

Development of New Compact 4-speed Automatic Transmission for Honda LIFE

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ABSTRACT

A new electronically controlled 4-speed automatic transmission has been developed for use in next-generation compact class vehicles and employed in the new Honda LIFE. In addition to new fourth gear shift and lock-up mechanisms, the new AT features a parallel triple-shaft structure with a flat torque converter and a case with no side cover. The control system components are also concentrated. These have made the unit more compact, the shortest in its class at 334 mm in overall length. The employment of Active Lock-up II to provide lock-up control has significantly increased the lock-up control area with no loss of drivability. In combination with the addition of a fourth gear and the reduction of friction by 30%, this expansion of the control area has contributed significantly to improved fuel economy.

In addition, the employment of clutch hydraulic pressure direct control using a linear solenoid, center positioning of idler gear trains on each shaft, and climbing and descending control, among a variety of other technologies, has resulted in a smooth and very stable shift feeling, superb quietness, and improved drivability.

1. Introduction

Honda re-entered the small passenger vehicle market with the 1986 model TODAY's Hondamatic with overdrive. During the 1988 full model change, a parallel dual shaft type hydraulic control 3-speed automatic transmission (3AT hereafter) was established. Since then, the 3AT has been adopted for this class of vehicle, but in response to the need for greater environmental protection and conservation of natural resources in recent years, and to realize the development concept for the 2004 LIFE full model change, an electronically controlled 4-speed automatic transmission has been developed. This electronically controlled 4-speed automatic transmission (new 4AT hereafter) was completely developed anew from the platform for the next generation of

compact class vehicles.

This paper reports on the major technologies adopted for the new 4AT.

2. Development Goals

In the development of this new 4AT as the AT for the next generation of compact class vehicles, the development targets were "compact", "improved fuel economy", and "commercial appeal beyond the vehicle's class". The following three items were set as development goals in order to achieve these targets.

- (1) Compact AT both in total length and longitudinal length, to achieve both high level of collision safety performance and a more spacious cabin.

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- (2) Achievement of a friction level equivalent to the 3AT and expansion of the lock-up control area to achieve a class leading level of fuel economy performance.
- (3) Achievement of quietness and shift quality equivalent to the small vehicle class to achieve a comfortable driving performance, including on expressways and suburban roads.

3. Basic Specifications and Basic Structure

Figure 1 shows the main cross-section of the new 4AT, and Table 1 gives the main transmission specifications.

As shown in Fig. 1, the new 4AT is a parallel, triple-shaft 4AT with one-way clutch in 1st gear. The structure is such that the 3rd gear train and the idler gear train are common.

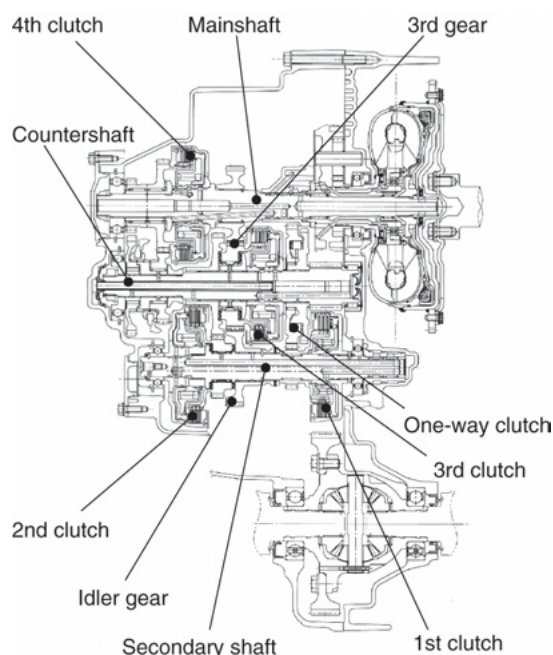


Fig. 1 Cross-section view of newly developed 4AT

Table 1 Transmission specifications

		Newly developed 4AT		Previous 3AT	
Engine specifications	Displacement (Type)	660cm ³ (NA)	660cm ³ (Turbo)	660cm ³ (NA)	660cm ³ (Turbo)
Dimensions (mm)	Overall length	334	334	328	347
Axis center distance (mm)	M/shaft ~ C/shaft	80	80	77	77
	C/shaft ~ S/shaft	80	80	—	—
	C/shaft ~ Differential	110	110	110	110
Torque converter	Diameter of flow path	φ190	φ190	—	—
	Lock-up clutch	Yes	Yes	—	—
Overall gear ratio	1st	15.282	13.448	15.341	13.975
	2nd	8.487	7.702	8.047	7.654
	3rd	5.358	4.938	4.940	4.483
	4th	4.068	3.488	—	—
	Rvs	9.997	8.792	10.873	10.873

Note: M/shaft: mainshaft, C/shaft: countershaft, S/shaft: secondary shaft

In addition, as will be explained in section 4.3.1, on the assumption of the adoption of a lock-up mechanism using in natural aspiration spec engines (NA engines hereafter), the structure and control system based on the assumption were all adopted in variation. This enables the new transmission to be compatible with anything from a 660 cm³ NA engine to a 660 cm³ engine with turbocharger, while maintaining the basic structure as it is.

4. Major Technologies and Results

4.1. Compact Structure

Towards the goal of being more compact, a parallel, triple shaft layout was adopted to balance compactness with enhanced gear noise quietness. As will be explained in section 4.4.3, the structure is such that an idler gear train that is common with the 3rd gear train is placed in the center of each shaft.

To shorten the total length, a flat type of torque converter was established, and the case has no side cover. Moreover, in order to shorten longitudinal length, the layout is such that the differential axis is located under the engine center. In combination with these measures, the control system was concentrated, as explained in section 4.4.1.

4.1.1. Squashed torque converter

In order to actualize the new 4AT “compact” target, it was necessary to place the torque converter torus section and the lock-up mechanism within a limited space, so a vital issue was flattening the torque converter.

It is known that squashing the torus section creates a separation phenomenon of internal circulation oil and causes a drop in torque ratio and capacity factor, leading to affect start-off performance, fuel economy, and cooling performance⁽¹⁾.

To address these issues, a method for optimizing design parameters independently developed based on the one-dimensional angular momentum theory⁽²⁾, and a three-dimensional CFD according to standard $k - \epsilon$ model⁽³⁾ were adopted to optimize the pump and turbine blades.

Figure 2 shows the results of turbulence energy calculations, for a conventional torque converter with a flattening rate of 92% and for the newly developed torque converter with a flattening rate of 81%. As shown in Fig. 2, the distribution of turbulence energy that expresses the size of hydraulic loss of the newly developed torque converter is confirmed as equivalent to that of the conventional unit.

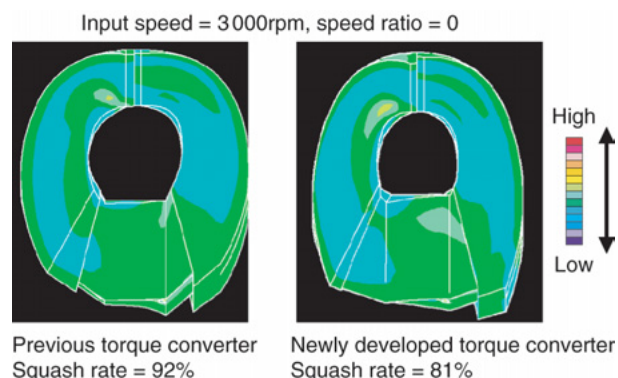


Fig. 2 Results of calculation of kinematic turbulence energy

By employing the methods above, the width of flow path is 6 mm less than the conventional unit as shown in Fig. 3, and at the same time, the performance achieves a high stall torque ratio of 2.5, which is equivalent to the conventional unit. Furthermore, in the range with speed ratio of 0.3 to 0.7, torque ratio characteristics better than the conventional unit were achieved.

4.1.2. Structure of case without a side cover

(1) Shortening total length

The total AT length must be no more than 350 mm so that it can be fitted in the engine room of the new model LIFE.

Using a conventional structure with an ordinary side cover would mean that, if the fastening rigidity and membrane rigidity required were to be ensured, the length would exceed the target. It is also predicted that the stress occurring between the shaft support bearing housings would exceed the strength target.

Therefore, a structure was adopted, as shown in Fig. 4, which gives the side cover functions to the transmission case and eliminates the side cover itself. As a result, it was possible to achieve the total length target, and even in the stress areas noted above it was possible to reduce the stress by 52% against the initial forecast by ensuring the section

area in the areas concerned and rigidity in the surrounding areas. Figure 5 shows the results of CAE analysis of the transmission case.

(2) Reduction in longitudinal length

In order to achieve the new model Honda LIFE's long room package, a layout was adopted such that the differential axis is placed under the engine center to shorten longitudinal length.

With this layout, as shown in Fig. 6, the direction of the final gear reaction force is in the forward direction, which is contrary to the conventional downward direction. However, the input on the transmission case membrane was an issue.

With the new 4AT, ensuring case membrane rigidity was a challenge due to the location of the Automatic Transmission Fluid (ATF) strainer. Therefore, as shown in Fig. 7, a center bolt type was adopted, placing the bolt and dowel pin in the vector of the reaction force of the final gear. These measures enabled the stress to be received in front of the ATF strainer and the later case walls to be made only to the thickness necessary for die-casting.

As a result, it was possible to shorten the longitudinal length of the power train without an increase in weight.

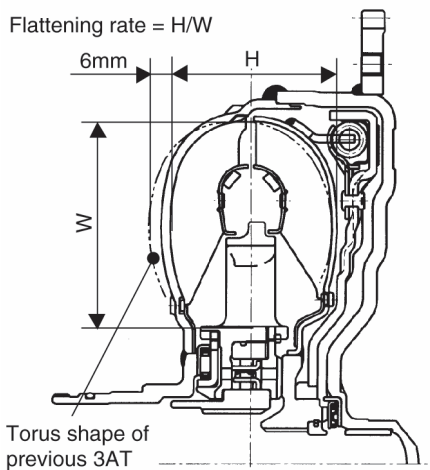


Fig. 3 Cross-section view of newly developed torque converter

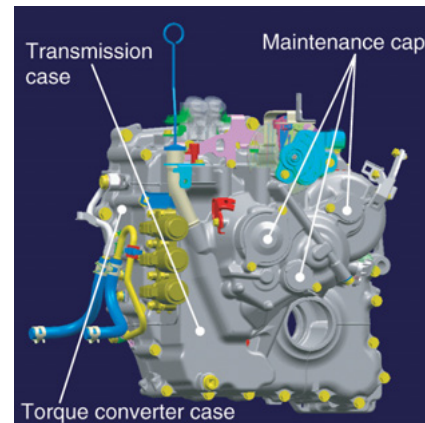


Fig. 4 Newly developed 4AT with side cover-less housing

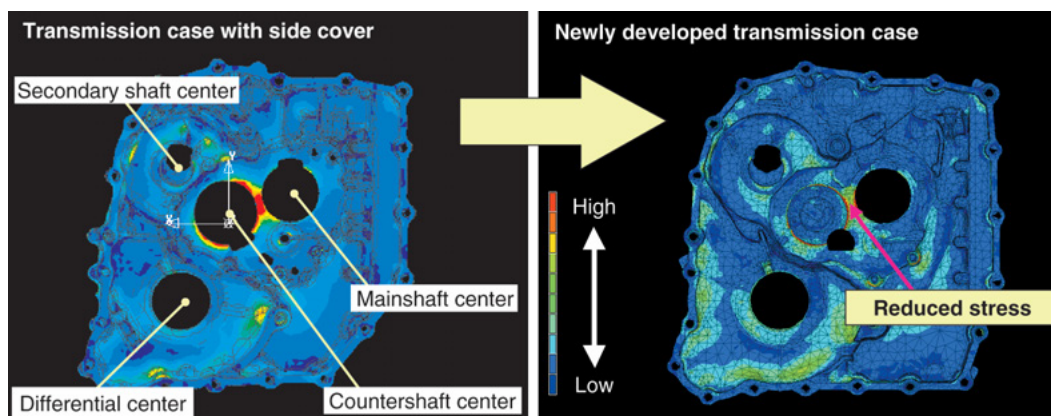


Fig. 5 Results of CAE analysis of newly developed transmission case

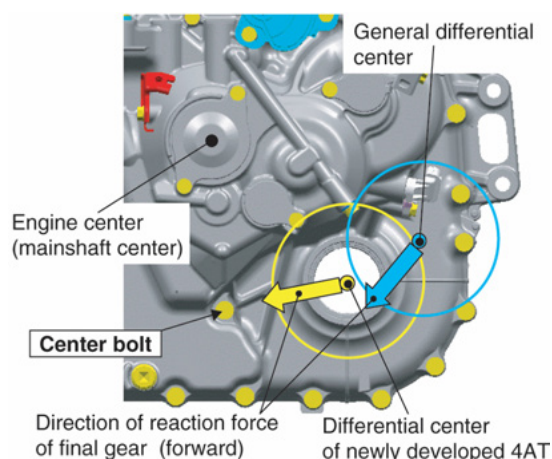


Fig. 6 Direction of reaction force

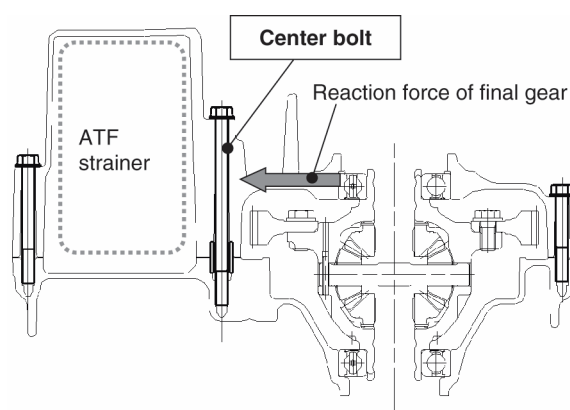


Fig. 7 Center bolt layout

Through the measures outlined above, the total length is 334 mm even while adding new elements and the longitudinal length of the power train, including engine and AT, is 480 mm. Both of these are the shortest in this class.

4.2. Friction Reduction

In the mini-compact car class, the use of high engine speeds is frequent, so friction reduction greatly contributes to improved fuel economy. The new 4AT was therefore developed with a target of achieving the same friction level as 3AT in order to achieve the best-in-class fuel economy.

4.2.1. Reduction in oil pump loss

Because electronic devices for electronic control are added with the new 4AT, the required oil pump capacity is greater than the 3AT and oil pump loss is also greater. Therefore, in order to prevent a drop in hydraulic pressure in high temperatures at low engine speeds, where any insufficient capacity is most noticeable, the diameter of the control valves were reduced, aluminum valves were adopted, and enhancements were made to surface pressure distribution when the valve body bolts were fastened. These measures enabled the increase in capacity over that of the 3AT to be kept to no more than 15%.

Moreover, the addition of a machined groove to the oil pump drive gear side and the optimization of the machining width of the relief groove for the grinding process enabled a mechanical loss reduction of 10%.

4.2.2. Reduction in differential churning loss

Differential churning loss was reduced by limiting the amount of oil between the AT case and the differential case and final driven gear to an appropriate amount.

First, the AT case bottom volume was increased, as shown in Fig. 8, reducing the oil level height without causing a drop in the oil pump aeration limit. Furthermore, the clearances were optimized between torque converter case and differential case, and between final driven gear and torque converter case.

This resulted in a reduction of 13% in differential churning loss.

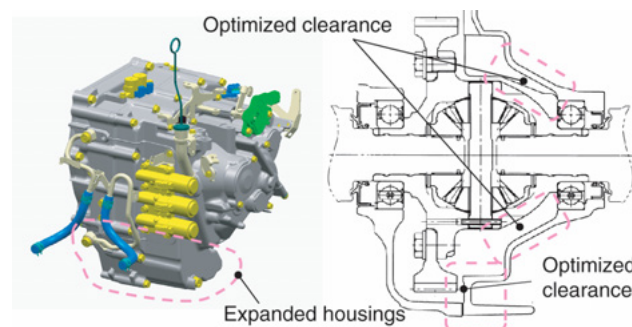


Fig. 8 Optimized area

4.2.3. Reduction in clutch drag

For each clutch pack, in order to reduce the lubrication oil shearing force caused by the friction plates, the target was to enhance emission performance as much as possible, while maintaining the oil retention function. To this end, conventional methods such as tuning the lubricant emission path were utilized and drag was reduced.

Next, with the new 4AT's 2/3/4 gear clutch for the NA engine, a new shape was adopted for the friction material grooves of the friction plates. This was applied in combination with the waved clutch plate. As a result, it was possible to further enhance the lubricant emission performance, and to reduce drag to no more than half of what it had been. The difference in friction with the new groove design is shown in Fig. 9.

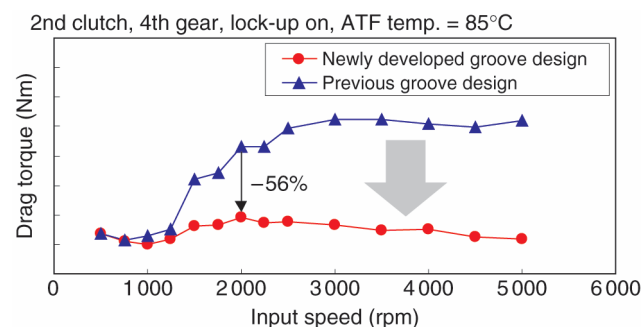


Fig. 9 Drag torque comparison

By reducing the oil pump loss, differential churning loss, and clutch drag, friction was reduced by 30%, and a 3AT level of friction was achieved with this new 4AT. Figure 10 shows the results of friction analysis of each element, before and after the countermeasures were taken.

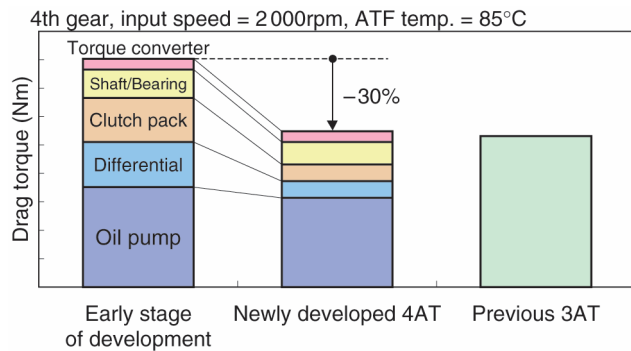


Fig. 10 Results of friction factor measurement

4.3. Driving Performance and Fuel Economy Performance

4.3.1. Addition of fourth gear and lock-up

Figure 11 shows the results of a fuel consumption simulation for the new 4AT carried out at the concept stage. As shown in the figure, greatly improved fuel economy performance cannot be expected simply by making it a 4AT. To achieve the fuel economy target, application of a lock-up mechanism was necessary.

Therefore, assuming adoption of a lock-up clutch for each variation and aiming to achieve both fuel economy improvement and advanced drivability, the Active Lock-up II was adopted⁽⁴⁾.

At the same time as adopting this system, a long torsion damper was adopted in the lock-up clutch, enabling engine torque fluctuation to be damped. Due to this torque fluctuation damping effect and to this system's highly accurate feedback control using linear solenoid, the lower limit speeds in the cruising range and in the lock-up possible range during acceleration were lowered, enabling the lock-up operation to be carried out from 2nd gear, 12 km/h or faster. As a result, in comparison with the lock-up control area adopted conventionally in this class, it was possible to greatly extend that control area, particularly in the low and medium speed ranges.

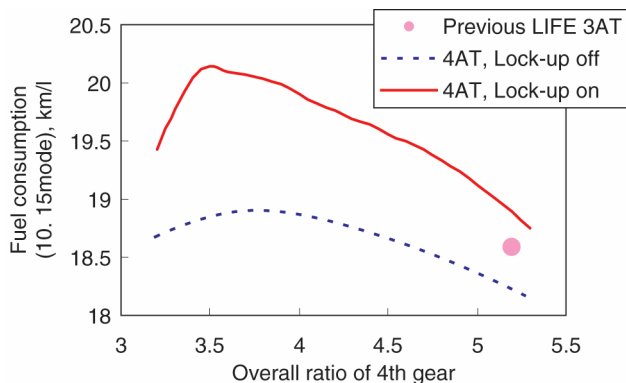


Fig. 11 Results of fuel consumption simulation

4.3.2. Setting the gear ratio

In setting gear ratios, the target was to achieve both improved fuel economy with the new 4AT for the NA engine and drivability in 4th gear. Therefore, the 4th gear ratio was set giving full consideration to cruising performance at 100 km/h, including climbing slopes on an expressway. As for the 1st gear ratio, it was set with emphasis on start-off and gradability, while close ratios were set between 2nd, 3rd, and 4th gears considering fuel economy improvements with lock-up. A comparison of the new 4AT gear ratios established against the 3AT, is shown in Table 1.

Through the fuel economy improvement countermeasures, including lock-up control, gear ratio setting, and friction reduction, a 7% fuel economy improvement in the Japanese 10.15 fuel consumption mode in comparison with the 3AT was achieved.

4.4. Enhanced Commercial Appeal

4.4.1. Shift quality

One aim with the new 4AT was to achieve a smooth and highly responsive shift feeling that would be acceptable even in the small vehicle class. The control system to achieve this target must be compact together with the lock-up control system requiring high accuracy. Therefore, a direct control system for clutch hydraulic pressure⁽⁴⁾, which has been used in Honda's high-class vehicles, was adopted with partial modifications added.

As a result of these modifications, in comparison with Honda's conventional system, it was possible to eliminate two ON/OFF solenoid valves, one ATF temperature sensor, and two hydraulic pressure switches. This created a concentrated control system unit. With these measures, it was possible to apply direct control and Active Lock-up II to the new 4AT, while maintaining its compactness. Table 2 shows the results of a comparison with other control systems.

This control system is one that directly controls clutch pressure using linear solenoids, and the control logic is composed of the following two controls.

- (1) Clutch transient response control that stably carries out clutch preparation in response to clutch and oil path status.
- (2) Torque-based control that calculates clutch standard pressure during shifting by estimating torque input into the AT and coefficient of friction of friction plate.

Table 2 Comparison of control systems

	Newly Developed 4AT	Honda LIFE/DUNK Previous 3AT	Honda STEP WAGON 4AT
Clutch control	Direct control	Indirect control	Direct control
Lock-up control	Active lock-up II	—	Active lock-up II
Number of control valves	15	15	14
Number of one-way clutches	1	1	0
Number of on/off solenoids	2	0	4
Number of linear solenoids	3	0	3
Number of ATF temp. sensors	0	0	1
Number of pressure switches	0	0	2

In the torque-based control, a setting method called G-design⁽⁴⁾ was adopted. It determines body G changes during shifting. Figure 12 is a concept diagram, showing up-shift.

Together with the adoption of this shift control system, a hydraulic centrifugal cancel mechanism was adopted for the 2nd, 3rd, and 4th gear clutch. These greatly enhanced clutch pressure control accuracy and quality stability, achieving a smooth, highly responsive shift feeling, and high gearshift responsiveness.

4.4.2. Control in climbing and descending conditions

When making mini-compact cars, which have small engine torque absolute values, into a 4AT it was expected that shifting becomes frequent due to insufficiencies in surplus driving force when climbing a slope, and insufficiencies in engine braking when descending slopes also becomes noticeable. Therefore, control in climbing and descending conditions was adopted in all variation. This has rarely been adopted in mini-compact cars; it is the first time it has been adopted in a mini-compact car fitted with an NA engine.

In response to the load generated by climbing and descending a slope, the PROgressive Shift schedule Management TEChnology (PROSMATEC) selects the optimum gear from among 2nd, 3rd, and 4th. This technology minimizes unnecessary shifting on ascending roads, and assists with engine braking on descending roads, enabling drivability that goes beyond the mini-compact car class to be achieved.

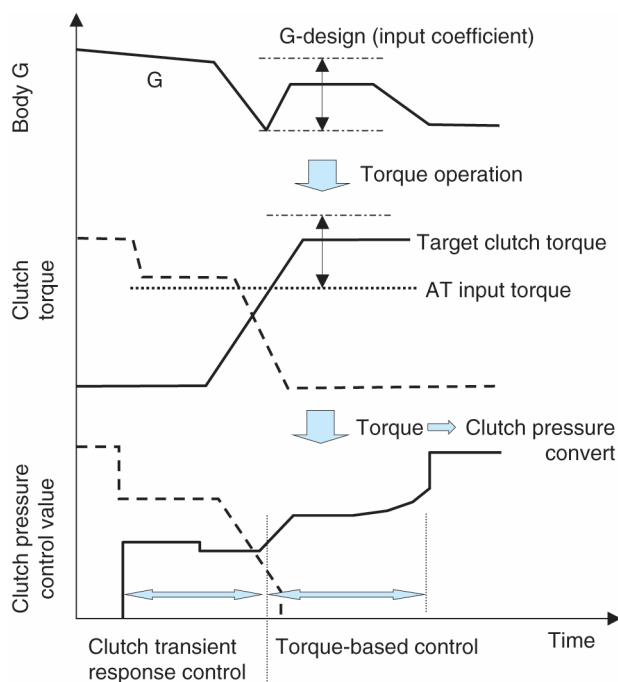


Fig. 12 Overview of new control logic (up-shift)

4.4.3. Noise and vibration (NV) commercial appeal

The new 4AT has a parallel, triple-shaft structure, adopting a layout whereby 1st and 2nd gears are driven through the idler gear. The conventional structure, with an idler gear train placed on each shaft end, is subject to shaft deflection due to driving force fluctuations. In order to prevent worsening of gear noise due to gear misalignment, the structure had to have the increased tooth width and adopt bearings to limit gear misalignment. Therefore, use of a

conventional structure would be the issue for making a compact new 4AT.

For the new 4AT, an idler gear train with multiplex meshing was placed at the center of each shaft of the parallel, triple shaft structure. Due to this, as shown in Fig. 13, the shaft deflection effect was minimized and gear misalignment was reduced. The target compact size was achieved, while gear engagement accuracy during input load fluctuations was enhanced.

At the same time, each gear's basic specifications were set, greatly enhancing total contact ratio in comparison with the 3AT. In addition, rib placement was optimized through CAE analysis, and case rigidity fully maintained. This minimized the generation of radiated noise due to case resonance.

As shown in Fig. 14, this resulted in a noise reduction of at least 4 dB in both acceleration and deceleration for AT unit 3rd gear noise.

Moreover, the benefits of a 4AT and the adoption of lock-up across a wide operation range reduced engine speed when driving, and have contributed to vehicle quietness in both the practical use range and in the high speed cruise range.

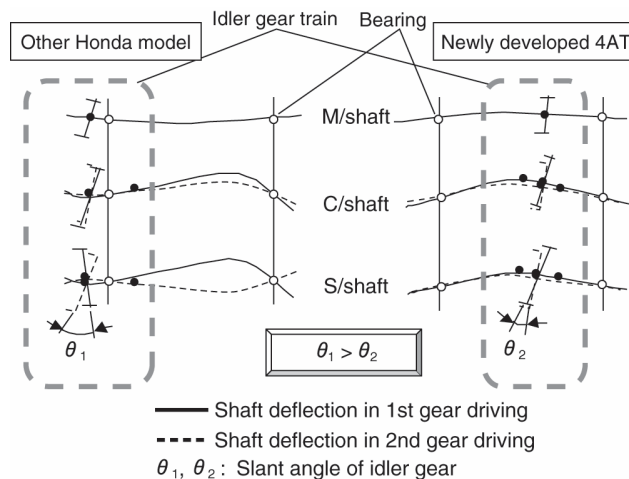


Fig. 13 Comparison of idler gear train

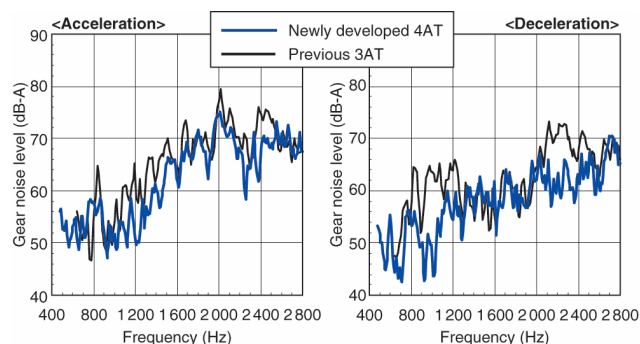


Fig. 14 3rd gear noise

5. Conclusion

In looking towards the next-generation compact class vehicle, the following results were obtained when a completely new 4AT was developed from the platform and installed in the new model Honda LIFE.

- (1) With the adoption of a parallel, triple shaft type structure, case components, flat torque converter, and differential axis placed under the engine center, both the total length and longitudinal length were reduced to best-in-class, at 334 mm and 480 mm respectively.
- (2) As a result of reducing oil pump loss, clutch pack drag, and differential churning loss, a friction value equivalent to 3AT was achieved, even though the 4th gear was added.
- (3) Adopting the Active Lock-up II in the lock up control area enabled lock-up control to be made from 2nd gear, 12 km/h. This, combined with the effects of a 4AT and friction reduction, achieved a 7% fuel economy improvement in the Japanese 10.15 fuel consumption mode.
- (4) With the adoption of a direct control system for clutch hydraulic pressure and a hydraulic centrifugal cancel mechanism, a highly responsive and high-level shift quality was actualized. In addition, drivability was enhanced with the application of the PROSMATEC.
- (5) As a result of placing the idler gear train in the center of each shaft and enhancing total contact ratio, combined with the adoption of a 4AT and highly practical lock-up mechanism, high level NV commercial appeal at the top of the mini-compact car class was achieved.

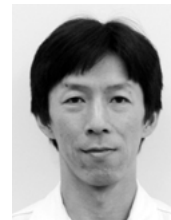
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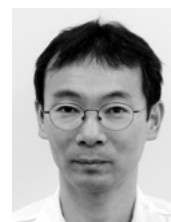
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