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Development of a new synchronizer with the lever mechanism

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Abstract

The Borg–Warner style manual transmission synchronizer has been used for a long time, and the multi-cone synchronizer is also the same basic structure and movement structure as the Borg–Warner style. We developed a new synchronizer called "Lever synchronizer" that inserts a lever between the sleeve, the synchronizer ring (hereafter described as "ring") and the hub. There are two styles of lever synchronizers, the high performance style and the inverted style. Mass production of the inverted style started in Nov. 1999, and of the high performance style in May 2002. This paper introduces both styles, the detail and the outline of the development.

1. The aim and structure of the lever synchronizer

1.1. High performance style

The lever synchronizer style is a split circle shaped lever that is inserted between the sleeve and the ring, the hub and the sleeve push the ring with doubled force by the lever. Fundamental structure of the lever synchronizer is as shown in Fig. 1 [1]. Currently in the Borg-Warner style synchronizer, the sleeve pushes the ring directly, but in the lever synchronizer the lever is inserted between the sleeve and the ring, to increase the pushing force for the ring to use the lever's leverage effect, and to increase the synchronizing ability.

The lever has a circular appearance from the front, and the lever is the upper point in force, the lower point is the fulcrum, and the middle point is the weight when seen from the side (Fig. 3). Between the sleeve and the ring, it is necessary to transmit the pushing force for the shaft direction and baulk action during synchronization.

There is a sloped surface on the sleeve that pushes the lever into position (Fig. 2). This sloped surface pushes the lever to the shaft position and forces it to the radius direction.

The friction torque generated on the ring works the lever to expand the radius outside and to obstruct the sleeve progress. The sleeve slope and the top of the lever act as the spline chamfer for the Borg-Warner style. Two lugs are formed for shaft direction on the circumference of the ring; these lugs are between the two levers. (Fig. 3)

This causes the friction torque to work on the ring, and the lug separates these two levers and spreads them in the outside radius direction. As a result, the top of the lever pushes back the sleeve slope, to set up the slope angle to allow it to obstruct the sleeve progress. Accordingly, the sleeve keeps pushing the ring through the lever when friction torque works on the ring, and promotes the synchronization. The baulk action of

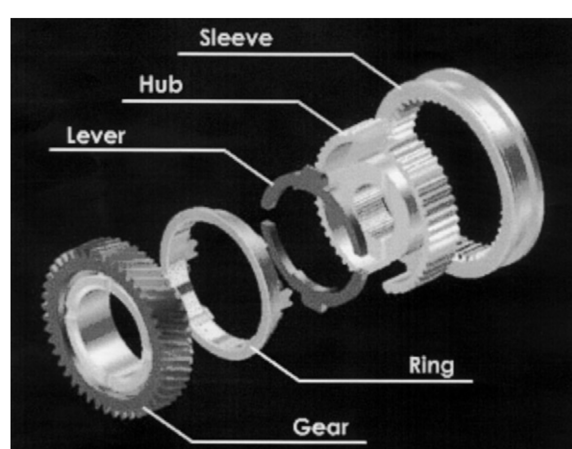

Fig. 1. Technical illustration of the lever synchronizer.

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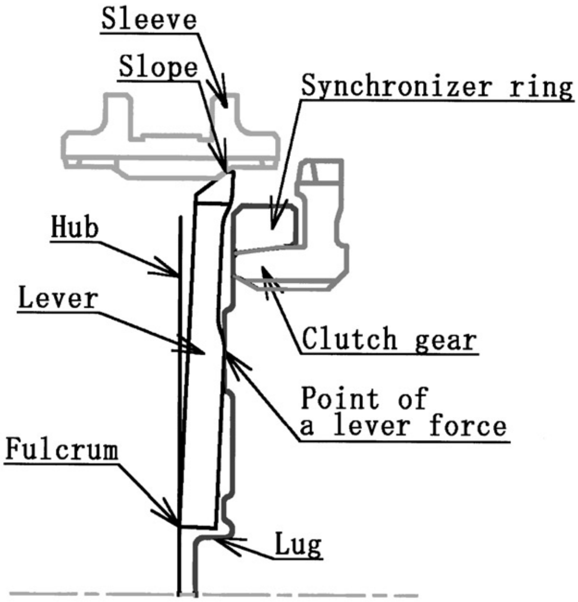

Fig. 2. Style of the high performance synchronizer with a lever mechanism.

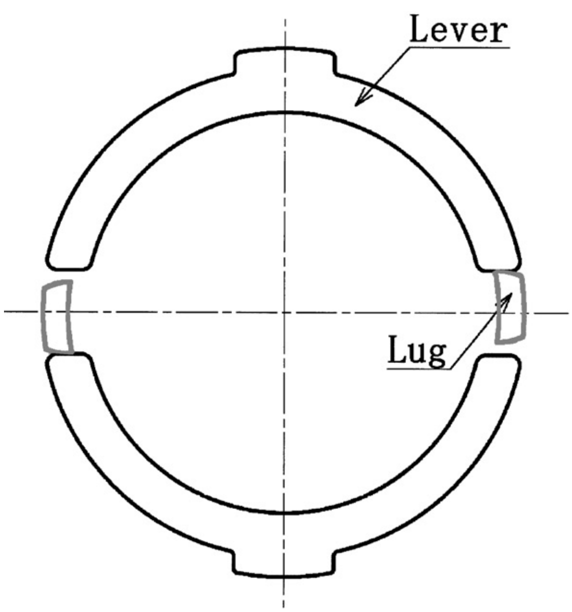

Fig. 3. Schematic drawing of the lever activity.

friction torque will dissipate when the synchronization is complete, and the sleeve progresses to push the lever in the radius direction, and to engage with the clutch gear. At this time, the lever pushes to the inside, and the ring will rotate a little with the other gear. At this point, it is the same as the Borg–Warner style.

Accordingly, it will complicate the force transmittance because of the lever work, but basically the function and operation are the same as the Borg–Warner style, the calculation method is also the same.

In what we call the "high performance style", the sleeve pushes the ring by doubled force on the lever. The high performance style allows us to get equal ability out of the multi-cone synchronizer and the single-cone synchronizer, allowing us to combine the multi-cone synchronizer and this lever, making it possible to design a higher quality than ever before. This will contribute to improve the operational feeling of the manual transmission.

The most unique characteristic of the high performance style is that it is possible to improve the quality to combine the low friction material and to set up the larger lever ratio. In the Borg–Warner style case, only the life will be longer using the low friction material, but in the lever synchronizer case, it will convert the low friction material non-wear quality to improve the synchronizer's ability. The copper case metal friction material will have improved wear capacity. It is possible to improve the quality and increase the lever ratio.

1.2. Inverted style

What we call the "inverted style" is geared towards developing the lever function. The mass production of the inverted style was initially applied to the fifth position of the five-speed transmission. To apply the inverted style, it is necessary to stroke the opposite side when the fifth speed sleeve is shifted to the reverse side. Inverted style is shown in Fig. 4, the top of the lever engages with the groove formed in the sleeve, and a slope is formed at both sides of the groove. When the sleeve progresses to the fifth gear side, it is synchronizing with the fifth gear the same as with the high performance style. In the opposite direction the sleeve progresses to the reverse side, synchronizing with the fifth gear.

To engage with the reverse gear after synchronization with the fifth gear, is the function of gear clash prevention when the car is stopped. The fulcrum of reverse position was formed at a different point from the fulcrum to fifth position, the point of the fulcrum and the weight replace each other, and the lower edge of the lever becomes the fulcrum and then pushes the ring. (Fig. 4(b)). To push the top of the lever to fifth position on the sleeve slope, and on the other side to push the top of the lever on the reverse shift, the friction torque worked for the ring to transmit to the sleeve's slope through the lever and to do the baulk action, which is the same as the high performance style. With the inverted style, it is possible to apply the shift pattern of the reverse shift and opposite side of the first shift like a commercial vehicle. The characteristic of this inverted style is to be able to add the function of the gear clash prevention with reduced cost. Another merit is improved drag torque and reduced heat when the car is running at high speed, because it does not increase the wear the of friction surface.

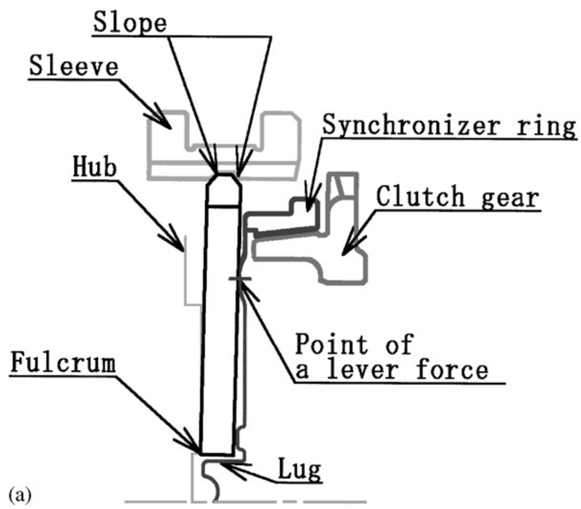

Fig. 4. (a) Inverted style synchronizer with a lever mechanism in the case of 5th position; (b) Inverted style synchronizer with a lever mechanism in the case of reverse position.

2. Calculation of the synchronization

The fundamentals of synchronization are the same as the Borg–Warner style, and the current formula is applicable [2]. T_c means cone torque, T_i means revolving torque of the ring during the sleeve pushes the lever to the inside. Fig. 5 shows each parameter of the lever synchronizer.

$$T_c = \frac{L \cdot \mu_c \cdot R_c \cdot F}{\sin \theta}, \tag{1}$$

$$T_i = \frac{R_r \cdot F}{\tan \alpha}, \tag{2}$$

where F: push force of the sleeve, L: lever ratio, μ_c: friction coefficient of the cone surface, R_c: cone radius, θ: cone angle, R_r: radius of the lug on synchronizer ring, α: angle of the slope on sleeve.

If the T_c/T_i equal to the baulk ratio: BT, so it will

$$BT = \frac{L \cdot \mu_c \cdot R_c \cdot \tan \alpha}{R_r \cdot \sin \theta}. \tag{3}$$

In fact, to calculate the synchronization to include the friction influence, basically the baulk ratio looked the same as the Borg–Warner style.

3. The issues and counter measures on the development process

The first issue on the process is the practical use of the lever synchronizer, whether it effects the lever baulk action or not. The case of the present Borg–Warner style, the sleeve progresses and then the key pushes the ring lightly, and the ring works to index the first friction torque and then begins the baulk action. The sleeve progresses from the place where the key begins to push the ring, and then the baulk action begins.

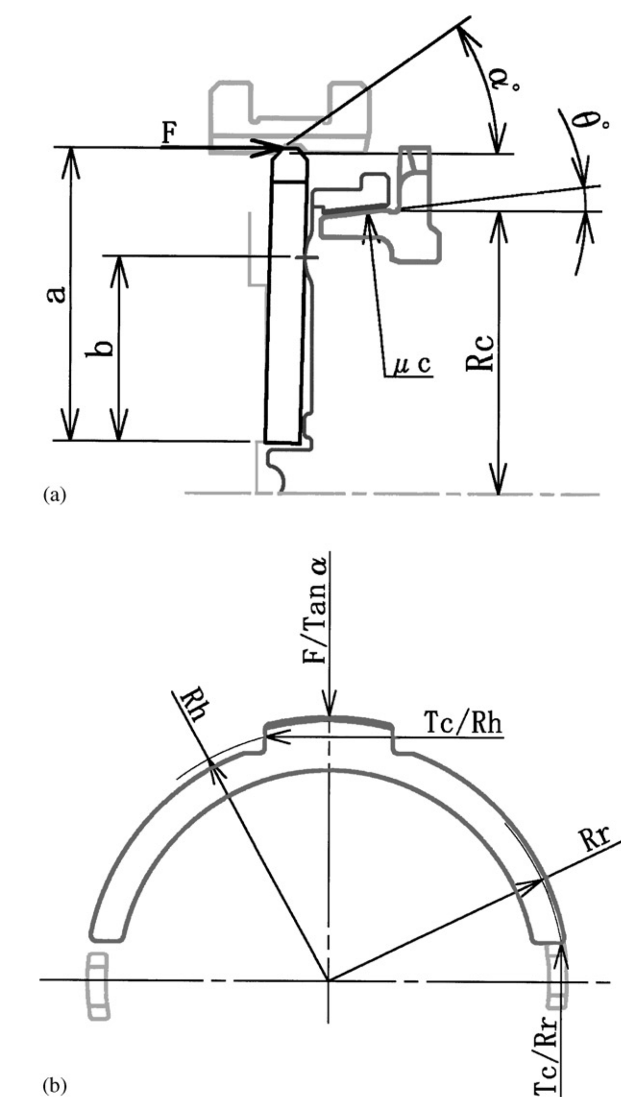

Fig. 5. (a) Parameter of the synchronizer system (cross section); (b) Parameter of the synchronizer system (front view).

The lever synchronizer, the place where the sleeve begins to push the ring through the lever, is the same as the sleeve's baulk place. It is necessary to work baulk action at the point the sleeve begins to push the ring. Porsche style synchronizer is a similar case in the past.

We performed tests using a real vehicle regarding this issue, and the result is to confirm the baulk action.

The reason to study baulk action is that the Borg–Warner style begins the baulk action after the ring rotates a little, but the case lever synchronizer always has the lever located at the baulk position. To explain the baulk action from the sleeve stroke basis (described above), from the view of time basis, the Borg–Warner style is basically the same as the lever synchronizer.

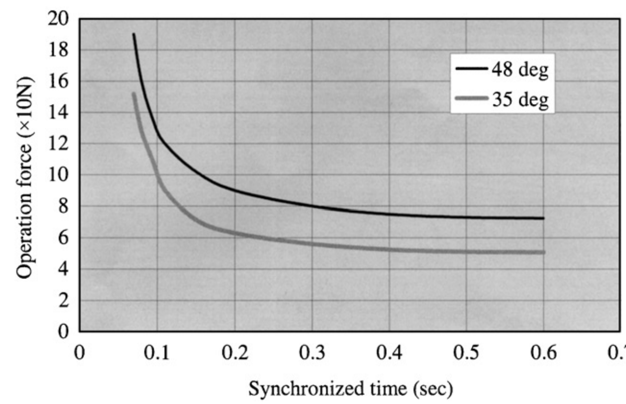

Fig. 6. Relationship between the operation force and synchronized time (4th → 5th shift).

3.1. The development of 5-R style

As mentioned above, the inverted style was the first style to sell on the market, we also called it the "5-R style", because it had the gear crash prevention system. The layout of the synchronizer developed actually was the fifth speed synchronizer installed to the input shaft side like the transmission for general FF cars.

Regarding the need for initial force when the synchronization starts, one theme is whether it needs a spring or not. This spring is to push the lever outside. Generally, it is necessary for the spring to spread over the lever to the outside because there will be situations that shift changes to fifth or reverse position without rotating the input shaft.

However we found after many kinds of experiments that this is not a problem without the spring, so we started the mass production with no spring. There was no trouble after the experiments to release the clutch for a long time at neutral position during the vehicle running, and then shift to the fifth speed. The biggest issue regarding the spring is how the influence from the centrifugal force affects the lever.

The fifth position is always working in synchronization during high-speed running, so in the case when the lever size is large, the influence from the centrifugal force acting on the lever cannot be ignored. After the synchronizing is completed, the sleeve proceeds to push the lever inside, so the shift operation will become heavy due to the centrifugal force. This situation is conspicuous at the slow shift feeling. Our first practical use of the 5-R type is set up about 1.2 lever ratio on fifth speed, and 48° angle of the sleeve slope, however there is a problem that the operation force will become heavy on fifth speed over 130 km/h. In this counter measure, to decrease the push weight when the sleeve pushes the lever after completion, the angle of sleeve slope changes to a small degree. In other words, lever ratio of fifth speed change of 1.5, and the angle of sleeve slope changes down to 35°, resulting in a decrease of the influence of centrifugal force. Fig. 6 shows the relationship between the operation force and synchronized time.

3.2. The development of high performance style

In the case of high performance style, the lever ratio was decided depending on the friction volume of the cone surface. Basically, the maximum lever ratio L was decided by the following formula:

$$L = \frac{(A - B - C)}{D}, \tag{4}$$

where A: the sleeve stroke until the sleeve engages with the clutch gear, B: dimensional precision and allowance, C: difference of thermal expansion between gear cone and the ring, D: allowance of friction volume.

As C is the combination of the case of the steel cone and the copper alloy ring it should be applicable, but this neglects both steel cone and steel ring because it has no thermal expansion.

In the case of the double cone, it is possible to neglect this because the combination of steel and copper their thermal expansion difference counteract each other. It is possible to increase the lever ratio with the combination of the steel ring and low friction material.

Though the high performance style is still in the process of development, we introduce the development situation of the copper alloy ring changes to the high performance style.

Cone diameter: 86 mm (single cone)
Taper angle: 7°.
Lever ratio: 2.

Fig. 7 shows the experimental results of synchronizer performance compared with the Borg–Warner style and the lever synchronizer during down shifting.

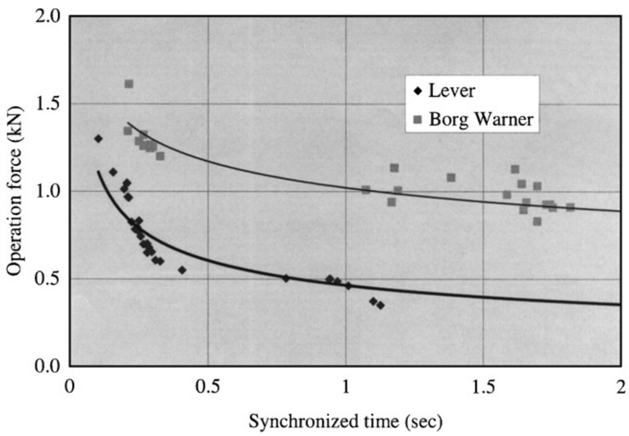

Fig. 7. Synchronizer performance compared with Borg–Warner style and Lever style (2nd→1st shift).

Furthermore, the figure demonstrates that the lever synchronizer has higher performance than Borg–Warner style in the same conditions. Definitely, it is a little improvement compared to the lever ratio under 0.4 s synchronized time, but it is excellent improvement that the level is the same or a little bit more than the lever ratio, over 0.5 s synchronized time.

The reason depends on the chosen sample, so it needs more detailed analysis regarding the relation of lever ratio and ability improvement in the future.

4. Conclusion

Though the lever synchronizer looks strange to the person who is familiar with the Borg–Warner style synchronizer over the past 60 years, the lever synchronizer succeeded in practical use. Thanks to everyone for their understanding and support it. In the future, we will continue to analyze more in depth, and we also expect the new development to be tried in combination with the new kind of friction material.

Recently, the improvements of the automobile have been to reduce the fuel cost. We also eagerly anticipate the improvement of the handling ability.

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[2] H. Hoshino, Simulation on synchronization mechanism of transmission gearbox, Nissan Diesel Technical Review No. 59.