

Development of New CVT for Midsize Vehicle

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ABSTRACT

A CVT for midsize vehicles was developed that simultaneously achieves high levels of fuel efficiency performance and driving enjoyment, reliability and marketability enabling deployment to global markets, and support for high-power direct injection engines. This was done by modifying the CVT for 2.4 L-class vehicles sold in Japan, expanding the ratio range, using CVTF with a high friction coefficient that simultaneously realizes both high efficiency and a high transmission capacity, and adopting protective control such as constant control of the clutch pressure. This enabled achievement of an overall length of 386.5 mm, total weight of 96.1 kg, and maximum transmission torque of 270 Nm, and also enhanced fuel efficiency by approximately 10% (CAFE Comb.) compared to the 2008 model year Accord 5AT and approximately 5% (JC08) compared to the 2010 model year STEP WGN CVT. Thus, CVT performance was obtained that can simultaneously realize high levels of both fuel efficiency and driving enjoyment. This CVT is applied from the 2012 model year STEP WGN and the 2013 model year Accord.

1. Introduction

Recently, high environmental performance is demanded of automobiles, and transmissions (T/M) are playing an extremely important role. Adoption of Dual clutch transmission, CVT, and multi-gear AT with more gears than conventional 4AT and 5AT is also increasing around the world. Honda adopted starter clutch-type CVT from the 1996 model year CIVIC⁽¹⁾, and has expanded application mainly to compact vehicles and hybrid vehicles^{(2), (3)}. For midsize vehicles, a CVT with a torque converter was used in the 2004 model year Odyssey⁽⁴⁾, and has been applied to minivans for the Japanese market. To meet global demands for even higher fuel efficiency in the future, there have been requests to apply CVT for midsize vehicles of this class not just to minivans for the Japanese market, but also sedans and SUVs around the world. Against this background, the transmission efficiency of the newly developed CVT was increased while also expanding the torque capacity and ratio range, with the aim of simultaneously realizing the high levels of driving performance and fuel efficiency performance required of midsize vehicles. In addition, an exhilarating and sporty shift feeling was realized so that AT users around the world can switch to the new CVT without a feeling of unnaturalness. This paper describes the development goals, basic structure, and key technologies of this new CVT.

2. Development Goals

The following three items were set as development goals to develop a CVT for midsize vehicles with world-class performance.

- (1) High fuel efficiency performance to achieve the year 2020 fuel efficiency standard established by the U.S.
- (2) Reliability to support next-generation high-power direct injection (DI) engines and various usage formats around the world
- (3) Driving performance marketability that enables worldwide deployment

3. Main Section and Key Specifications

Figures 1 and 2 show the main section and external view of the new CVT for middle-size vehicles (hereafter “this CVT”), and Table 1 lists the key specifications.

The basic layout of this CVT has the following features.

- (1) Expansion of the ratio range to 6.54 to simultaneously achieve high levels of fuel efficiency and driving performance
- (2) Advanced control of a vane-type oil pump with half-feed switching mechanism, and expansion of the half-feed operation area
- (3) Adoption of an electric oil pump to support an idling-stop system

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Table 1 CVT specifications

		2013 model year Accord	2012 model year STEP WGN	2008 model year Accord (5AT)	2004 model year Odyssey
Engine specification	Type	2.4L DOHC DI	2.0L SOHC i-VTEC Idle Stop	2.4L SOHC i-VTEC	2.4L SOHC i-VTEC
	Max power (kW/rpm)	137/6400	110/6200	150/7000 135/6500	118/5500
	Max torque (Nm/rpm)	243/4000	193/4200	230/4500 225/4500	218/4500
Ratio	Low OD	2.645 0.405	2.645 0.405	1 st : 2.651 5 th : 0.566	2.470 0.450
	Ratio range	6.54	6.54	4.68	5.48
	Secondary	1.558	1.558	-	1.514
	Final	3.238	3.238	4.437	3.350
	Reverse	0.703	0.703	2.000	1.735
	Transfer (4WD)	-	0.279/1.411	-	-
Dimensions	Overall length (mm)	386.5	386.5	379	385
	Pulley axis distance (mm)	180	180	-	170
	Weight (kg)	96.1 (Wet)	97.3 (Wet)	92.6 (Wet)	95.3 (Wet)

- (4) Use of CVT fluid (CVTF) that simultaneously realizes both high efficiency and a high metal friction coefficient
- (5) Optimization of the surface properties of the pulley V-surface
- (6) Adoption of a hydraulic circuit that enables constant control of the clutch pressure using a dedicated linear solenoid, and protective control that cooperates effectively with the throttle and other systems

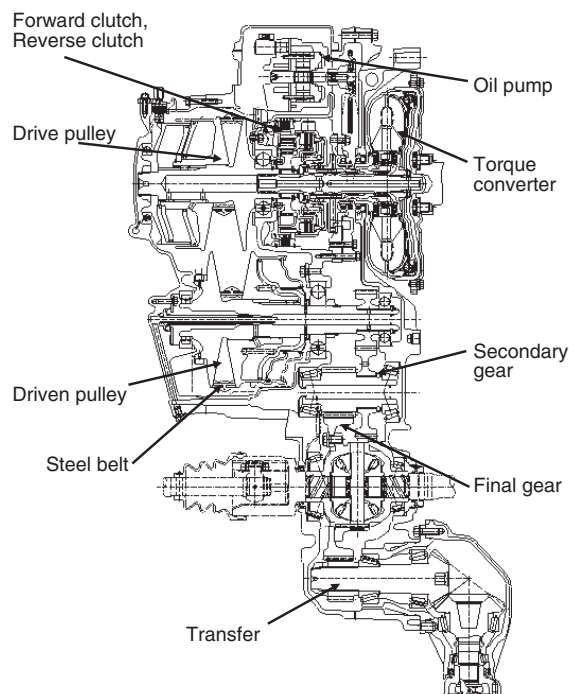


Fig. 1 Main section of CVT

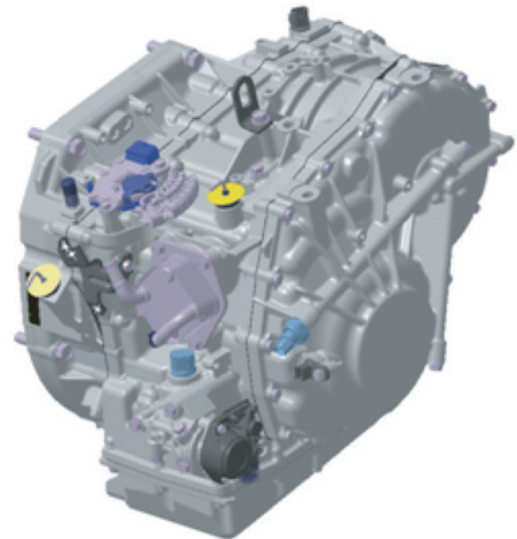


Fig. 2 External view of CVT for STEP WGN

4. Key Technologies

4.1. Expanded Ratio Range

The distance between the drive (Dr) pulley and driven (Dn) pulley axes was increased from 170 mm for the conventional CVT to 180 mm and the ratio range was expanded to simultaneously achieve high levels of the contrary characteristics of fuel efficiency performance and sufficient driving force (Fig. 3).

4.1.1. Fuel efficiency performance

In order to optimize fuel efficiency over the entire

operating range, a high ratio was secured to enable active use of the range with good engine fuel efficiency.

4.1.2. Sufficient driving force

A low ratio is secured to obtain sufficient driving force in consideration of the various models in which the new CVT may be used and the operating conditions in each destination.

The distance between axes, shaft diameters, pulley diameters, belt-line alignment between the drive and driven pulleys, and other settings were optimized based on the above two main points, and assuming use of a conventional 30 mm-wide metal belt with proven results. This greatly expanded the ratio range to 6.54 compared to 4.68 for the 2008 model year Accord 5AT and 5.48 for the conventional CVT.

In addition, a basic framework was constructed that realizes good fuel efficiency performance, powerful acceleration performance, and a smooth drive feeling.

4.2. Expanded Oil Pump Half-Feed Operation Area

The feed flow rate of a displacement pump such as the vane-type pump used in this CVT is proportional to the engine speed, so when set to secure the feed flow rate required to drive the T/M in the low engine speed range, the feed flow rate becomes excessive in the high engine speed range. As a result, unnecessary motive power is consumed to drive the pump, which is an issue reducing fuel efficiency.

Therefore, the developed control works to enhance fuel efficiency while driving by constantly calculating the excess flow, which is the difference between the estimated half-feed operation flow rate and the flow rate required to drive the T/M (sum total of the shift flow rate, leak flow rate from the hydraulic circuit, and lubrication flow rate) in the current operating state (Fig. 4). The variable capacity pump is then operated in the full-feed state when the excess flow value is less than the prescribed value, and switched to the half-feed operation state when the excess flow value is the prescribed value or more. This control enabled expansion of

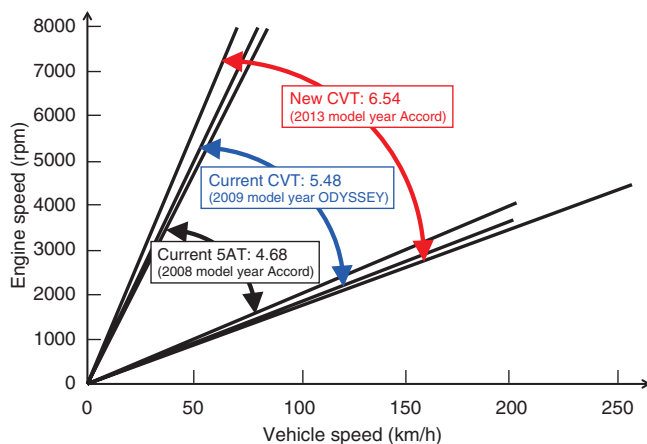


Fig. 3 Ratio coverage comparison

the half-feed operation area compared to the conventional CVT (Fig. 5).

On the other hand, the excess flow rate used as the judgment parameter for switching to the half-feed operation state is calculated from various parameters in consideration of the effects of variance with respect to the design specifications and test results. However, this does not necessarily match the operating state of each vehicle, so reliability of control is provided by simultaneously applying control to return from the half-feed operation state to the full-feed operation state when the calculation results deviate from the actual vehicle conditions.

4.3. Idling-Stop System

Fuel efficiency performance was enhanced by basically using the high-efficiency, compact electric oil pump also used in CVT for K-cars, and by stopping the engine when the vehicle is stationary with the transmission in the D range. In addition, the ring gear driven by the starter motor uses a helical ring gear to enhance NV performance (reduce ring gear meshing sound) during engine restart. When the electric oil pump is positioned above the static oil level while the engine is stopped in consideration of environments where the engine may be exposed to water, air accumulates in the suction circuit, which may give rise to the issue of delayed response and abnormal noise due

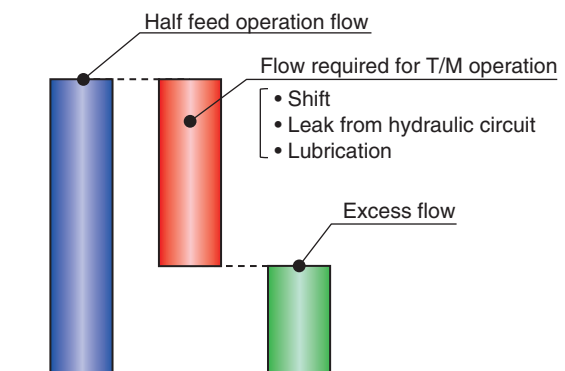


Fig. 4 Detail of half feed operation

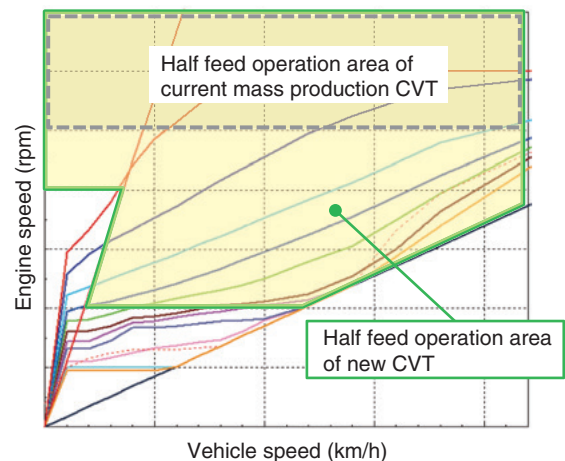


Fig. 5 Expanded half feed operation area

to trapped air at pump startup. To address this issue, the structure introduces a hydraulic circuit drain to the suction circuit so that the circuit is constantly filled with CVTF. This enabled the electric oil pump to be positioned above the oil level (Fig. 6).

4.4. CVTF with High Metal Friction Coefficient

One performance characteristic demanded of CVTF is enhancement of mechanical efficiency. Methods of enhancing this characteristic using CVTF include the following:

- (1) Reduction of CVTF mixing resistance by lowering viscosity
- (2) Reduction of the required pulley hydraulic pressure by increasing the coefficient of friction between the metal belt and pulleys

The developed CVTF (name: HCF2) secured good normal range viscosity and shear stability by the addition and blending of the optimal amounts of multiple viscosity modifiers (Fig. 7).

In addition, the coefficient of friction of the metal belt was increased by 10% or more compared to the mass-production CVTF (name: HMMF) by use of a new blend of friction modifiers and a Ca-based additive. At the same time, the contrary characteristic of wear resistance was also enhanced and wear was reduced by use of a new S-based extreme pressure agent (Fig. 8).

As a result of the above measures, HCF2 achieved high performance that is among the top level in the industry, and contributed greatly to increasing the transmission capacity of the CVT mechanism and reducing fuel consumption.

The above fuel efficiency enhancing technologies

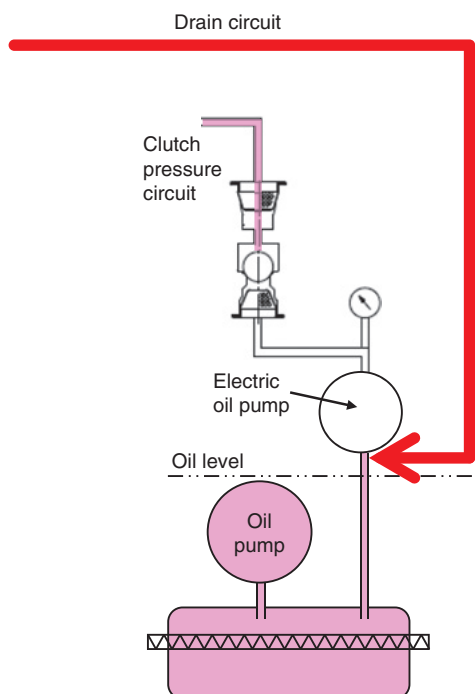


Fig. 6 Hydraulic circuit of electric oil pump

successfully enhanced fuel efficiency by approximately 10% (CAFE Comb.) compared to the 2008 model year Accord 5AT and 5% (JC08) compared to the 2010 model year STEP WGN CVT.

4.5. Pulley V-surface Lapping Finish

Belt-type CVT transmits motive power by the friction force between the belt and pulleys, so a certain friction coefficient value or more is required between the belt and pulleys. In addition, CVT with this structure experience constant micro-slipping between the belt and pulleys, and this slipping produces a certain amount of belt and pulley wear.

It is known that the coefficient of friction tends to drop as this wear progresses, so in consideration of worldwide deployment, technology is needed that can maintain a certain coefficient of friction or more even after driving for long distances. Therefore, the surface properties of the pulley V-surface were optimized as an effective measure for reducing wear.

A lapping process that uses the optimum combination of lapping film granularity and machining condition parameters was added to the conventional pulley V-surface grinding

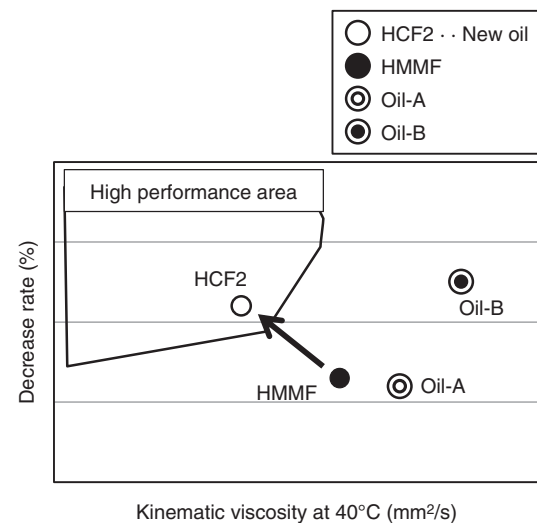


Fig. 7 New CVTF viscosity characteristics

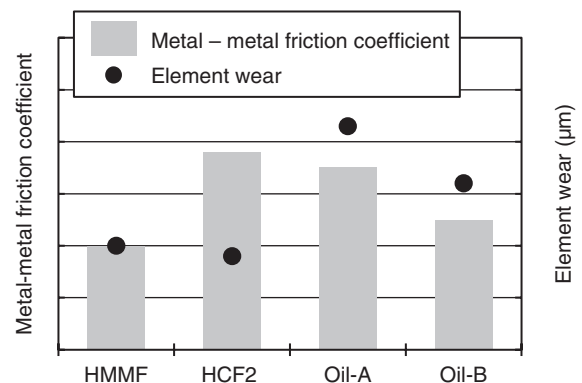


Fig. 8 HCF2 friction coefficient

process. Specifically, the surface property of peak height was reduced to lower aggressiveness towards the belt, while at the same time the valley depth was increased to enhance the oil film retention performance. By manufacturing-in these surface properties, belt wear was reduced while at the same time suppressing the drop in the coefficient of friction (Fig. 9).

4.6. Protective Control

Protective control is performed in accordance with the reliability of each part of this CVT in order to avoid the weight increase resulting from excessive strength increase to support various vehicle usage formats around the world. Figure 10 lists the protective control subjects.

4.6.1. Engine speed control

Oil pump reliability is increased by restricting the maximum engine speed in accordance with the CVTF oil temperature.

Differential gear reliability is increased by restricting the right-left rotation speed difference when single wheel slip occurs.

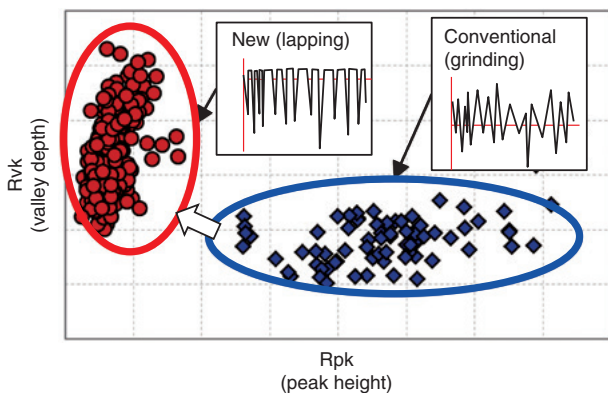


Fig. 9 Surface properties of the V-surface

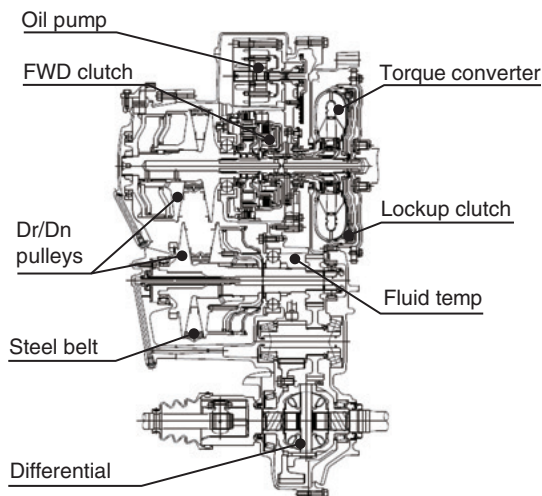


Fig. 10 Protective control subjects

4.6.2. Engine torque cooperative control

The amount of generated heat is reduced and the friction material life is extended by performing cooperative control on the engine torque when engaging the clutch.

The input torque upper limit is obtained from the required driving force, and launch torque cooperative control is performed for the Dr and Dn pulleys in accordance with the pulley input torque characteristics. This achieves control to the proper pulley hydraulic pressure and enhances reliability while at the same time realizing smooth and powerful launch characteristics.

Regarding the metal belt, dedicated linear solenoids are provided to control the clutch hydraulic pressure, and constant control is performed so that the clutch capacity is always the belt transmission capacity or less to increase toughness with respect to belt slip when the rotation speed change abruptly (Fig. 11).

4.6.3. CVTF temperature control

CVTF life is extended by constantly monitoring the oil temperature and controlling the engine upper limit speed so that the oil temperature stays below a certain value.

Torque converter reliability is enhanced by performing cooperative control on the engine torque when stalled to keep the internal CVTF temperature to the allowable value or less.

Lockup clutch life is extended by the adoption of lockup clutch protective control that estimates the friction material temperature and performs control so that the lockup clutch is used at the allowable friction material temperature or less.

These reliability enhancing technologies simultaneously realized a maximum transmission torque of 270 Nm, 4WD support, and helped ensure the reliability needed to support various usage formats around the world, while maintaining the same overall length and weight as the conventional CVT.

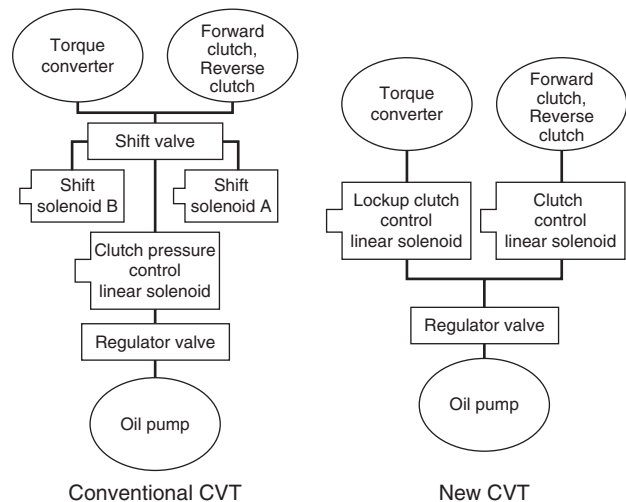


Fig. 11 Hydraulic circuit of new CVT

5. Driving Performance

The new CVT responds quickly to driver demands, provides a high continuing acceleration feeling, and realizes an exhilarating and sporty drive feeling. This enables conventional AT users to switch to the new CVT without a feeling of unnaturalness, while still making use of the smooth characteristics of a CVT.

5.1. Launch Characteristics

Launch control was enhanced and the engine speed is increased with a linear and quick response. This maintains high continuing acceleration and enhances the linear engine rev-up feeling (Fig. 12, Fig. 13).

5.2. Kick down

The step shift amount was increased, and the shift gain for step shift was set to quicken the shift response. In addition, control is performed to swiftly and linearly increase the engine speed after step shift, and to correct the target engine speed to a higher level. This increased the acceleration force, enhanced the response, clarified the acceleration response, and enhanced the smooth engine rev-up feeling (Fig. 14, Fig. 15).

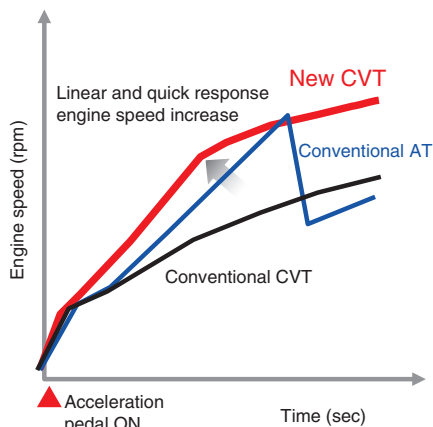


Fig. 12 Launch engine speed characteristics

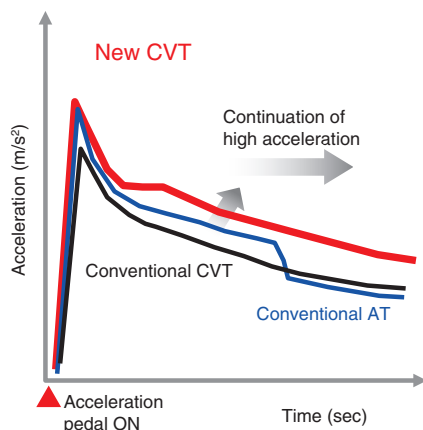


Fig. 13 Acceleration characteristics

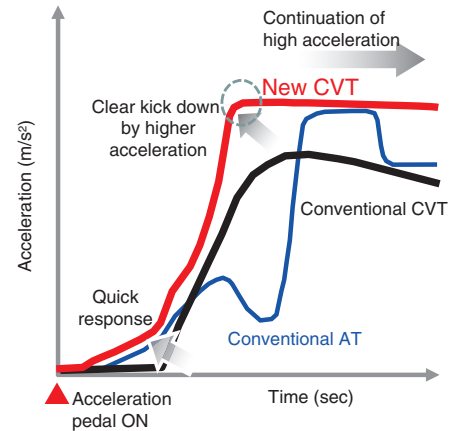


Fig. 14 Kick down characteristics

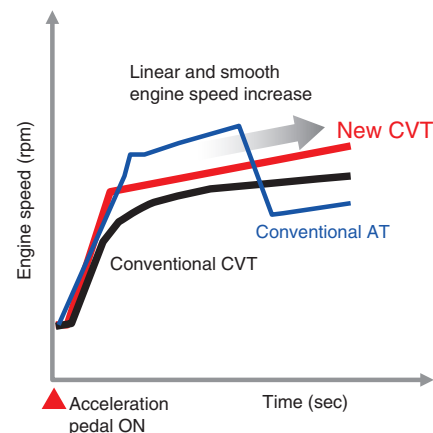


Fig. 15 Linear acceleration characteristics

6. Conclusion

A new CVT for midsize vehicles was developed, and the development goals were achieved. CVT transmission efficiency was enhanced, increasing fuel efficiency by approximately 10% compared to the conventional 5AT in the US CAFE Comb. mode and approximately 5% compared to the conventional CVT in the Japanese JC08 mode.

Reliability was achieved that can support both next-generation high-torque DI engines and various usage formats around the world.

Shift control technology was constructed that realizes appropriate driving force control and launch characteristics that provide an exhilarating and sporty drive feeling.

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