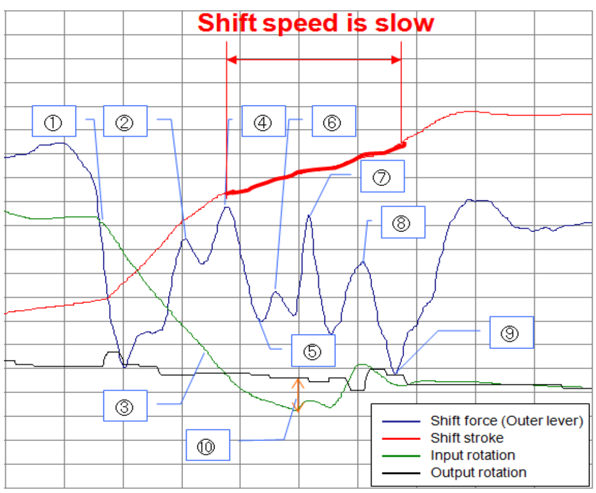

Figure 5: Shifting with slow speed

① Release shift from 1st shift
② Key spring load
③ Synchronization starting
④ Synchronization completion
⑤ Push through completion
⑥ Resynchronization
⑦ Double bump: 1st time
⑧ Double bump: 2nd time
⑨ Shift completion
⑩ Drive shaft speed difference

At number ① and under cold condition, drag torque is big and so the input rotation speed is falling quick. Rotation difference between input shaft and output shaft is 204 rpm at release shift moment. At the status of number ③ the synchronized load is small, because the brake does not work and so the input rotation is falling continues. At the starting point of synchronization, a rotation difference is already available. At number ④ the synchronized load is small. Before load rise up, synchronization is completed. At ⑩ the input shaft rotation goes under the output shaft rotation and so a big rotation difference occurs for a long time and so scratching is hearable in the vehicle. From the point ④ to ⑨ there is shown when the synchronized load is small after synchronization is completed, then the shift speed is slow. Inertia energy is small that sliding sleeve chamfer is rebounded at gear piece chamfer. At the area ③ to ④ there is a large drag torque at this shift timing, therefore a large synchronized load is necessary.
The drag torque is high and so the fall of input drive shaft rotation is early, therefore synchronized load is small and after synchronization the difference between input shaft and output shaft rotation is large. Synchronized load is small and therefore the shift speed is slow. The drag torque can produce the rotation difference of the sliding sleeve and the gear piece, therefore the teeth of the sliding sleeve can not engage and scratching occurs.

IV. COUNTER MEASUREMENTS FOR SCRATCHING

1) Friction reduction:
One possibility is to reduce the friction at the time point of shift, so therefore the cam can be tuned up to the minimum. The key spring load was increased. The negative effects for this possibility are the change of the shift feeling, synchronizer ring durability will change and the synchronizer ring biting. The synchronization load will rise up quicker and this effect is good to avoid scratching and the other good thing is that the synchronizer force will increase.

Key spring load

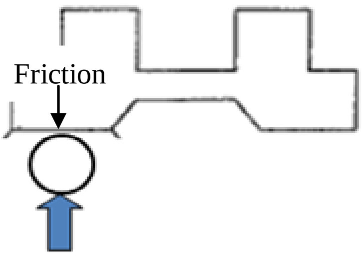

Figure 6: Reduce friction

2) Synchronizer ring oil groove tuning:
One possibility to avoid scratching is to change the geometry from this

to that

Figure 7: Synchronizer ring change

The width for the two rectangles gets smaller and the width between the four rips gets bigger. If the geometry gets changed like this then the synchronization load rises up quickly. The negative effect will be that the synchronizer ring durability will change and the synchronizer ring biting. The good thing is that the synchronizer force will increase. Optimized synchronizer ring geometry for the oil groove has to be developed by the transmission manufacturers for their special usage.
The effect of rising up the synchronizer load quicker is shown in the graph below.

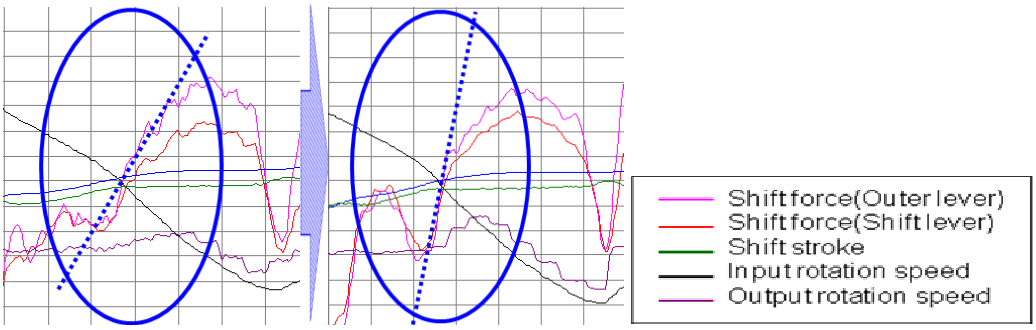

Figure 8: Rising up the synchronizer load quicker

3) Reduce the drag torque:
Drag torque has also a big influence in scratching. There are many possible ways to reduce drag torque. One way could be to reduce the oil amount, but this change has also an influence on the durability of the transmission. Another way could be to use low viscosity oil for example BOT 350 M3, but normally only use low viscosity oil will not solve the problem of too much drag torque in the transmission.

4) Reduce the shift force on outer lever:
This can be done by changing the geometry of the outer lever and by changing the force from the key spring there. The two geometries for shifting and selecting are shown in the graph below. The slope for both geometries can be decreased or increased and in combination with the force from the key spring it is possible to change the shifting force in the way it is necessary. The key spring moves the slopes up and down. If the shift force should be optimized then the left geometry has to be improved. The gradients of both slopes for shifting don´t have to be the same. The gradients of the slopes are only one part of the whole shifting system and so the transmission manufacturer can investigate on the gradients to get an optimized shifting feeling in the vehicle. Another big influence on the shifting behavior has the outer shift mechanism, the shift tower and the synchronization of the gears.

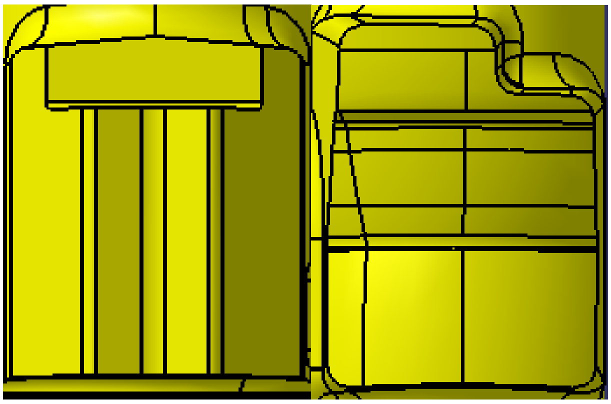

Figure 9: Shift force reduction on the outer lever

If the synchronizer force is too high and so the shifting force is too high then the shifting force can be decreased with the two geometries and the key spring as it is explained above. Some gearboxes have only one geometry and key spring for the shift, select and reverse direction.

5) Distance between locking teeth and meshing teeth:
Another reason for scratching could be that the distance of the teeth of the locking synchronization and the teeth of the pre-meshing gear is too high. If it is possible to reduce the clearance then the likelihood of scratching can be reduced, but if the elements are to close then the abrasion of the synchronization will increase.

6) Improvement of engagement:
This countermeasure wants to change the sliding sleeve chamfer angel and so a reduction of reaction force can be done. The graph below shows that the sliding sleeve chamfer angle should be decreased. For this reduction it is necessary to secure the engagement length of sliding sleeve chamfer and the gear piece. For example the sliding sleeve chamfer angle will be decreased from 36° to 31° then the reaction force will be lower as in the original condition. At the sliding sleeve chamfer teeth there should be a tip and no radius.

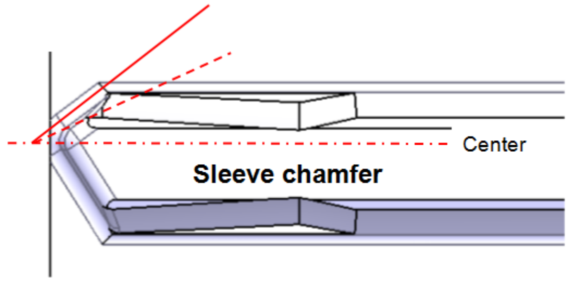

Figure 10: Sleeve modification

All the gearboxes and the scratching area shown in the graph below were measured under the temperature condition of -25°C. All the cycles in the graph below are different gear sets of transmission types. The pink x are the gearboxes where scratching occurs. The blue line for scratching is based on all measured transmissions. Scratching occurred only if the angular momentum of the output shaft is under 0.58 kg*m²/sec. If the chamfer tip radius of the sliding sleeve and gear piece are 0.1 mm and chamfer angle of the gear piece is sharp enough, then the values of angular momentum of the output shaft are above the 0.58 kg*m²/sec line and no scratching is hearable. The radius of the gear piece and the sliding sleeve are big enough to pass the durability test for these parts. The problem with scratching under cold condition can be solved, if transmission developer produce gearboxes at which their angular momentum of the output shaft is higher than 0.58 kg*m²/sec.

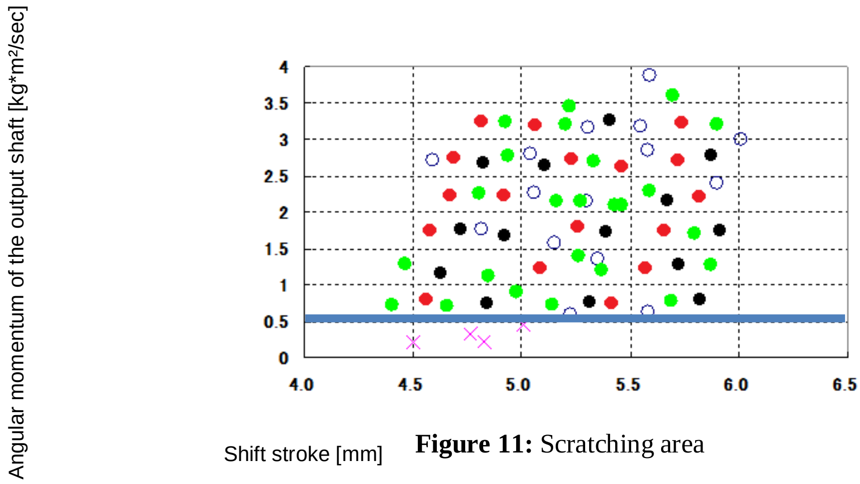

Figure 11: Scratching area

V. CONCLUSION

The problem scratching was solved by number 6 - Improvement of engagement. The sleeve chamfer was decreased, the gear piece angle was decreased and the tip radius was reduced to its technical limits. The transmission passed then all the cold chamber tests with these improvements. Sliding sleeve chamfer durability was also checked and passed all the tests. The other mentioned counter measurement ideas have more bad influences in shifting behaviour or do not solve the scratching problem.

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