

Development of New CVT for Global Compact Car

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ABSTRACT

A new CVT that is lighter in weight and more highly efficient than the previous CVT for use in compact vehicles has been developed and used in the 2014 model year FIT. The allowable torque capacity was expanded to that of the 1.8-L engine class, making this CVT usable in a greater number of vehicle models. The ratio coverage was also expanded and the transfer efficiency was increased to enhance fuel economy and drivability.

Integration of hydraulic control system functional parts and reduction in the number of case component parts were carried out as structural modifications. Pulley side pressures were also reduced by the use of new CVT fluid so that the pulley could be made more compact and lighter in weight. These measures achieved a weight reduction of approximately 10%.

Enhancements were made in cooperative control of the power train and in CVT shift control, providing a more linear acceleration feeling than in previous models.

1. Introduction

There has been growing concern about environmental problems on a global scale, and exhaust gases from motor vehicles are said to have a major impact on CO₂ emissions. Measures to heighten the environmental performance of motor vehicles are being pursued in many directions, and enhancement of the environmental performance of transmissions is an important part of this effort, together with the evolution of internal combustion engine technology.

CVT that enable efficient operation of an internal combustion engine are being widely adopted in Japan for use as equipment to enhance environmental performance in vehicles ranging from mini-compact cars to midsize cars. Meanwhile, step automatic transmissions and Dual Clutch Transmissions (DCT) are being adopted overseas as drive systems optimized to their various regional environments of use, but there is also a movement to adopt the CVT as part of recent initiatives to reduce CO₂ emissions. For expanded application, the CVT will need increased drivability as well as lighter weight and greater compactness to increase installability in vehicles, in addition to increased environmental performance.

Honda has used the CVT since 1995⁽¹⁾, expanding its application from hybrid vehicles⁽²⁾ to compact⁽³⁾ and midsize vehicles⁽⁴⁾. It has also been applied to mini-compact cars in

Japan⁽⁵⁾ and the range of CVT-equipped vehicles in other countries has also been expanding, starting with use in midsize vehicles⁽⁶⁾ for the North American market in 2013. Currently, this CVT is being applied in global models of compact vehicles to bring about increased environmental performance worldwide. This paper will describe the system development goals, its basic construction, and its main technology.

2. Development Goals

The construction of this CVT was changed from that of the CVT previously used in compact vehicles. In order to supply a framework provided with performance for use in global models, technology to increase environmental performance was applied, it was made more compact and lighter in weight, and its driving performance was enhanced. The development goals are as follows:

- (1) Expand the ratio coverage and increase the transmission efficiency in order to achieve a balance between driving performance and fuel economy adapted to the environment of use
- (2) Reduce the weight and increase the torque capacity to enable installation in multiple vehicle models for global deployment
- (3) Enhance the drivability of CVT vehicles by evolution of cooperative power train control and CVT shift control

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3. Basic Specifications and Performance

Figure 1 shows the external appearance of the new CVT, Fig. 2 shows the main section view, and Table 1 shows the main specifications.

In order to reduce the weight, the framework construction has been modified from that of the CVT previously used in compact vehicles and instead adopts the same framework as the CVT used in midsize vehicles. The pulley bearing layout has been modified and the hydraulic control system and hydraulic supply unit have been integrated.

The basic specifications and dimensions are the same as the previous CVT, with the ratio coverage expanded and the final gear changed to a lower ratio. The basic framework parts were made installable in vehicles with a wide range

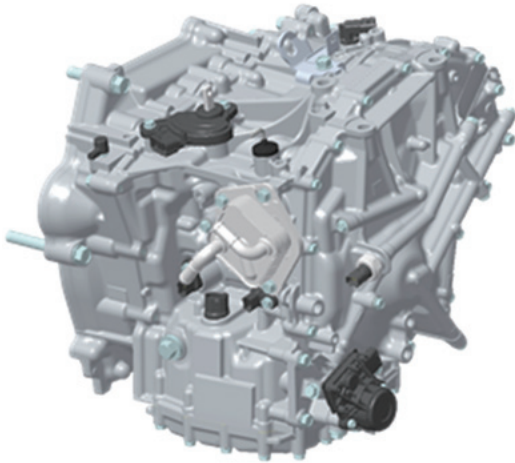


Fig. 1 Appearance of new CVT

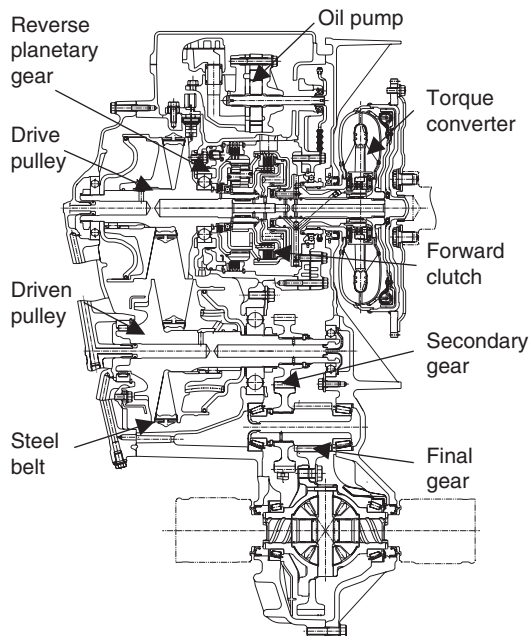


Fig. 2 Main section

Table 1 Main specifications

		2014 model year FIT	2008 model year FIT
Engine	Type	1.3 L/1.5 L	1.3 L/1.5L
	Max. power [kW/rpm]	97/6600 (1.5 L)	88/6600 (1.5 L)
	Max. torque [Nm/rpm]	155/4600 (1.5 L)	146/4800 (1.5 L)
Ratio	Low OD	2.526 0.408	2.419 0.421
	Secondary	1.266	1.266
	Final	3.941	3.875
	Reverse	1.119	1.024
	Overall	12.60 2.036	11.86 2.065
Dimension	Overall length [mm]	368.5	368.5
	Pulley axis distance [mm]	156	156
	Weight [kg]	69.4 (1.3 L)	77.6 (1.3 L)

of engine displacements by designing the system to support engines up to the 1.8-L class. A weight reduction of approximately 10% compared to the previous CVT was achieved.

4. Main Technologies

4.1. Expansion of Ratio Coverage

In order to achieve a higher-level balance between performance in acceleration from a standing start and performance in fuel economy in accordance with the distinctive characteristics of vehicles with this CVT, the ratio coverage was set at 6.2, which is approximately 8% broader than Honda's previous CVT. Figure 3 shows a comparison of the ratio coverage settings. The ratio was set by keeping the ratio on the overdrive (OD) side the same as previously and expanding the ratio on the low side. In other words, standing start performance was enhanced and acceleration performance that in combination with shift control technology yields responsiveness was achieved. For the purpose of reduction in size and weight, the center distance between the drive pulley and driven pulley was made the same 156 mm as previously, the shaft diameter was reduced, and the pulley outer diameter was enlarged. The new CVT fluid developed for the 2013 model⁽⁶⁾ was adopted. The effect of that fluid's high metallic coefficient

of friction enabled reduction of the load needed to hold the belt, allowing a reduction in shaft rigidity. Reducing the diameter of the shaft allowed the winding diameter of the belt to be reduced so that the ratio could be enlarged.

4.2. Increase in Efficiency

Figure 4 shows a comparison of transmission efficiency in cruising vehicles. An increase of approximately 1.0% to 1.5% relative to the previous CVT was achieved, enhancing performance in the high-vehicle-speed range. The following measures were taken to achieve higher efficiency.

4.2.1. Reduction in oil pump capacity

The higher coefficient of friction in the new CVT fluid has enabled a reduction in the thrust. The area of the pulley

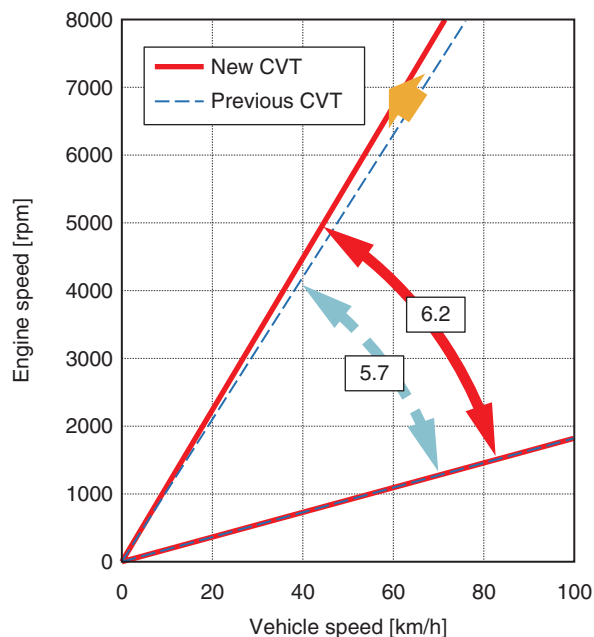


Fig. 3 Comparison of ratio coverage

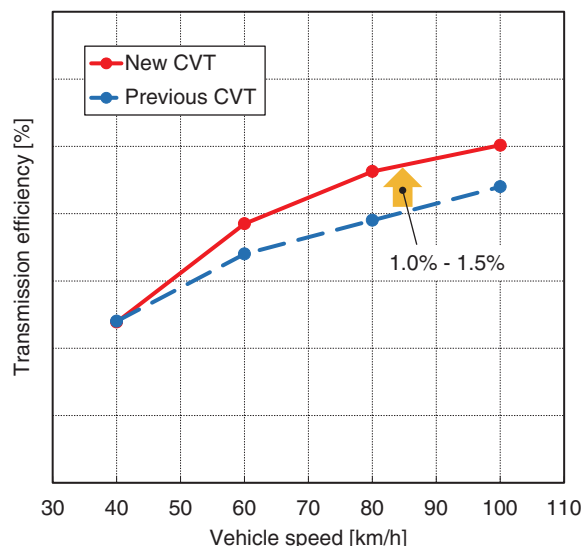


Fig. 4 Comparison of transmission efficiency

piston was therefore reduced and the piston shape was enhanced, reducing the dead volume in the piston chamber. This enabled a reduction in the amount of oil needed to fill the pulley piston chamber during sudden speed changes, for example, and the oil pump capacity was therefore reduced by approximately 10%.

4.2.2. Reduction in oil stirring resistance

The amount of lubrication for each part and the oil flow routes were laid out with the aim of reducing the friction that occurs when the oil is stirred by the internal rotor. The effect that stirring resistance has on the final gear is particularly strong because that gear is located in the bottom portion of the transmission. A baffle plate was therefore installed to limit the inflow of oil to the final gear unit. Figure 5 shows a diagram of the oil flow in the final gear unit. The inflow of oil to the final gear unit is regulated by the area of the opening at the bottom. The oil that is scooped up is channeled onto the rear surface of the baffle plate and is used for lubrication. The slope of the rear surface was further given a sloping shape so that lubricating oil coming from the upper portion will be smoothly channeled back into the oil pan chamber.

4.2.3. Reduction in friction

The friction was also reduced and low-friction bearings were adopted in such areas as the sealing ring that serves as a rotating sliding part, the oil seal, and so on. The reverse brake disk unit drag torque was reduced.

4.3. Reduction in Weight

In order to increase the vehicle driving performance and fuel economy performance while seeking increased torque capacity in the basic framework, the CVT was made approximately 10% lighter in weight than the previous CVT.

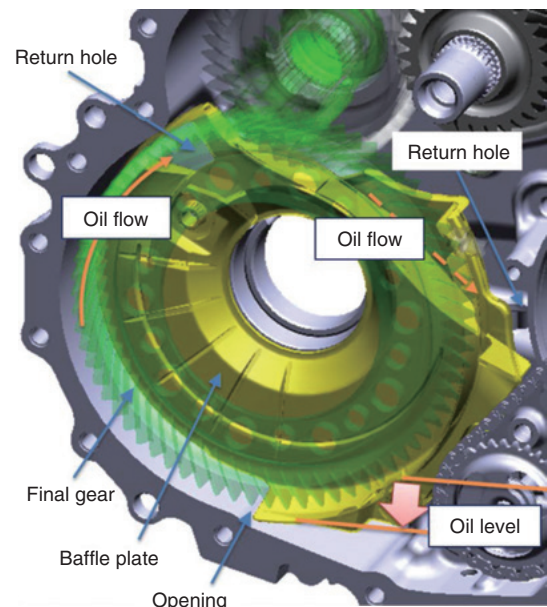


Fig. 5 Oil flow image around final gear

4.3.1. Reduction in pulley size and weight

The effect of pulley side pressure reduction resulting from the new CVT fluid's effect in increasing the coefficient of friction between belt and pulley⁽⁶⁾ enabled a reduction in the applied load on the shaft and the V-surface portion. This enabled a reduction in weight while maintaining strength and rigidity equal to previous levels. Figure 6 shows a comparison of stress generated in the driven pulley at low ratio, and Fig. 7 shows the displacement that occurs in the V-surface portion at that time. When the V-surface portion was made thinner and the shaft portion smaller in diameter, the high stress generated at the base of the V-surface and the displacement of the V-surface portion were made equal to the previous CVT.

4.3.2. Function-integrating construction

The hydraulic control system parts were previously scattered around the case. In the new CVT, however, the hydraulic supply unit was integrated functionally as a valve body assembly and the supply passages were integrated into the oil passage body, thus simplifying the parts. This achieved an approximately 1.2-kg weight reduction.

Figure 8 shows the configuration of the hydraulic control system parts.

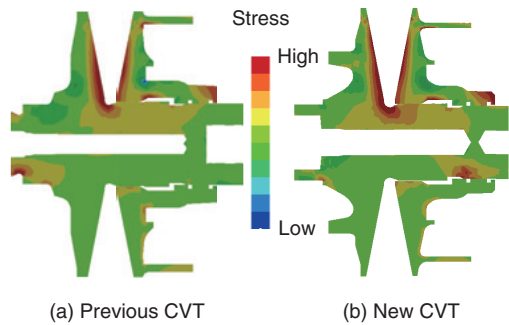


Fig. 6 Comparison of generating stress map

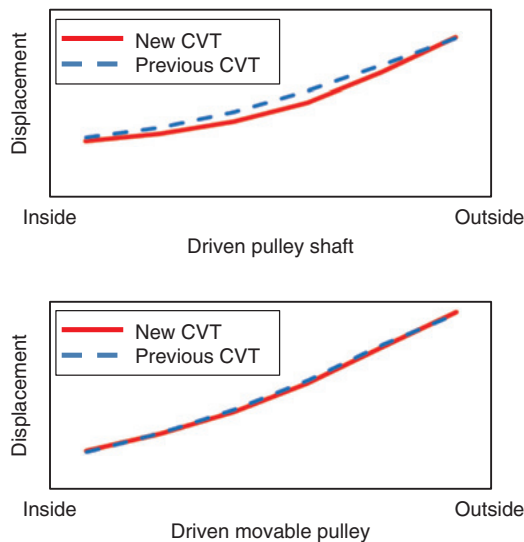


Fig. 7 Comparison of generated displacement

4.3.3. Reduction in case size and weight

The transmission case and the left side cover were used as support structures for both ends of the drive and driven pulley shafts. The elimination of the intermediate plate found in the previous structure realized an approximately 3.1-kg reduction in the total weight of the case parts. Figure 9 shows the configuration of the case parts.

A formed-in-place gasket was also adopted in place of the previous seal made by paper packing. This enabled the gasket to follow the relative displacement between the matching surfaces of the case. As a result, the tightening stiffness could be optimized and the height of the tightening boss as well as the bolt length could be reduced 10 mm, achieving a reduction in the case weight.

Figure 10 shows a diagram of areas where formed-in-place gaskets are used. Figure 11 shows details of bolt tightening.

4.3.4. Reduction in size of reverse mechanism

New nitrided material was used to achieve greater strength in the reverse planetary ring gear. The increased

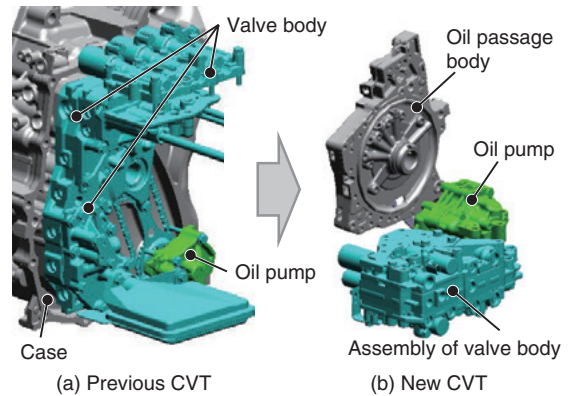


Fig. 8 Configuration of hydraulic control unit

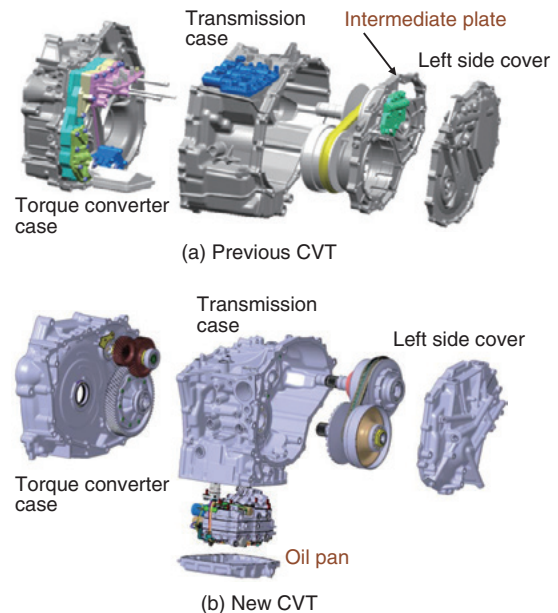


Fig. 9 Case parts composition

coefficient of friction of the new CVT fluid enabled the surface contact pressure on the reverse brake disk facing to be maintained while making the reverse brake disk more compact. This reduced the size of the reverse mechanism by approximately 12%. Figure 12 shows comparative section views of the reverse system.

4.3.5. Reduction in weight of bearings

As a result of the reduction in thrust achieved by use of the new CVT fluid, the load on the pulley supports was reduced and the pulley support bearings were reduced in size and weight. Taper bearings were used for the secondary and final shafts to maintain the needed capacity

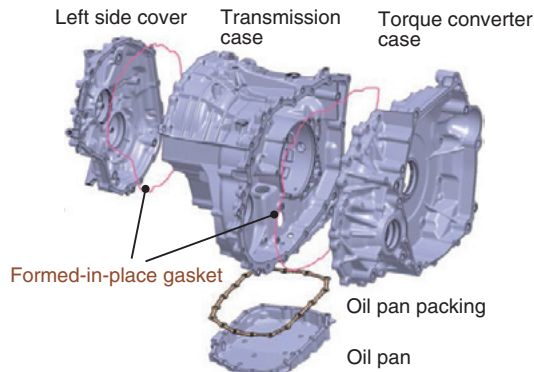


Fig. 10 Formed-in-place gasket

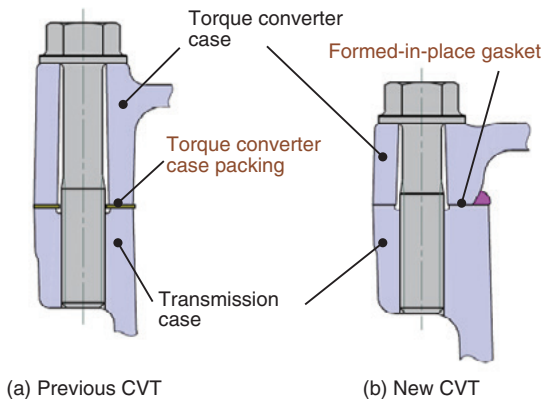


Fig. 11 Detail of bolt tightening

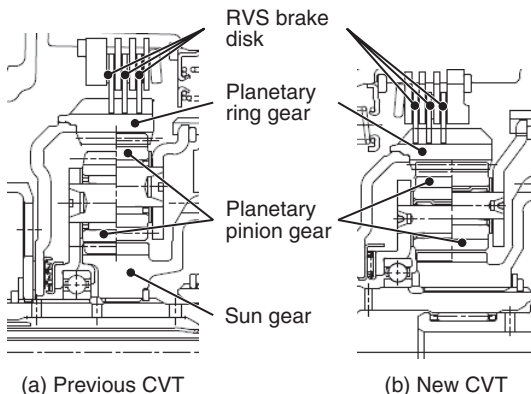


Fig. 12 Comparison of RVS system

while reducing the size and weight. As a result, a weight reduction of approximately 23% was achieved in the bearings compared to the previous CVT. Figure 13 shows comparative section views of the secondary shaft and final shaft. Low friction specifications were adopted for the taper bearings, giving consideration to the effect on efficiency, as well.

4.4. Technology to Enhance Driving Performance

Cooperative control of the power train, with drive force as the target value, was adopted as a technology for enhancing drivability of the CVT vehicle. In CVT vehicles, the CVT responds to driver demand for acceleration by stepless downshifting, and this can tend to delay the acceleration response. Previous drive-by-wire (DBW) cooperative control would set the throttle position according to the accelerator pedal position, so that when engine speed increased due to the ratio change, the engine load decreased and torque was reduced. In this CVT, implementation of power train cooperative control of the kind shown in Fig. 14 that has drive force as a target value determines engine torque output according to the ratio change in the CVT.

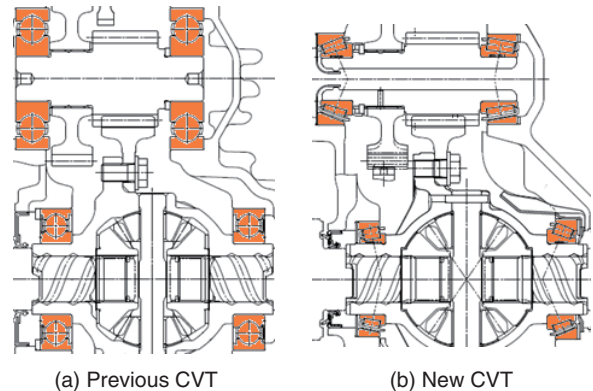


Fig. 13 BRG shape at secondary and final shaft

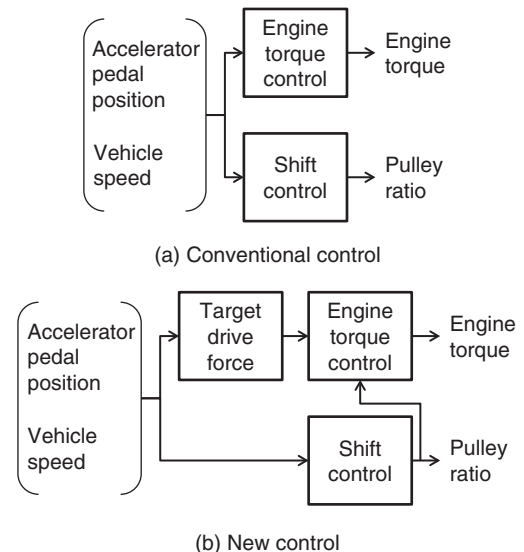


Fig. 14 Schematic diagram of cooperative control

Therefore the reduction in engine torque due to rise in engine speed could be limited, achieving a stable increase in acceleration response. Figure 15 shows time-series changes in engine torque during acceleration under conventional control and the new control.

Enhancement of shift control during kick-down resulted in enhanced acceleration feeling in response to sudden driver demand for acceleration. Figure 16 shows

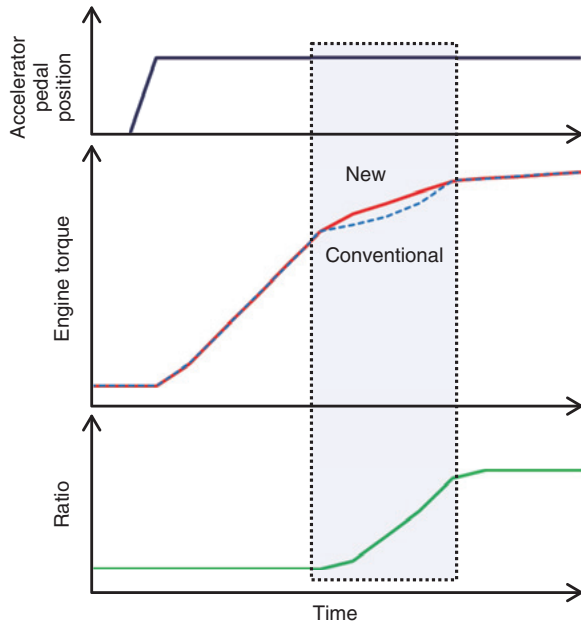


Fig. 15 Schematic diagram of torque response

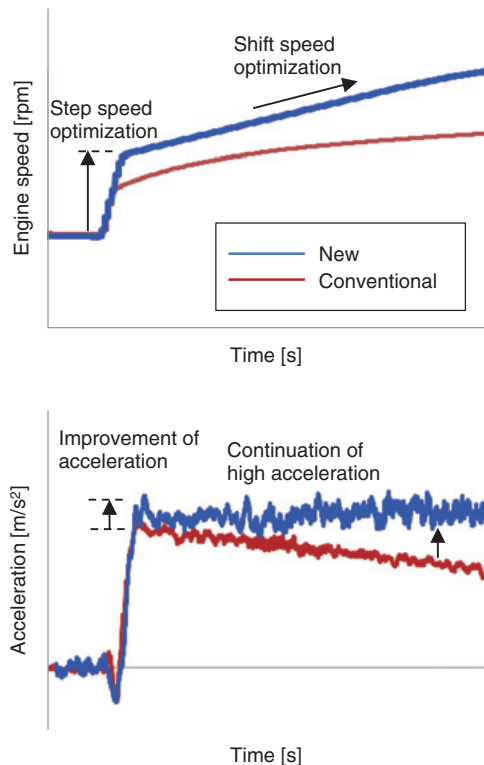


Fig. 16 Comparison of kick-down characteristics

time-series waveforms for acceleration and engine speed during kick-down. Acceleration during initial kick-down was increased by increasing the amount of the step shift. Continued acceleration after kick-down was also achieved by maintaining the higher engine speed after the step shift.

4.5. Control Technology for Increased Fuel Economy

The accuracy of input torque information provided to the CVT control system was increased as a technique for increasing fuel economy.

Previously, engine torque was estimated from engine speed, intake manifold vacuum, ignition timing, and other such information, and CVT pulley pressure was decided accordingly. This CVT uses highly accurate engine torque information according to the engine control state calculated in cooperative control of the power train, as described above, and CVT pulley pressure is thus optimized. Setting the ratio by the target drive force also assures controllability of the drive force while limiting the rate of fuel consumption.

Increased transmission efficiency and the new cooperative control have yielded an approximately 7% increase in fuel economy in JC08 mode.

5. Conclusion

A new CVT was developed for use in a global compact car and the following technologies were established:

- (1) A balance between driving and fuel economy performance was achieved by expanding the ratio coverage by approximately 8% and increasing the transmission efficiency by approximately 1.0% to 1.5%.
- (2) A reduction in weight of approximately 10% relative to the previous CVT was achieved by modification of the framework structure and use of a new CVT fluid.
- (3) Cooperative control of the power train and enhancement of shift characteristics yielded increased drivability and enhanced acceleration feeling.

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