

Development of New Manual Transmission for Middle-Torque Engine

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ABSTRACT

A new 6-speed manual transmission has been developed that supports 300 Nm of maximum input torque, which corresponds to middle torque in the company's manual transmission series. This transmission supports maximum input torque of 300 Nm in the same size as the previous model used with torque of up to 235 Nm.

To improve fuel economy, it has furthermore increased transmission efficiency and thereby achieved top-level efficiency. It also uses a preceding sleeve tooth and offset gear dog to achieve a smooth and refreshing shift feeling. It uses a constant-mesh reverse system with main shaft braking system, which reduces reverse gear noise and mitigates the load when putting the shift lever into reverse.

1. Introduction

Downsizing of diesel engines continues to be the mainstream practice, and Honda also has developed a new compact diesel engine. As this engine is planned to be installed into vehicles for Europe, we need a transmission with reliable capacity of 300 Nm of torque in a size small enough to be installed into a compact vehicle, which is why the new higher-torque, lightweight and compact 6-speed manual transmission (new 6MT) was developed. This paper introduces the technical features of the transmission.

2. Development Targets

The development concept for the new 6MT was to attain higher torque capacity in a lightweight and compact transmission, along with higher efficiency and product appeal. The following development targets were established in order to achieve this.

- (1) Achieve the same or smaller size as the previous 2.4 L gasoline engine 6MT so that the new 6MT, while accommodating maximum torque capacity of 300 Nm,

could be mounted on a FIT-class compact automobile with the new compact engine.

- (2) Achieve top-level transmission efficiency.
- (3) Enhance the change feeling and product appeal in reverse.

3. Basic Construction and Specifications

The gear train was given a constant mesh-type synchromesh construction, with gears 1 through 6 always in contact, with a parallel dual-shaft configuration. To increase transmission efficiency, splashing-type lubrication was used, while ball bearings were used as differential side bearings. A constant mesh-type reverse system was used to both shorten overall length and reduce reverse gear noise, which is an element of product appeal in reverse. A helical gear was used for the reverse gear. Finally, a main shaft brake system (MBS) that uses the third-gear synchronizer when operating reverse gear was used in order to reduce load during reverse operation and reduce synchronizer drag torque. Table 1 shows the major specifications and Fig. 1 the longitudinal section.

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Table 1 Specifications of transmission

Transmission type		6-speed manual
Torque capacity (Nm)		300
Gear ratio	1st	3.642
	2nd	1.884
	3rd	1.179
	4th	0.869
	5th	0.705
	6th	0.592
	Reverse	3.671
Final		3.571

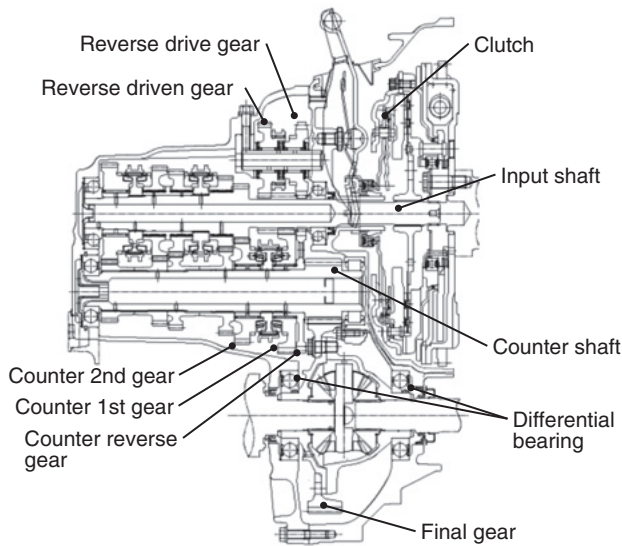


Fig. 1 Main section of transmission

4. Higher Torque Support in a Lightweight and Compact Transmission

4.1. Shortening the Overall Length

To curb the increase in weight, the following changes were made to shorten overall length while leaving the inter-shaft distance as is. This resulted in support for higher torque without changing the overall transmission length.

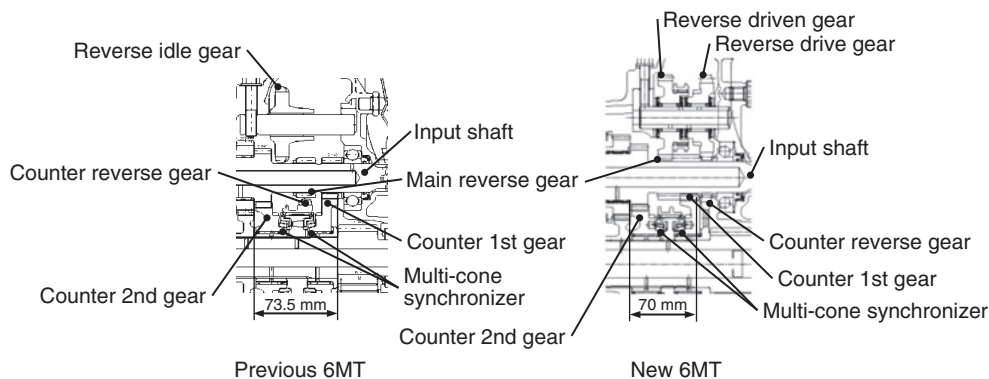


Fig. 3 Layout of 1st, 2nd and Reverse Gears

Figure 2 shows the relationship between transmission allowable torque and length of a transmission case with gear train inside. The case is shorter than that of the previous 6MT with the same level of torque.

- (1) Using a constant-mesh reverse system with MBS resulted in the clutch gear, which was molded onto the end face of the previous gear, being brought inside the gear, reducing the overall width from first to second gear, including reverse gear (Fig. 3).
- (2) With first and second gear it is necessary to deal with two issues: increasing gear tooth root strength with impact load and providing a contact ratio that would reduce gear noise. In consideration of the goal of a lightweight, compact transmission, the increase in gear width in the new 6MT was kept to a minimum by imparting higher-stress support with water-jet peening while securing the needed contact ratio through the use of small modules.
- (3) To reduce gear misalignment, the main shaft and countershaft were made more rigid by increasing their inner diameter.

4.2. Higher Torque Support

In conventional development, a theoretical tooth shape is used and gears are designed for strength without accounting for gear misalignment. These designs are then evaluated in comparison to results of past durability tests of stand-alone transmissions. With this method, however, actual gear life is sometimes shorter than calculated. It is assumed this

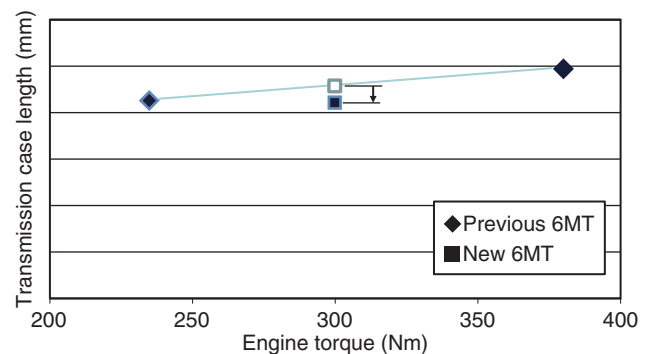


Fig. 2 Comparison of transmission case length

may be caused by misalignment that results in a decrease in tooth bearing ratio, but to increase a transmission's torque capacity from 235 Nm to 300 Nm without increasing its overall length, it was necessary to establish a method for more accurately predicting gear strength. Therefore, gear misalignment was calculated using Romax brand gears and gear strength was designed after predicting strength reduction based on deviation in tooth shape. Stand-alone gears were compared for tooth root stress and tooth pitting life data and the target torque capacity was provided by making the minimal necessary increase in tooth width.

Figure 4 shows a conceptual diagram of this stance on gear strength design. The vertical axis of the graph represents tooth root stress or tooth profile pressure, while the horizontal axis represents the gear working number. The intersection of the S-N line or P-N line and the target gear working number, that is, the durability cycle intersection, is the limit of tooth root stress or tooth profile pressure, and gears need to be designed so that the maximum tooth root stress or tooth profile pressure, taking tooth shape deviation into account, is within this limit.

Figure 5 uses the tooth root stress of the first gear as an example to show the degree of influence of each element making up gear strength when increasing torque support from 235 Nm to 300 Nm. The increase in gear width was kept to the minimum necessary by correctly predicting strength reduction based on misalignment and deviation in tooth shape for the gear of each speed. As a result, the width of first gear was increased by 1.5 mm, second gear by 0.5 mm and sixth gear by 1.5 mm.

4.3. Reducing Weight

Designing the transmission to support higher torque increases its weight by enlarging the external diameter of the main shaft and countershaft to reduce misalignment. However, by doing the verification previously described and enlarging the shaft inner diameter only as long as there is no impact on gear strength, and by giving each gear a

form that accounts for slanting, weight was reduced. Figure 6 compares the gear and shaft weight against the previous 6MT. The weight was successfully reduced compared to the previous 6MT for the same level of torque.

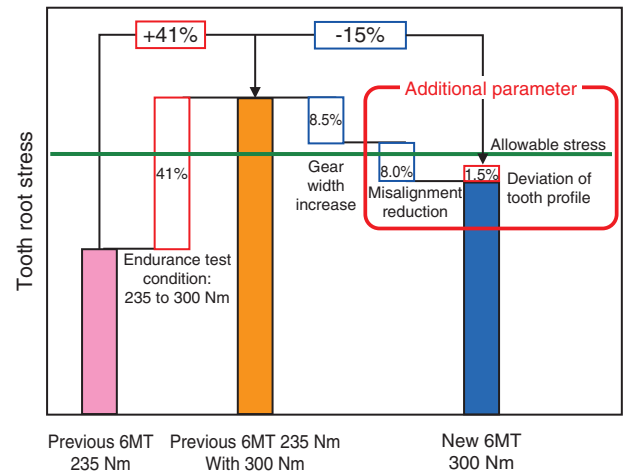


Fig. 5 Contribution to gear strength

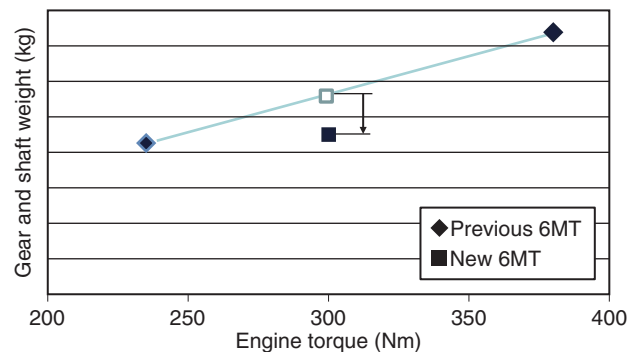


Fig. 6 Comparison of gear and shaft weight

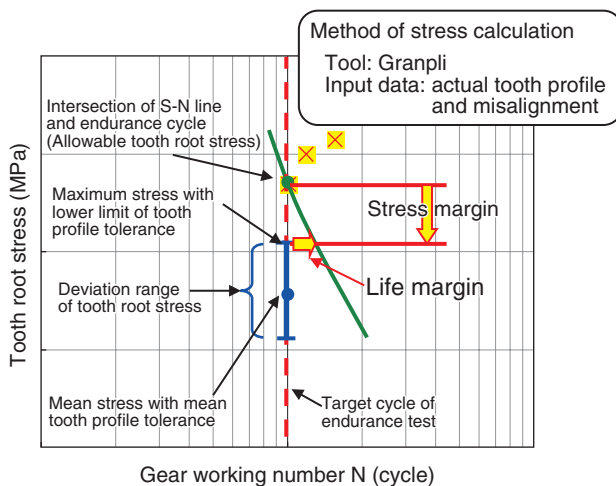


Fig. 4 Concept diagram of gear design

5. Increasing Transmission Efficiency

The following techniques resulted in the transmission reducing loss torque 15% compared to the previous 6MT supporting 380 Nm and the same or greater transmission efficiency as the previous 6MT supporting 235 Nm.

- (1) Using splashing-type lubrication
- (2) Reducing synchronizer drag torque
- (3) Using ball bearings as differential bearings

5.1. Using Splashing-type Lubrication

Though the maximum permissible torque is 300 Nm, the same gear splashing-type lubrication was used as in the previous 6MT supporting 235 Nm. With gear splashing-type lubrication there is usually the issue of reduced lubricity when the gears are rotating at lower speeds, but the lubricity at lower gear rotation speeds was enhanced by enabling gears to get splashed with oil from the rotation of the counter reverse gear. The construction is shown in Fig. 7.

5.2. Reducing Synchronizer Drag Torque

Conventionally, synchronizers have been designed with large capacity by focusing on reducing shift load when operating the engine at maximum rotation speeds. However, here a study was done on users' usage status, with the results showing that, more importantly than the value of shift load itself, users preferred small deviations in that load at each shift level in the normal zone. Thus, an effort was made to revise the target load and thereby reduce multi-cones and drag torque (Fig. 8). Additionally, the reverse synchronizer was removed due to the use of MBS.

5.3. Using Ball Bearings as Differential Bearings

A competitor's 300 Nm class transmission uses tapered roller bearings as the differential bearings. While tapered roller bearings yield higher capacity in a compact size, efficiency tends to decline because a preload is applied. The recently developed transmission increases transmission efficiency by using ball bearings similarly to the previous 6MT supporting 235 Nm.

First, the size of the ball bearings was increased, then to additionally bring out the capabilities of the bearings, a gutter plate was used so that even at lower rotation speeds bearings could be dependably lubricated with lubricating oil splashed by the final gear. The construction is shown in

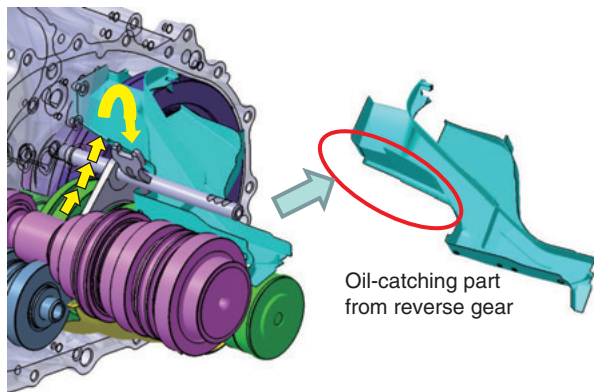


Fig. 7 Lubricating system 1
Details of main gutter plate

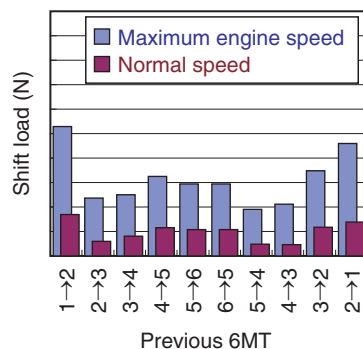


Fig. 8 Comparison of shift load

Fig. 9. Installing a gutter plate with two-level construction for lubrication at both lower and higher rotation speeds achieved lubrication volumes 6.6 times greater than in conventional constructions.

With these technologies, increased torque capacity and the same or greater transmission efficiency than the previous 6MT for the same level of torque were achieved (Fig. 10).

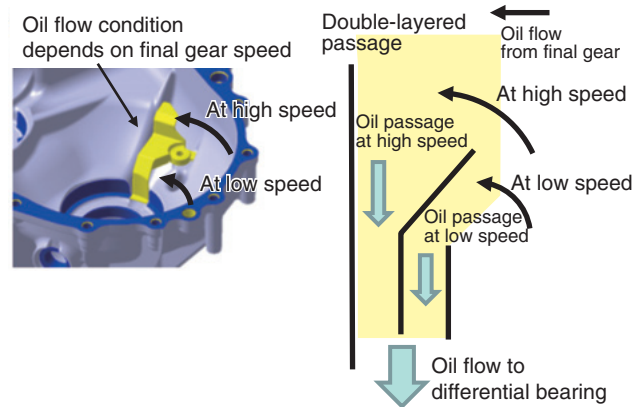


Fig. 9 Lubricating system 2
Details of gutter plate for differential bearing

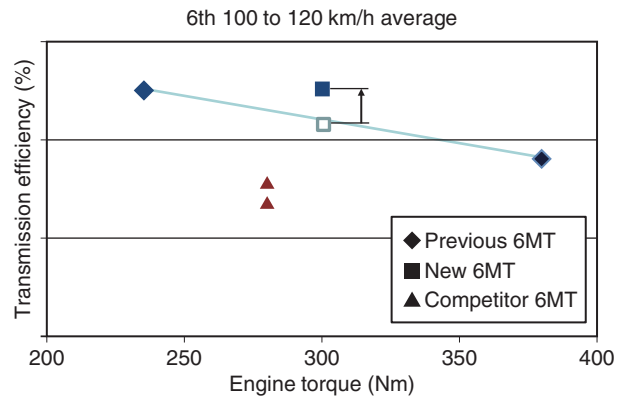
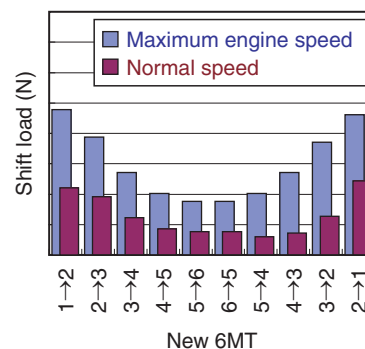


Fig. 10 Comparison of transmission efficiency



6. Technology to Increase Product Appeal

6.1. Improving Change Feel

Focusing on sensory performance when changing gears, an attempt was made to improve the feel by focusing on the following.

- (1) Swallow feel
- (2) Intuitive operating feel
- (3) Smooth operating feel

6.1.1. Improving swallow feel

“Swallow feel” refers to the feel of gear-shifting when the shifter seems to be drawn into the in-gear position, without any feel of resistance or bumpiness. To improve this performance, the detent spring load and detent groove shape of each part of the transmission (Fig. 11) were revised to emphasize an operating feel that the load is being turned over (drawn in) when shifting. The load imparted by the shift arm detent was designed to be larger and other loads to be smaller as compared to the previous model, which shortened stroke when drawn in by 6 mm, increased drawn-in load with the same stroke by 4 N and enhanced the swallow feel as compared to the previous model (Fig. 12).

6.1.2. Intuitive operating feel

“Intuitive operating feel” refers to being able to clearly distinguish the various in-gear positions through the sense of touch with the hand and an operating feel that makes it easy to change gears. To enhance this performance, the forms of the components that make up the change operation pattern, namely the shift piece, interlock and fork (Fig. 13), were revised to reduce the select direction backlash (gate

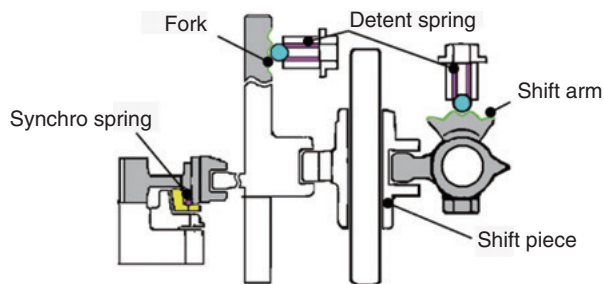


Fig. 11 Detent system

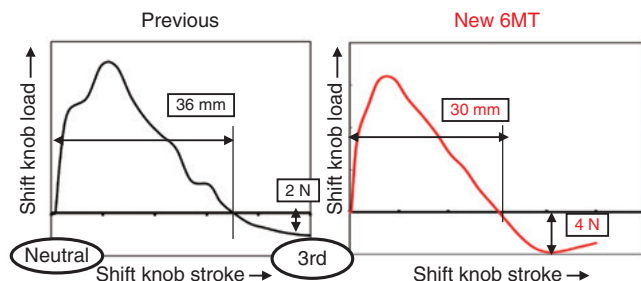


Fig. 12 Characteristic of shift feeling

width) after getting in gear and to create a change pattern with a wider frontage (slant shift width) when shifting diagonally, such as from second to third gear. Increasing the select stroke within the transmission and making the ratio up to the knob smaller reduced the influence of the internal backlash.

As a result, gate width was reduced 3 mm and slant shift width increased 5 mm as compared to the previous model, achieving intuitive operating feel (Fig. 14).

6.1.3. Smooth operating feel

“Smooth operating feel” refers to an operating feel in which double-bump, a phenomenon in which the driver feels bumpiness during dynamic shifting, is inhibited. Focus points already known for inhibiting double-bump are inhibiting the drivetrain torsion amplitude and shortening the sleeve meshing time. A variety of initiatives have been tried during development of transmissions up to now⁽¹⁾⁻⁽³⁾. Using the software AMESim (by LMS), the double-bump phenomenon was visualized and behavior analysis was conducted by dynamic simulation, which made it possible to quantitatively evaluate the influence of each parameter. An outline of the simulation model is given in Fig. 15 and an example of simulation output in Fig. 16. Depending on the preceding sleeve tooth and amount of gear dog offset, the double-bump load ratio, an indicator of double-bump, changes.

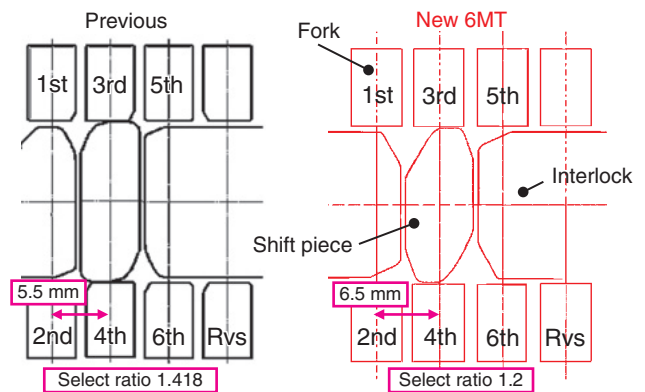


Fig. 13 Change piece layout

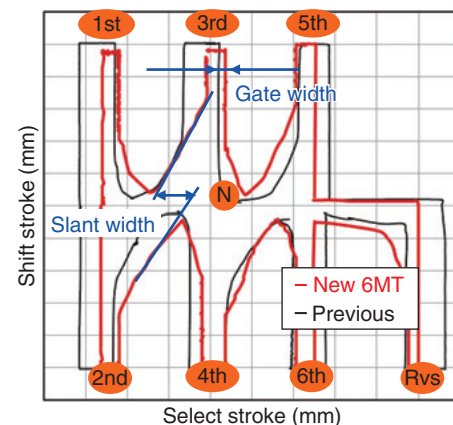


Fig. 14 Change pattern

- (1) Inhibiting drivetrain torsion amplitude: Drivetrain torsion amplitude is widely known as a factor in the double-bump phenomenon, but it has been uncertain how much influence there is from synchronizer synchronization torque (below, synchronization torque) and structural components. A study was therefore done under previous model specifications, results were compared with a sensory-based evaluation, and the influence of parameter changes was confirmed. As a result, it was confirmed that there are differences in

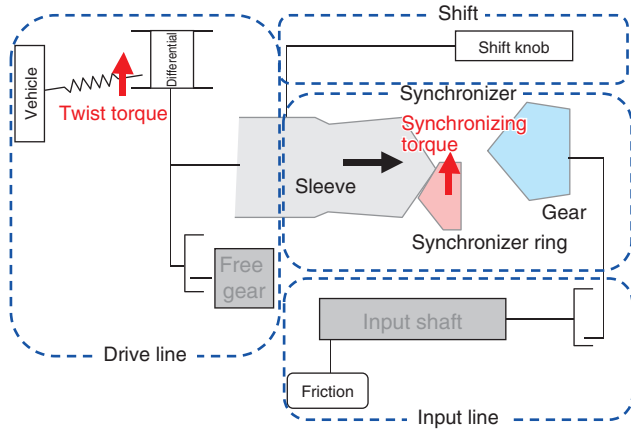


Fig. 15 Outline of dynamic simulation

how the double-bump phenomenon occurs depending on differences in conditions, such as synchronization torque, driveshaft rigidity, gear ratio, transmission inertia and synchronization capacity, and that enhancements are needed for upshifting from first to second gear and from second to third gear (Fig. 17).

Based on these results, the following measures were taken.

- Adjusting synchronizer size, taking users' usage styles into account (see 5.2)
- Revising lever ratio within the transmission by reducing sleeve stroke. The new 6MT uses a preceding sleeve tooth (Fig. 18) among other measures, which shortened sleeve stroke by 8% as compared to the previous 6MT.

These measures inhibited excessive synchronization torque and reduced drivetrain torsion amplitude.

- Shortening sleeve meshing time: When synchronization torque has disappeared as a result of sleeve advancement, twisting on the output shaft side becomes undone, which results in a difference in rotation speed and a failure of synchronization. However, shortening the sleeve meshing time shortens the time of this failure of synchronization, which has the effect of reducing the frequency of double-bump⁽¹⁾. Specifications were studied for the form of a chamfer that makes the timing of sleeve and gear dog meshing end early.

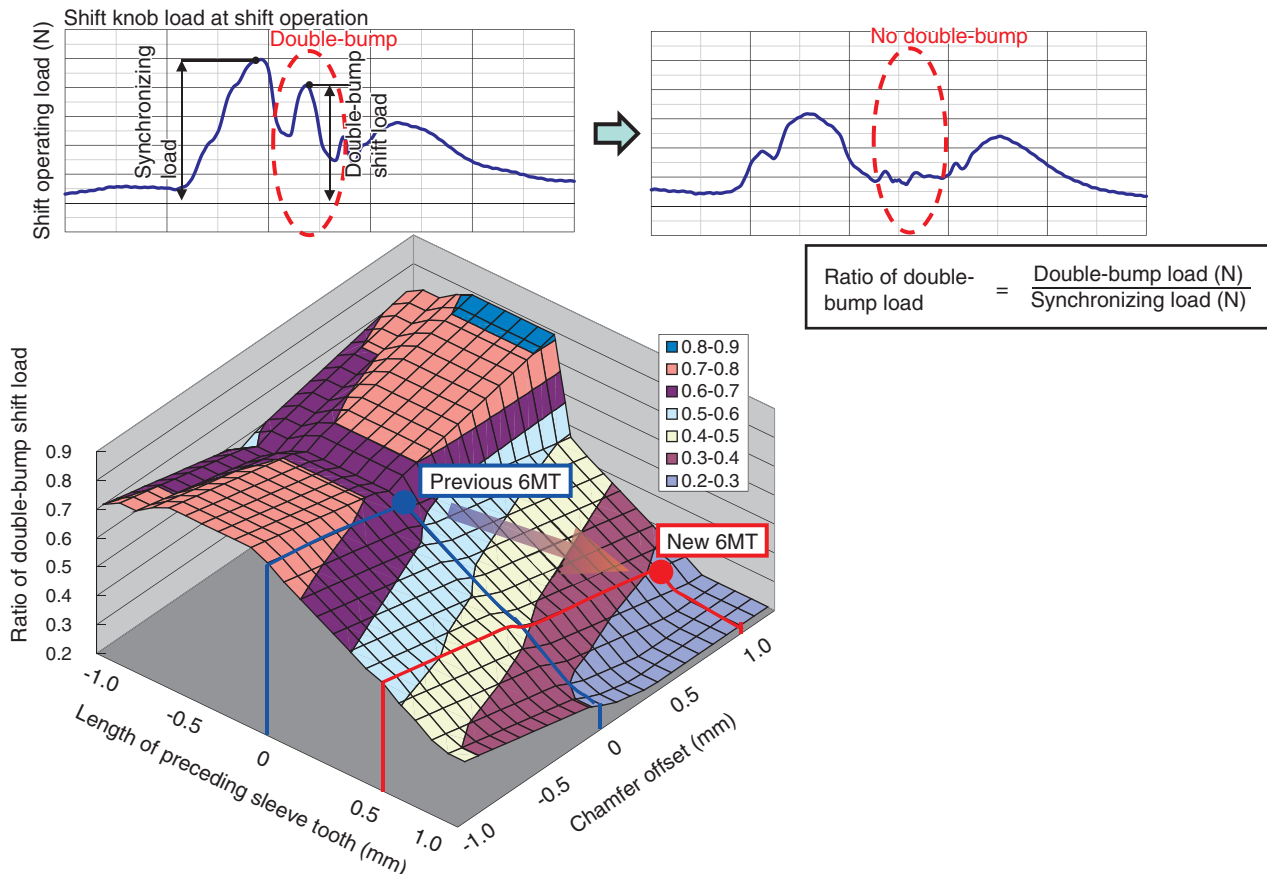


Fig. 16 Example of AMESim simulation output

Compared to the previous model, the chamfer form of the new 6MT is characterized by the second gear having a sleeve with a 0.7 mm preceding tooth and gear dog offset of 0.3 mm and the third gear having a sleeve with a 0.7 mm preceding tooth and gear dog offset of 1 mm. Since the transmission's equivalent inertial mass is particularly higher in second gear (Fig. 19), specifications were decided that took account of the dog push-through load when shifting down.

The application of these technologies reduced double-bump load to a great extent and achieved smooth shift operation. The double-bump frequency reduction effect is shown in Fig. 20.

6.2. Product appeal in reverse

Changing to a constant-mesh reverse system and using a

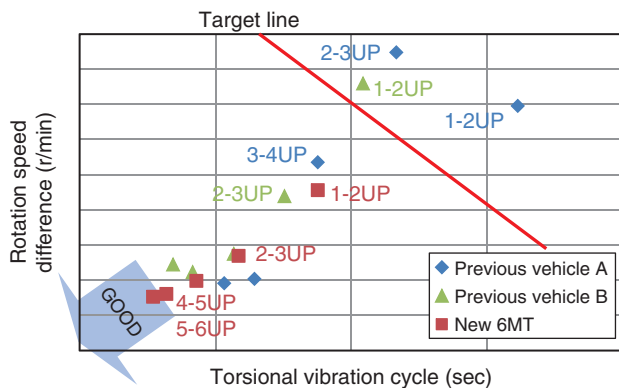


Fig. 17 Relationship of rotation speed difference and torsional vibration cycle of drivetrain

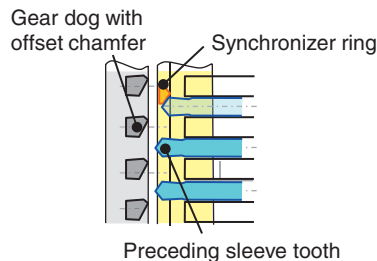


Fig. 18 Preceding sleeve tooth and gear dog with offset chamfer

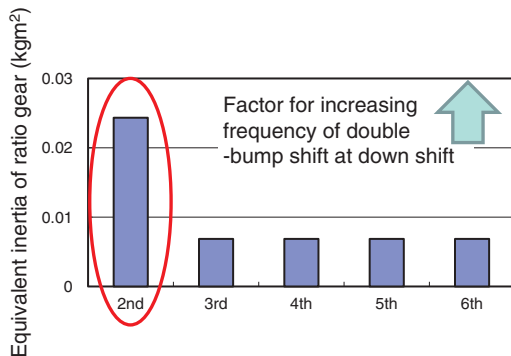


Fig. 19 Comparison of equivalent inertia of each speed ratio

helical gear as the reverse gear reduced gear noise.

In the previous constant-mesh reverse gear mechanism, the reverse gear silencing mechanism was a reverse-specific synchronizer ($\phi 44$ single) placed on the same shaft as the reverse idle gear (Fig. 21). However, since there are size restrictions in the layout, a synchronizer on the same shaft as the reverse idle gear made reverse shifting heavier.

Thus, the new 6MT uses a gear silencing mechanism that makes the third synchronizer ($\phi 66$ single) work during reverse shifting (Fig. 22). The result was lower reverse

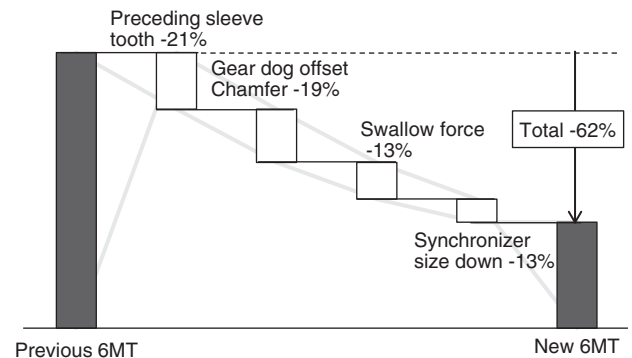


Fig. 20 Contribution to reducing frequency of double-bump shift

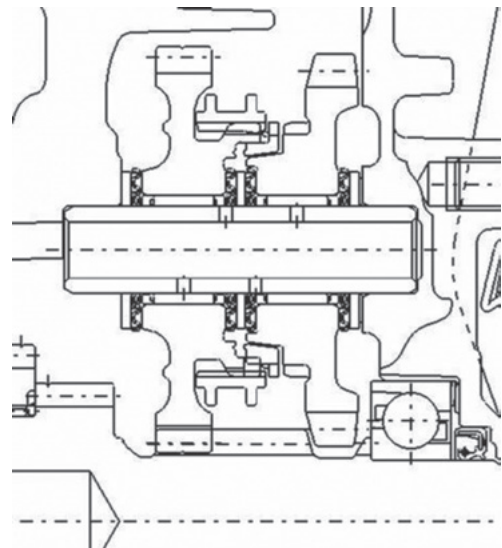


Fig. 21 Previous reverse system

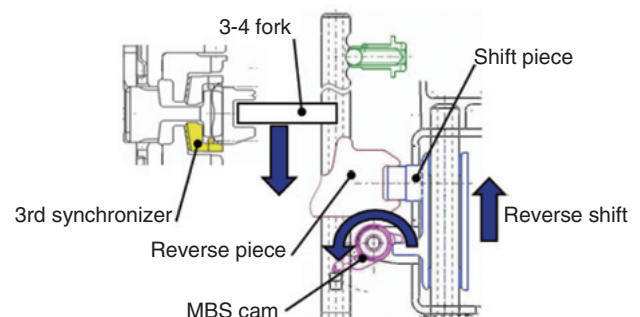


Fig. 22 Main shaft braking system

Table 2 Achievement of reverse system performance

Reverse system performance	Reverse gear noise	Reverse shift load
New 6MT	60 dB	59 N
Previous reverse system	60 dB	97 N
Previous sliding type	75 dB	63 N

gear noise and reduced shift load due to the increase in synchronizer capacity. Table 2 compares the previous and new construction.

7. Conclusion

A new manual transmission for middle-torque engines was developed with the following characteristics.

- (1) Torque capacity of 300 Nm was achieved by using a new gear strength evaluation method that considers misalignment.
- (2) With the help of the new gear strength evaluation method, the inner diameter of the main shaft and countershaft was enlarged and the gear form was optimized, which achieved lighter weight.
- (3) The use of a splashing-type lubrication system, reduction of synchronizer drag and use of ball bearings as differential side bearings helped to achieve top-level transmission efficiency.
- (4) Improving the detent mechanism and change pattern and using a preceding sleeve tooth and gear dog offset chamfer improved swallow feel, intuitive operating feel and smooth shift feel.
- (5) The constant-mesh reverse mechanism reduced reverse gear noise and also reduced reverse operating load.

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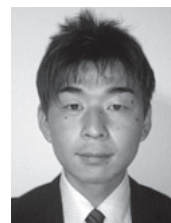
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