

New CVT for 2018 Model Year N-BOX

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ABSTRACT

A new CVT was developed based on the basic structure of the K-car CVT that started mass production in 2011, mainly with the goal of increasing efficiency. This new CVT was equipped on the 2018 model year N-BOX.

The new CVT reduces oil pump workload with the dual-rotor oil pump system, new CVT fluid, and enlarged pulley piston diameters, and enhances transmission efficiency with reduced friction in various areas, including reduced stirring resistance due to decreased oil levels. With these technologies, transmission efficiency was enhanced by 2% over the 2012 model year N-BOX CVT.

In addition, powertrain cooperative control has been adopted for better traction, together with the new shift control logic, G-design Shift logic. These changes provide quick response to driver demands and maintain high acceleration to achieve an exhilarating driving experience.

1. Introduction

With environmental issues such as global warming drawing increasing focus in recent years, the demands for reduction of automotive CO₂ emissions are growing even more. The transmission plays a large role in fuel economy improvements, and transmission performance also greatly contributes to drivability: what makes driving enjoyable to the driver.

Starting with the 1996 model year CIVIC⁽¹⁾, Honda has expanded its use of CVTs, which combine both fuel economy performance and driving excitement. Honda currently uses CVTs in a wide assortment of its compact⁽²⁾ and mid-size⁽³⁾ gasoline models, including its overseas models.

For the Japanese K-class, Honda has developed a lightweight, compact CVT characterized by primary reduction mechanisms with parallel shaft⁽⁴⁾. Since applying this CVT to the 2012 model year N-BOX, it has sequentially rolled out the CVT to other models, improving the overall fuel efficiency of K-cars.

For this full model change of the N-BOX, a new CVT was developed based on the basic structure of the previous K-car CVT, with more driving excitement, while realizing further weight reductions and enhanced transmission efficiency. This paper introduces the basic construction and key technologies of this new CVT.

2. Development Goals

The following items were the goals in developing the new CVT for K-cars:

- (1) Enhance transmission efficiency by reducing the oil pump workload through reduced oil pressure and other measures, and by reducing friction in various areas; and
- (2) Enhance drivability by developing powertrain cooperative control and CVT shifting control.

3. Key Specifications and Basic Construction

Table 1 compares the key specifications between the 2018 model year N-BOX CVT (hereinafter, “new CVT”) and the 2012 model year N-BOX CVT (hereinafter, “previous CVT”). Also, Fig. 1 depicts an exterior drawing of the new CVT, and Fig. 2 gives the main section view. The distance between pulley shafts and pulley ratio are set to be the same as those in the previous CVT, while the final reduction ratio was decreased from the previous CVT given the weight reductions to the vehicle body.

The four-shaft layout of the previous CVT was retained, situating a parallel shaft primary reduction mechanism upstream of the continuously variable transmission mechanism and eliminating the secondary reduction mechanism. While the case structure follows suit with a simple configuration, comprising just the transmission case

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Table 1 Specifications (NA model)

			2012 model year N-BOX	2018 model year N-BOX
Ratio	Primary reduction	Forward	1.605	1.605
		Reverse	1.187	1.290
	Pulley (low – overdrive)		2.293 - 0.420	2.293 - 0.420
	Final gear		5.176	4.318
Dimension	Overall length [mm]		344.5	344.5
	Pulley axis distance [mm]		147	147
Weight (Wet) [kg]			59.6	56.9

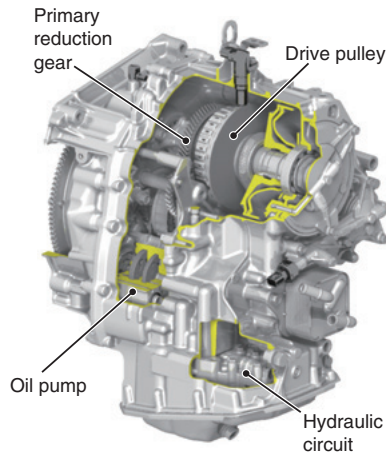


Fig. 1 Appearance of new CVT

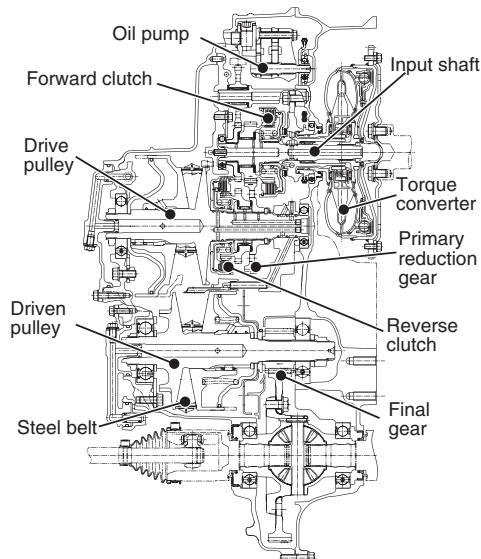


Fig. 2 Main section of new CVT

and torque converter case, changes were made to adapt to the new oil pressure control system and enlarged pulley diameters.

The new CVT will be mated to two engine types: naturally aspirated (NA) and turbocharged (TC). The differences are adjusted for with different torque converters, forward primary reduction ratios, and final reduction ratios.

4. Transmission Efficiency Enhancements

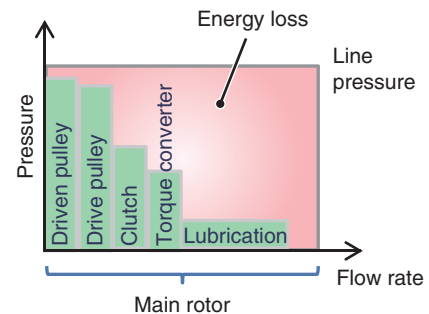
Three main factors are known to degrade transmission efficiency in CVTs: metal belt friction, loss in driving the oil pump, and stirring resistance. In the new CVT, oil pump drive torque was reduced by reducing the pump discharge pressure, in turn achieved by adopting the dual-rotor oil pump system and new CVT fluid, as well as by enlarging pulley piston diameter. Also, stirring resistance was reduced by decreasing the oil level for enhanced transmission efficiency.

4.1. Dual-rotor Oil Pump System

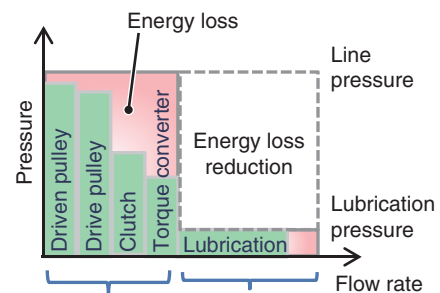
For the new CVT, the dual-rotor oil pump system was adopted, reducing oil pump drive torque. The new pump system comprises an oil pump with two sets of rotors and a hydraulic circuit, which is equipped with a switching valve and switching control solenoid.

4.1.1. Operating principle and hydraulic circuit

A conceptual diagram of energy loss in the oil pump of the previous system is given in Fig. 3(a). The line



(a) Conventional system



(b) Dual-rotor oil pump system

Fig. 3 Concept of energy loss reduction

pressure, or oil pump discharging pressure, is controlled to cover the required hydraulic pressure, as determined by the driving conditions. Loss was high in the previous system, particularly in driving conditions that required higher hydraulic pressures. The entire discharge volume was first brought up to line pressure, then pressure was successively reduced to regulate pressures for the pulleys, clutch, torque converter, and lubrication.

In the new system, discharge is bifurcated, with pressure reduced on the one side to discharge the lubrication pressure directly. This reduces the oil pump workload as given in Fig. 3(b). As shown in detail in the hydraulic circuit of Fig. 4, two sets of oil pump rotors are arranged with independent discharge oil passages, with discharge on the main rotor constantly regulated to the line pressure by the main regulator valve. Meanwhile, the sub-rotor incorporates a switching valve in the discharge oil passage that can select between feeding to the main regulator valve and regulating to line pressure, or feeding to the lubrication regulator valve and regulating to the lubrication pressure. During rapid shift changes and other driving conditions that require heavy flow at high pressure for the pulleys, both rotors can discharge to line pressure to secure sufficient discharge volume. In steady driving and mild acceleration, the sub-rotor discharges at lubrication pressure to reduce loss.

Hereinafter, the state in which sub-rotor discharge is regulated to line pressure by the main regulator valve will be referred to as “high-pressure mode,” and that in which sub-rotor discharge is regulated to lubrication pressure by the lubrication regulator valve will be referred to as “lubrication mode.”

4.1.2. Oil pump construction and specifications

The construction of the oil pump is shown in Fig. 5. The compact construction has two sets of rotors driven by a single shaft, with a single barrier plate positioned within the oil pump between the main rotor and sub-rotor. The pump has a shared suction port but is fitted with independent discharge ports for each rotor.

Theoretical discharge for the main and sub-rotors was

set as described below, aiming to keep total actual discharge equivalent to that of the previous system and to increase fuel efficiency to the utmost.

In combining the theoretical discharge of the main and sub-rotors to equal actual discharge, reducing the main rotor theoretical discharge too much would decrease drive torque for lubrication mode but, due to a balance judgment to be described below, also limit how frequently lubrication mode is used in driving, limiting fuel efficiency savings. Conversely, whereas increasing the main rotor theoretical discharge too much would allow for more driving in lubrication mode and drive torque in lubrication mode would be reduced only slightly, again limiting fuel efficiency savings.

Upon fixing the discharge volume, the workloads needed to drive the oil pump in the decided drive modes were calculated to combine the main and sub-rotor theoretical discharges such that total actual discharge equals that of the previous oil pump. The results are shown in Fig. 6, giving the reduction in workload between the main rotor theoretical discharge and the previous system, as well as the frequency in time that the vehicle is driven in lubrication mode. In the new CVT, the theoretical discharge that minimizes the combined workload was selected to

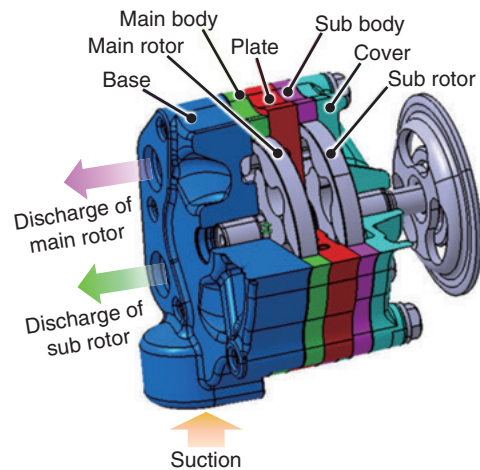


Fig. 5 Construction of dual-rotor oil pump

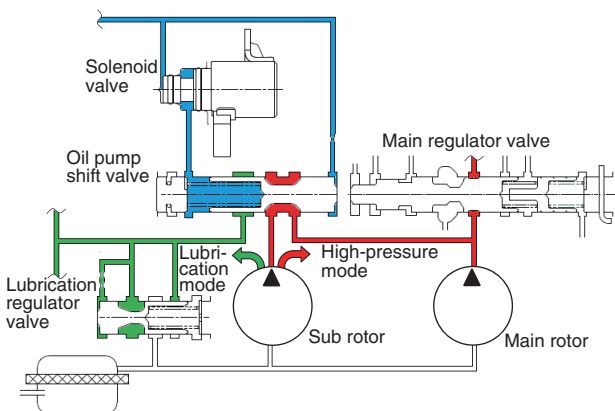


Fig. 4 Hydraulic circuit

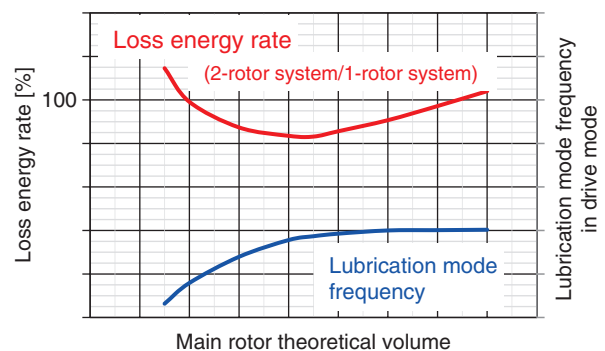


Fig. 6 Setting of oil pump volume

secure the needed discharge volume while improving fuel economy performance.

As an example, Fig. 7 gives the oil pump drive torque when driving with a line pressure of 1 MPa. In lubrication mode, drive torque was reduced by approximately 30% compared to that of the previous system.

4.1.3. Discharge mode switching control

For mode switching, a control system was adopted to continuously calculate the flow rate balance for the driving conditions and switch between high-pressure and lubrication modes based on the calculations.

More specifically, the system switches to lubrication mode when the main pump discharge volume sufficiently exceeds the sum total of pulley side pressure flow needed for rapid change, the flow needed for the torque converter, and leakage of each part; when this volume is insufficient, the system switches to high-pressure mode (see Fig. 8).

4.2. New CVT Fluid

The new CVT will use the new CVT fluid⁽³⁾ as rolled out starting with CVTs for 2013 mid-size models. The higher metal friction coefficient has reduced the belt clamping force needed to transmit torque, reducing line pressure.

4.3. Enlarged Pulley Piston Diameter

The maximum system pressure is set to be either the

drive pulley side pressure or driven pulley side pressure, depending on the driving conditions. In such a system, reduction of the drive pulley side pressure by enlarging the drive pulley piston diameter is effective in reducing line pressure, particularly in steady driving. For the new CVT, the drive pulley outer piston diameter was enlarged from 150 mm to 160 mm, increasing the pressure receiving area by approximately 15%. Reducing clamp force with the aforementioned new CVT fluid and using CAE to effectively reduce stress (see Fig. 9) has enlarged piston diameter while reducing weight.

4.4. Reduced Oil Pump Drive Torque

The reductions to oil pump drive torque under steady driving at 60 km/h are shown in Fig. 10. Oil pump drive torque was reduced approximately 37% for similar

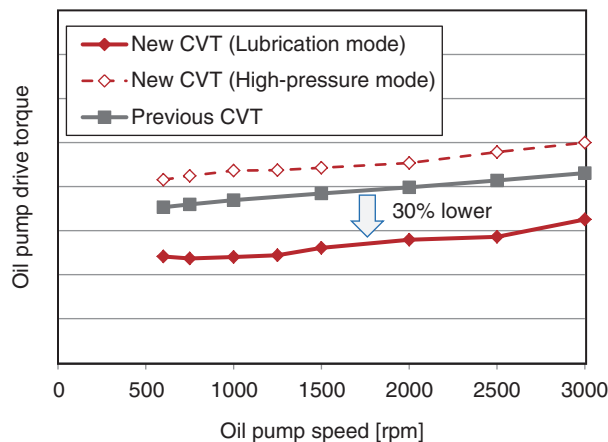


Fig. 7 Oil pump drive torque characteristic

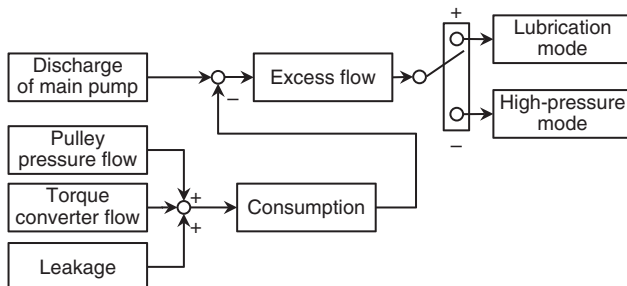
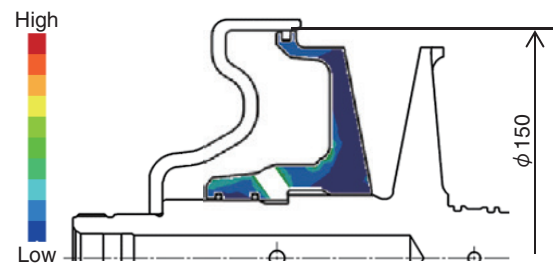
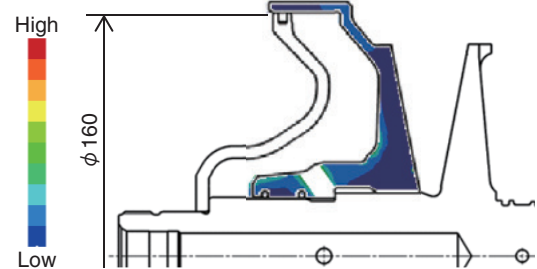


Fig. 8 Judgment of flow balance



(a) Previous CVT



(b) New CVT

Fig. 9 Drive pulley construction and stress contour

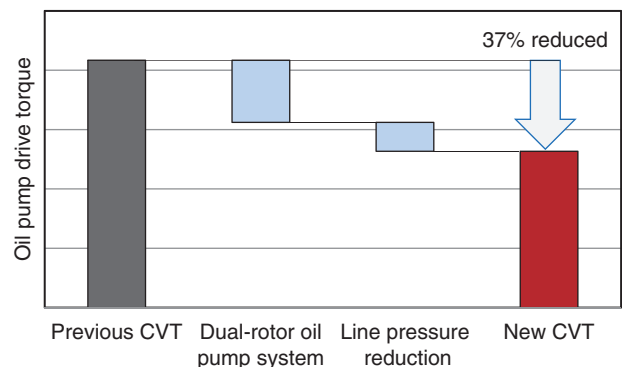


Fig. 10 Reduction of oil pump drive torque

conditions thanks to reductions in loss from adopting the dual-rotor oil pump system, and to reductions in line pressure from adopting new CVT fluid and enlarging the drive pulley piston diameter.

4.5. Friction Reductions

In order to reduce friction for each area, the other sliding and revolving areas, namely the oil seal and seal rings, were replaced with low friction parts, and oil levels were reduced to reduce gear stirring resistance.

While reducing oil levels does reduce stirring resistance, it also adds the concern of reduced oil pressure when oil shifts to one side within the transmission during acceleration, deceleration, or cornering, forcing air intake from the strainer. Sloshing from the gears and inertial forces make it challenging to accurately predict the motion of oil between the gaps in the complex shapes in the transmission. In development for the previous system, the oil level and position of the strainer intake port had to be experimentally confirmed.

In development for this CVT, CVT fluid agitation from the gears and air entrainment was modeled with CFD^{(5), (6)} in the design phase to predict dynamic behavior of the fluid in the transmission. As a result, strainer intake port position and the required fluid amount were effectively rationalized, reducing the fluid level by approximately 5 mm. Results from analysis of oil agitation from the gears and pulleys are given in Fig. 11(a), and those from analysis of fluid shifted by inertial force during deceleration in Fig. 11(b).

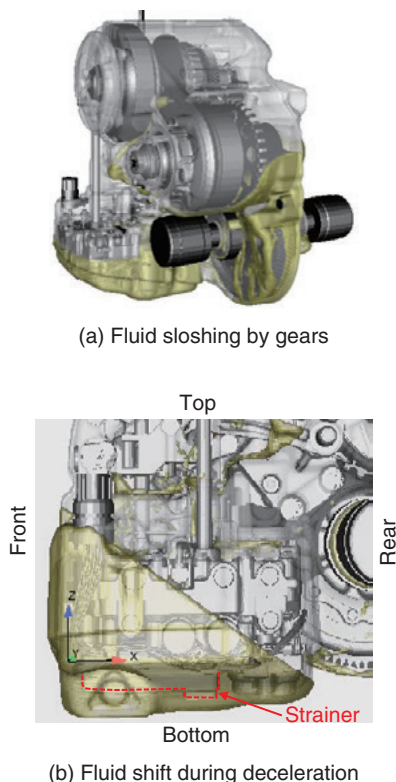


Fig. 11 Simulated trajectory of new CVT fluid

Transmission efficiency for the new and previous CVT by vehicle speed for steady driving conditions is given in Fig. 12. Transmission efficiency in steady driving was increased 2% with the technologies described in the previous sections. In addition, CVT weight was reduced by approximately 2.7 kg by reducing pulley shaft weight, lowering oil volume, and making other adjustments.

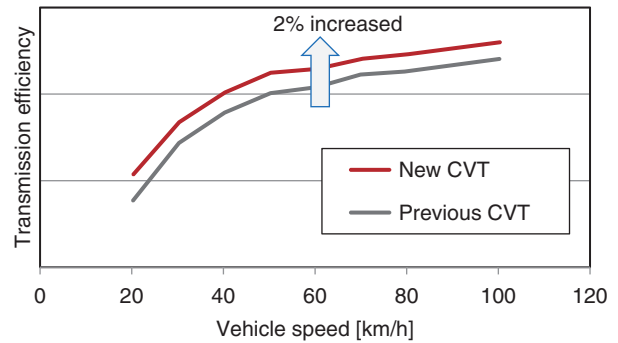


Fig. 12 Increased transmission efficiency

5. Drivability Enhancements

A new shift control logic, G-design Shift logic, was adopted to enhance drive feel in the new CVT. G-design Shift logic offers powertrain cooperative control with drive force target values and responds quickly to driver demands to maintain a high, sustained acceleration feel. By designing these controls to optimally fit driver feel, the system achieved an exhilarating, sporty drive feel.

5.1. Powertrain Cooperative Control

Figure 13 diagrams the control structure for both the previous drive-by-wire cooperative control and the newly adopted powertrain cooperative control with drive force target values. In the previous control system, the throttle is opened according to the accelerator pedal position. When engine speed is increased by changing the CVT ratio, engine load has a tendency to decrease, in turn reducing torque and resulting in acceleration that gradually tapers off.

In the new CVT, powertrain cooperative control is adopted with drive force target values. Engine torque output is determined according to the change in CVT ratio, thus allowing the system to restrict decreases in engine torque as engine speeds increase.

5.2. G-design Shift Logic

The G-design Shift logic offers shift schedules for quick response and sustained high acceleration. If the system clearly senses an intention to accelerate from driver input in terms of accelerator pedal position and pressing speed, it switches over to a dedicated shift schedule.

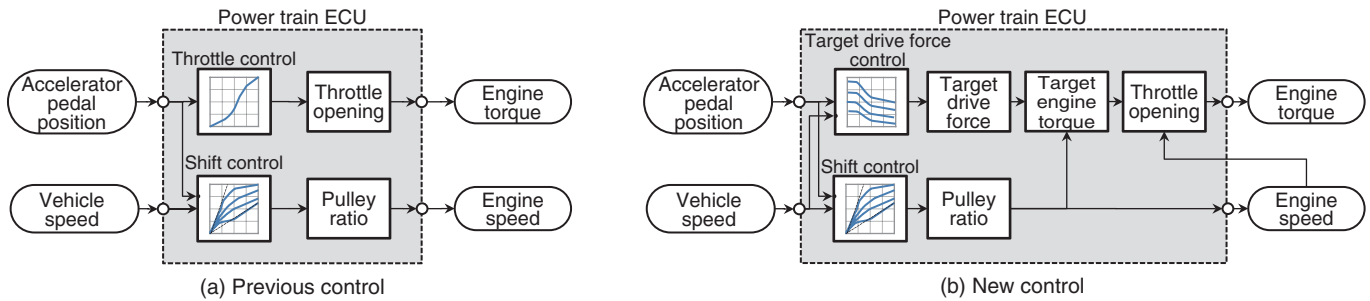


Fig. 13 Schematic diagram of cooperative control

5.3. Acceleration Feeling at Launch

When launching from a stop or from the low-speed range, if the system judges that the driver intends to accelerate, the dedicated launching shift schedule is selected to keep engine speed elevated, producing acceleration launch performance with sustained high acceleration (see Fig. 14).

5.4. Direct Feel during Kick-down Acceleration

The shift schedule after step shifting by kick down was revised for the new CVT. Images of the new and old shift schedules are given in Fig. 15. Whereas in the previous system, the shift characteristics were controlled to converge to the normal shift schedule even after kick down, the new CVT has a dedicated setting of the shift schedule after step shifting by kick down that increases vehicle speed with engine speed synchronously.

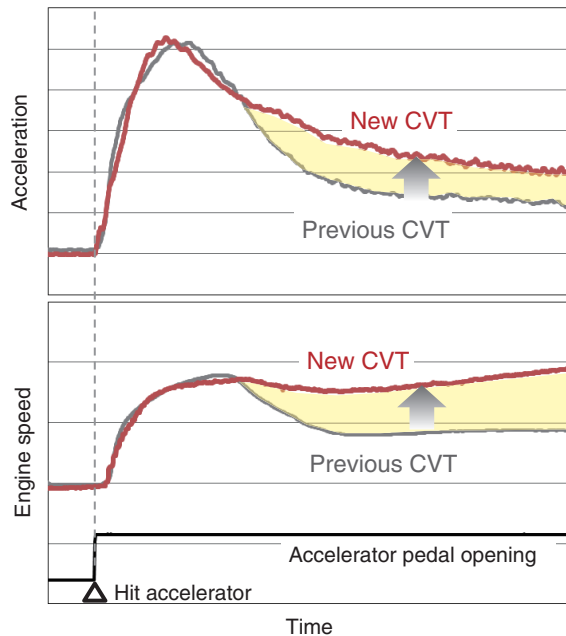
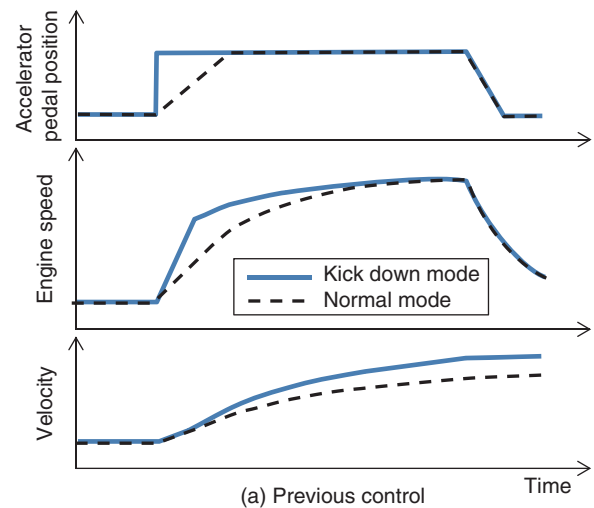
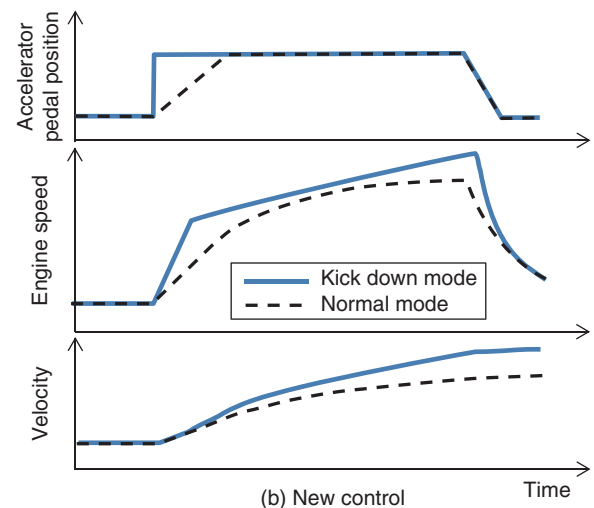


Fig. 14 Launch acceleration characteristics

The shift schedule after step shifting is designed to optimally increase engine speed according to accelerator pedal position, achieving acceleration performance that feels linearly linked to engine speed and maintains high acceleration (see Fig. 16).



(a) Previous control



(b) New control

Fig. 15 Kick down shift control

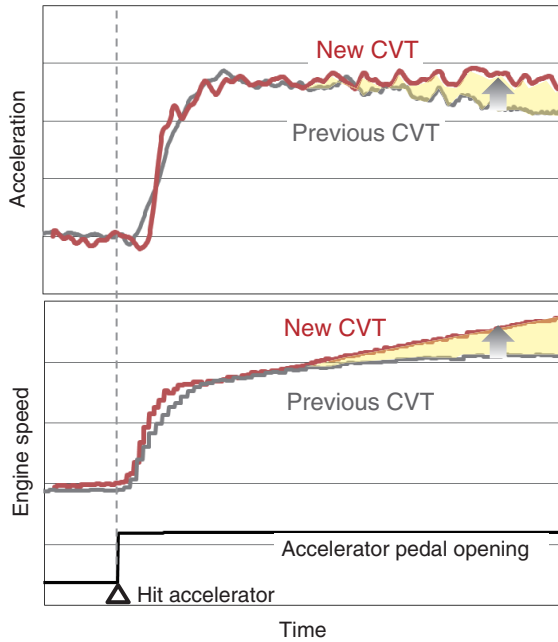


Fig. 16 Kick down characteristics

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6. Conclusion

A K-car CVT was developed with the following results:

- (1) Transmission efficiency was enhanced by 2% with technologies including a dual-rotor oil pump.
- (2) Acceleration characteristic matching driver feel was achieved with powertrain cooperative control and new shift control logic.

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