

Development of 8-Speed DCT with Torque Converter for Midsize Vehicles

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ABSTRACT

Honda has developed the world's first 8-speed dual-clutch transmission equipped with a torque converter that achieves greater fuel economy performance while highlighting the pleasure of driving. The torque converter was adopted to provide smooth, powerful initial acceleration, together with quick shifting enabled by reduced inertia in the driveline; rhythmical, seamless acceleration by multi-staging with close ratios; and other such elements that create a sporty driving feel. Wider range, lower friction, and other such measures have achieved a 15% increase in power performance and an 8% increase in fuel economy performance relative to a conventional 5-speed automatic transmission. The use of common gears across the entire gear train, a unique dual shaft structure, an ultra-flat torque converter, and other such techniques enabled the size and weight to be kept down to the level of a conventional 5-speed automatic transmission for the same vehicle class while simultaneously increasing the number of gear stages.

1. Introduction

The transmission plays an important role in the high level of environmental performance that is being required of motor vehicles today. There is growing adoption worldwide of a wider range of ratios in transmissions, multi-staging, and the use of continuously variable transmissions (CVT). The dual-clutch transmission (DCT) is one multi-stage transmission that achieves a balance of environmental performance with the elements that make driving fun and yield a direct, linear gearshift feeling in response to throttle operation. On the other hand, transmissions that use clutch operation to make a standing start have issues affecting product appeal, such as a jerky feeling⁽¹⁾.

Given this background, Honda has developed the first 8-speed DCT with torque converter in the world to achieve a balance between product appeal for standing starts and a sporty gearshift feeling in a midsize vehicle. This paper will describe the development goals for this DCT, its basic construction, and the principal technologies involved.

2. Development Goals

The following items were defined as goals for the development of this DCT.

- (1) Creation of a sporty driving feel
- (2) Achievement of fuel economy performance at the top level in its class
- (3) Assuring installation on a par with conventional 5-speed automatic transmissions (AT)

3. Basic Structure and Main Specifications

Figure 1 shows a main sectional view of the DCT, while Fig. 2 shows the vehicle speed map and Table 1 the main specifications.

The gear train was structured with driven gears shared by 1st, 2nd, and reverse, by 3rd and 4th, by 5th and 6th, and by 7th and 8th gears. The transmission also incorporates a dual shaft structure, with an inner shaft that directly links to the clutch and an outer shaft that is combined with a shift mechanism for gear selection. An ultra-flat torque converter with a high-attenuation damper was also adopted. These three features were steps taken to achieve eight speeds while also keeping the overall length of the transmission down to that of a 5-speed AT.

The adoption of a torque converter achieved powerful, smooth standing-start performance. The diameter of rotating parts was also reduced, and instead of the tandem clutch⁽²⁾ ordinarily found with a conventional DCT, a small-diameter

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single clutch was arranged on each shaft in order to reduce inertia. These measures enabled quick gear shifting.

With expansion of the gear range to eight gears, the gear ratios could be lowered and set closer. Compared to the 2008 model-year TSX, the 1st gear ratio was lowered

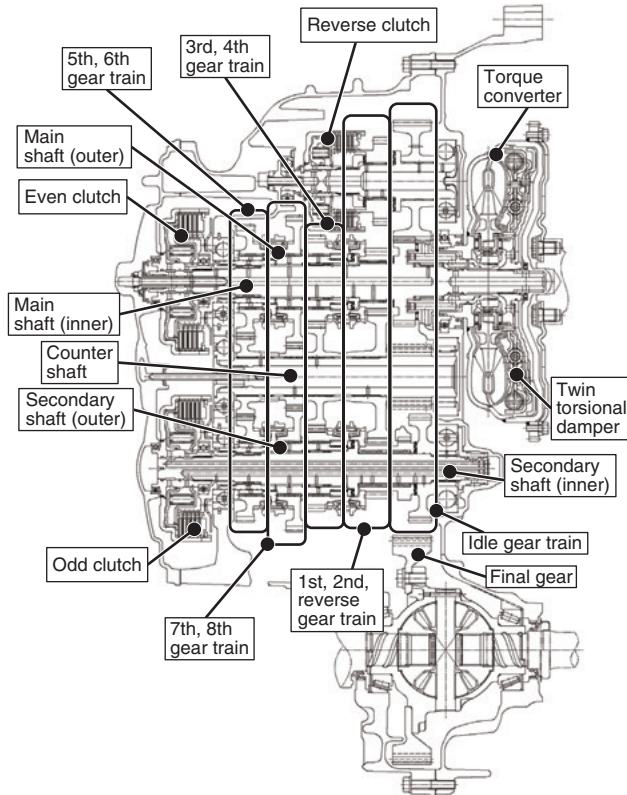


Fig. 1 Main section of 8-speed DCT

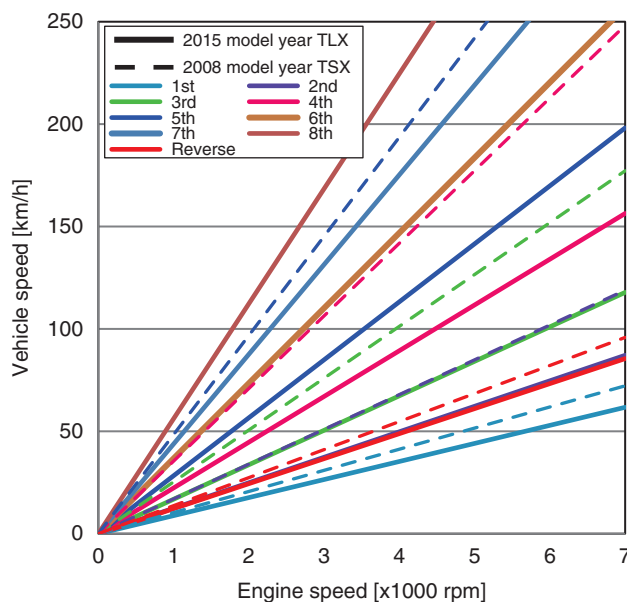


Fig. 2 Vehicle speed map

Table 1 Transmission specifications

Model		2015 model year TLX 2.4 L	2008 model year TSX 2.4 L
Torque capacity [Nm]		270	230
Overall gear ratio	1st	14.084	11.768
	2nd	9.974	7.160
	3rd	7.379	4.801
	4th	5.560	3.429
	5th	4.389	2.512
	6th	3.383	-
	7th	2.835	-
	8th	2.212	-
	Reverse	10.169	8.875
Ratio range		6.367	4.687
Overall length [mm]		388	379
Weight [kg]		95.0	92.6

20% and the top gear (8th gear) ratio was raised 12%. This achieved a balance between sporty driving and fuel economy performance. The wider ratio range enabled raising the ratio range to 7.0.

4. Main Technologies

4.1. Torque Converter with High-Attenuation Damper

The effect that adopting a torque converter has on vehicle body acceleration in a standing start at full throttle is compared with competitors' vehicles in Fig. 3. The time taken to reach peak vehicle acceleration was reduced by

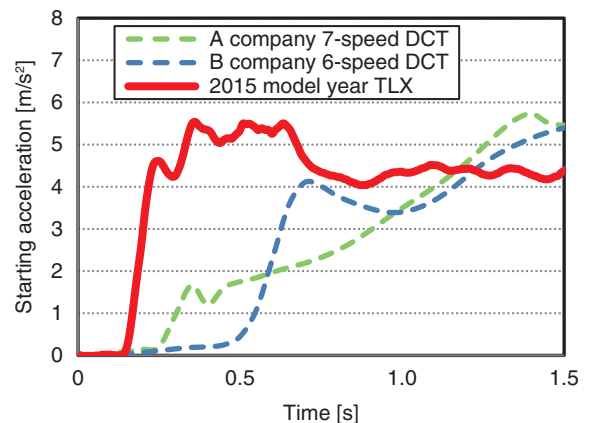


Fig. 3 Comparison of starting acceleration

approximately one second compared to other companies' DCTs.

Measures taken to reduce inertia and reduce friction in this DCT raised the issue of a rattling noise in the gears due to the engine speed fluctuation while the lockup clutch (LC) was engaged. In order to limit those engine speed fluctuations, a twin torsional damper (Fig. 4) was developed. This involved adding intermediate inertia and a secondary damper to a conventional single torsional damper, as well as optimizing the inertia arrangement, the spring layout, and the load distribution. These measures achieved a 40% reduction in the damper spring rate and a 30% reduction in the friction generated during damper operation. The result was a 58% reduction in rotational fluctuations in the main shaft, which were the origin of the vibration underlying the rattling noise. This achieved a balance between realizing the feeling of direct response from expansion of LC direct drive range and resolution of the rattling noise (Fig. 5).

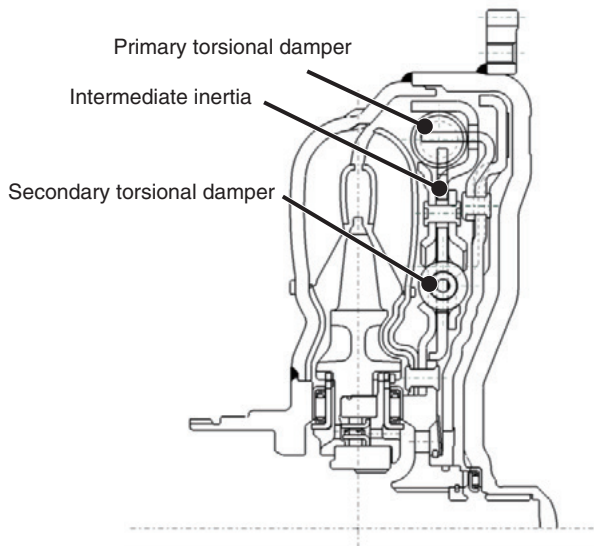


Fig. 4 Structure of twin torsional damper

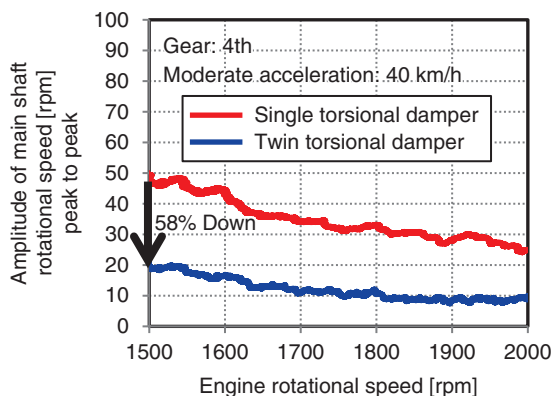


Fig. 5 Comparison of damping effect

Another measure was taken with regard to the increase in total torque converter length due to adoption of the twin torsional damper. By making the torque converter flow path ultra-flat, that length was kept equal to or shorter than the dimension of conventional torque converters. New blades were designed by analysis using computational fluid dynamics (CFD), and this successfully maintained the torque converter characteristics on a par with those of a conventional 5-speed AT while also reducing flow path width by 33%.

4.2. Dual Clutch

All the gear changes in a DCT are performed using two clutches. Consequently, the stored heat and increased number of operations during consecutive gearshifts made clutch durability an issue.

Adopting a single structure for the clutches has enabled appropriate distribution of lubricant to each clutch. The development of new facing materials and the use of a new fluid has reduced the coefficient of static friction by approximately 30% relative to a conventional AT and enabled reduction in the number of disks. As a result of measures to optimize heat capacity, the durability of the clutch could be assured while also keeping the unit to the same size as a conventional AT clutch.

4.3. Shift Mechanism

The shift mechanism is based on the manual transmission (MT) structure with a hydraulic servo piston used to operate the shiftfork (Fig. 6). The structure of this DCT was devised to reduce inertia in the synchronization parts when selecting a gearshift stage. Since the load required for synchronization is small, the diameter of the

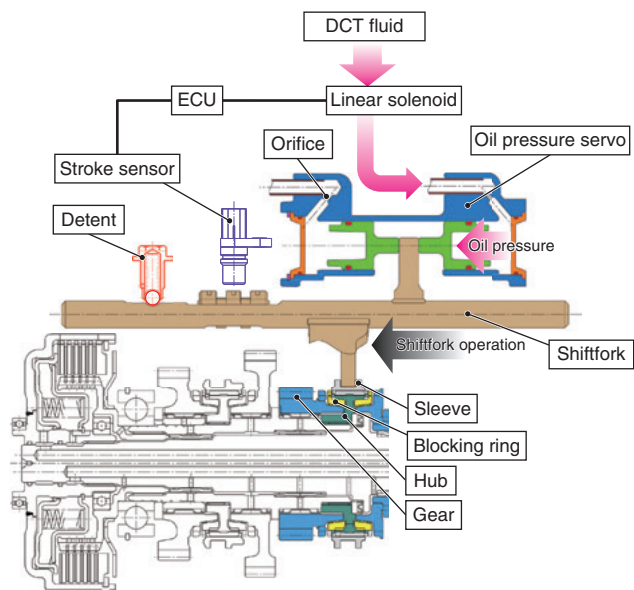


Fig. 6 Gear shift system

hydraulic servo piston could be made smaller. As a result, the responsiveness was increased and the gearshift stage could be selected more rapidly.

However, one distinctive DCT issue is the noise from operation of the shift mechanism. The gearshift noise in an MT occurs simultaneously with the shifting operation by the driver, and so does not become an issue. In a DCT, however, the gearshift noise occurs at a different time from the change in gear. The cause of this is the gear rattling noise that occurs while the gearshift is taking place. It occurs at three points during the gearshift operation process: at the start of balk, at the point when the sleeve comes in contact with the gear dog, and when the sleeve engages the gear dog teeth (Fig. 7).

During the shift operation process, there is a correlation between the sleeve stroke speed and the gearshift noise (Fig. 8). Given this result, the issue of gearshift noise was resolved by reducing the stroke speed.

The method used to reduce the stroke speed involved hydraulic control matched to the stroke, change of the detent shape, and addition of an orifice in the hydraulic servo piston chamber. However, reducing the stroke speed sometimes results in breakdown of synchronization in the process from balk to dog contact, and this was addressed by adjusting the detent profile to provide the proper

brake load for the torque that causes the breakdown of synchronization.

4.4. Hydraulic Control System

In a conventional AT, a gearshift is completed when the clutch reengages the gear. In the DCT, however, the next gear must first be selected by the shift mechanism before the clutch reengages the gear, which means that gearshift responsiveness becomes an issue. This issue was addressed by enabling simultaneous control of the shift mechanism and the clutch. For that purpose, a hydraulic circuit structure was adopted that augments the linear solenoids used to control the clutch on each shaft by placing linear solenoids to operate the shift mechanism, which consists of two sets on each shaft, together with ON/OFF solenoids.

The volume of the clutch accumulator was also reduced in order to shorten clutch control time when shifting gears. The shift shock caused by variations in clutch control pressure then becomes an issue. Hydraulic sensors were therefore applied, and the linear solenoids were trained to make corrections to the hydraulic pressure. This reduced the difference between the target hydraulic command value and the actual hydraulic pressure, and it achieved a balance between gearshift responsiveness and product appeal.

4.5. DCT Control

In order to obtain the exhilarating gearshift feeling that is intended for the DCT, a balance between resolution of the “shift-busy” feeling and gearshift responsiveness was achieved using the following methods.

In order to resolve the “shift-busy” feeling, the gear stage regions on the shift map were configured so that 10% or more of each region could be secured by means of the accelerator pedal (AP) opening (i.e., throttle opening). This configuration allows drivers to select gear stages more

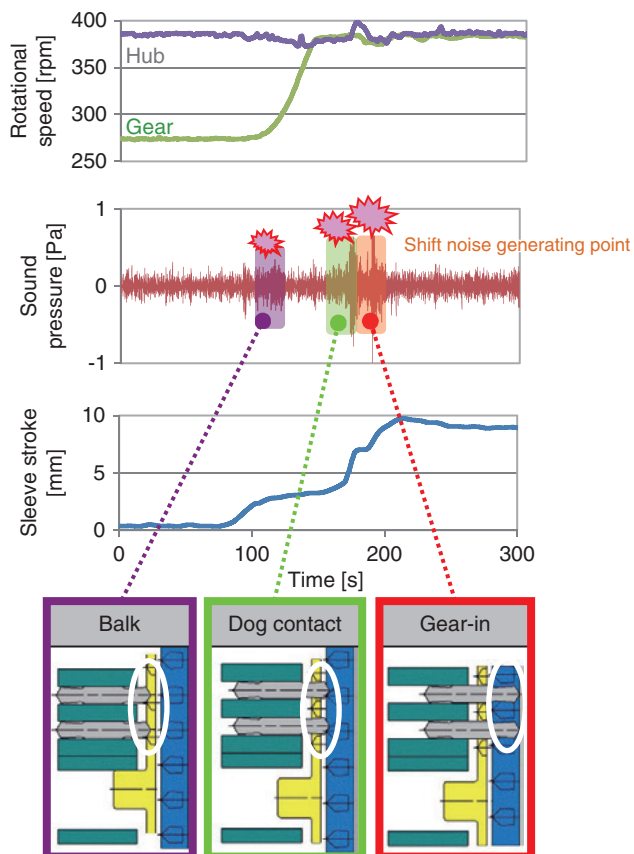


Fig. 7 Shift noise generating point

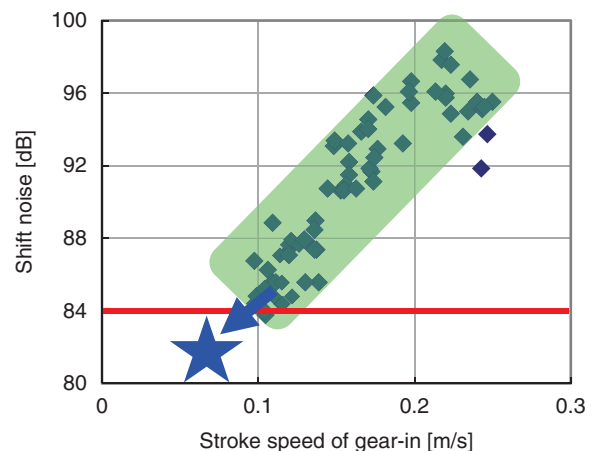


Fig. 8 Relationship between shift noise and stroke speed

easily (Fig. 9).

Gearshift responsiveness was addressed by adopting fast shift control (Fig. 10). This uses the driver's accelerator pedal operating speed to predict the drive force that will be demanded by the driver, and implements control that initiates kick-down (KD). When the accelerator pedal operating speed and the throttle opening exceed the judged value (fast shift judgment), the gear stage is selected according to the predicted AP opening. This enables the drive force demanded by the driver to be produced quickly.

4.6. DCT Fluid

The DCT structure includes the wet-type clutch and other such constituent elements of an AT together with a shift mechanism and other such constituent elements of an MT. A new fluid was therefore developed to satisfy the characteristic requirements that arise from both those constituent elements.

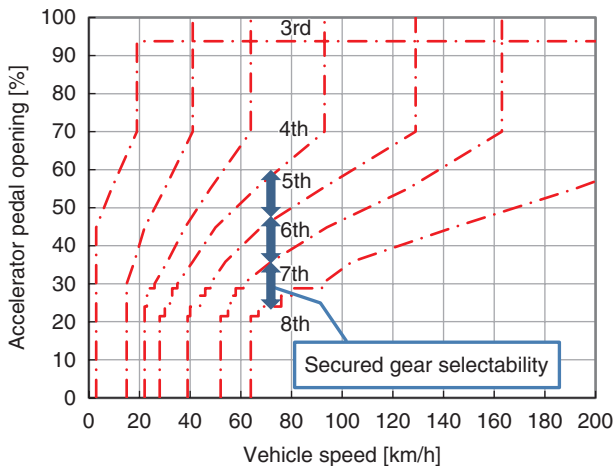


Fig. 9 Shift map (only KD line)

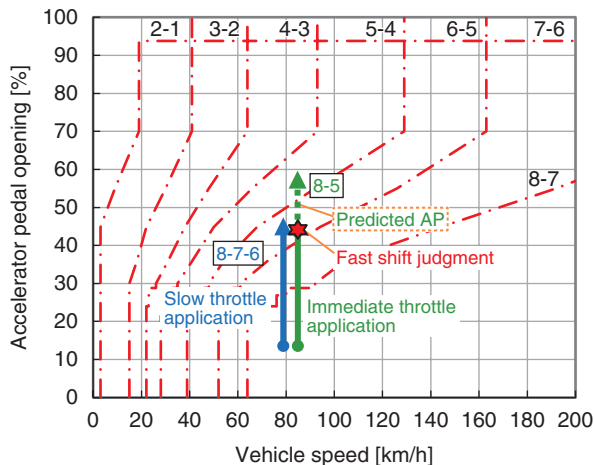


Fig. 10 Fast shift

The types and compounded amounts of friction modifiers, which are performance additives, were adjusted to optimize the wet-type clutch frictional characteristics. The amount of sulfur type extreme-pressure additive was also increased in order to assure the necessary reliability of the gears and shift mechanism.

Steps were also taken to lower viscosity in the normal temperature region with the aim of reducing agitation resistance in order to increase fuel economy. A low molecular weight-type viscosity index improver was adopted, and with a base oil optimally suited to it due to its viscosity, achieved a kinematic viscosity of 5.5 mm²/s at 100°C (Fig. 11). This places the fluid at the top level for such fluids that are compatible with DCT construction.

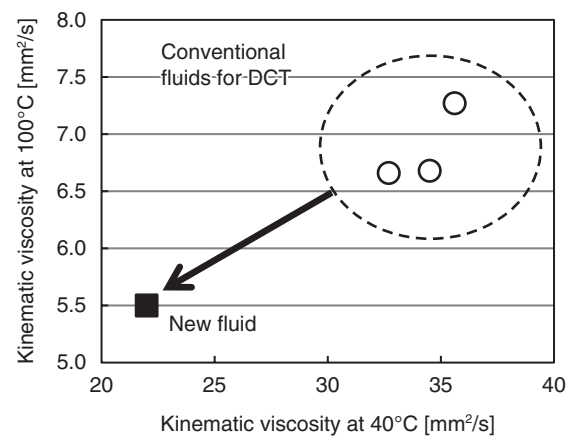


Fig. 11 Viscosity characteristics of new fluid

5. Driving Performance and Fuel Economy

5.1. Driving Feel

In order to produce a sporty driving feel, rhythmical gear shifting and a direct feeling of power were achieved at levels exceeding the 2008 model-year TSX and DCTs from other manufacturers.

The rhythmical quality of gear shifting was evaluated under the two headings of rate of change in engine speed when changing gears and gear change interval. In this DCT, the ratio of an adjacent gear ratio (hereafter, the common ratio) is set to be linear so that from 1st through 5th gear the common ratio is low by comparison with the 2008 model-year TSX and DCTs from other manufacturers (Fig. 12). This brought the rate of change in engine speed when gears are shifted at wide-open throttle to an average 7.2% lower than in the 2008 model-year TSX (Fig. 13). Similarly, the gear change interval was also shortened (Fig. 14) and rhythmical gear shifting was realized.

The feeling of direct response was evaluated under the two headings of gear change time and LC direct drive

range. In addition to superiority in hardware terms, such as its low inertia construction, this transmission has shortened gear change time 37% in average shifting up from 1st to 2nd, 2nd to 3rd, and 3rd to 4th gears relative to the 2008 model-year TSX (Fig. 15) by increasing the estimated torque accuracy of torque-on-demand control of the engine and by adopting predictive pre-shifting.

About LC control, a superior feeling of direct response was achieved by lowering the slip ratio and expanding the direct drive range. Figure 16 shows a comparison of LC slip ratios.

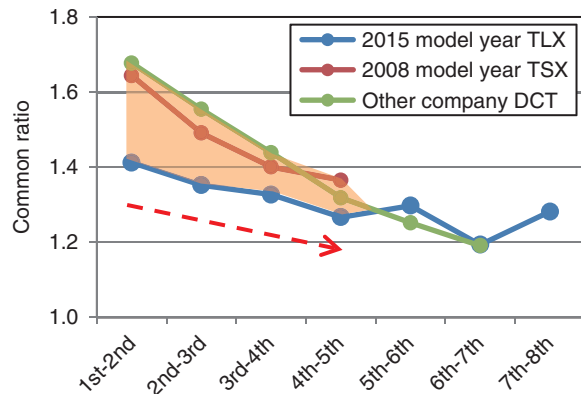


Fig. 12 Common ratio

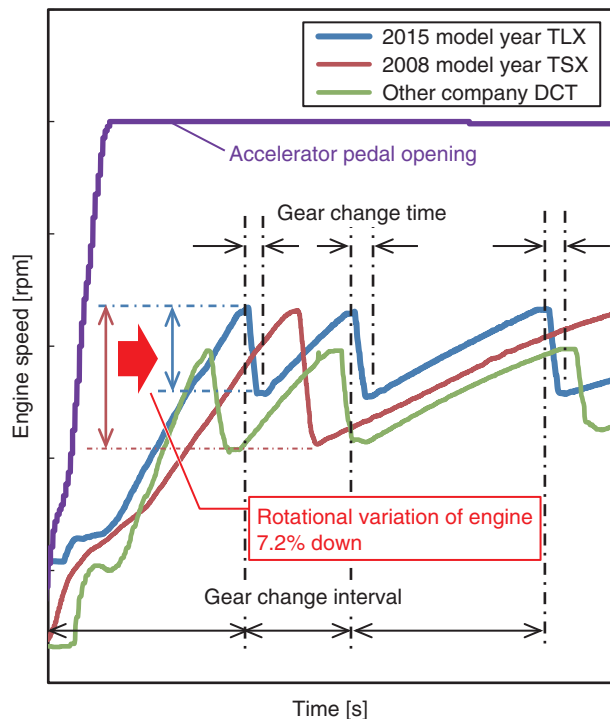


Fig. 13 Engine rotational variation

5.2. Driving Performance

The gear ratios in the low-speed gear train were lowered to enhance drive force and shorten gear change time. With this, the 2015 model-year TLX achieved a 1.3-second reduction relative to the 2008 model-year TSX in the time taken to accelerate at wide-open

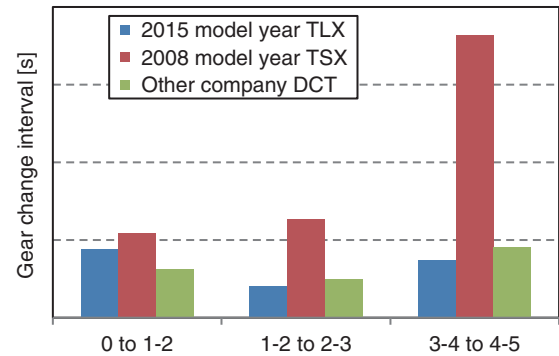


Fig. 14 Gear change interval

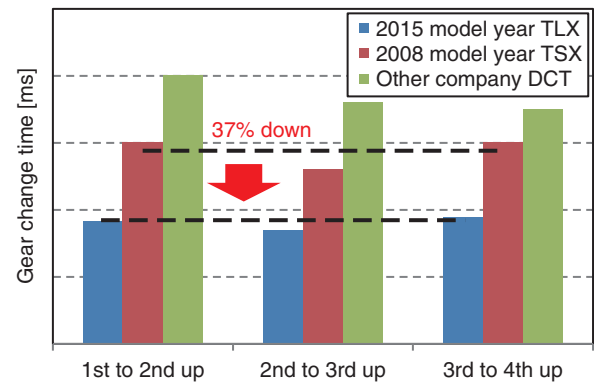


Fig. 15 Gear change time

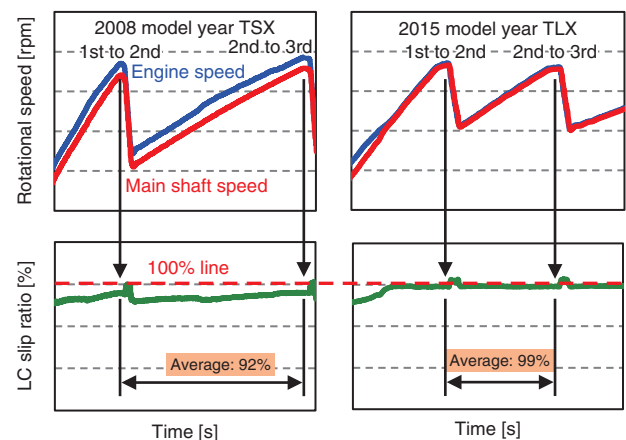


Fig. 16 LC slip ratio

throttle from 0 to 60 mph. This realized a 15% rise in driving performance. Figure 17 shows a comparison of longitudinal acceleration when accelerating at wide-open throttle.

5.3. Friction Torque

The adoption of line pressure control in response to the torque that needs to be transmitted by each clutch, reduction in agitation resistance by construction with separate clutch chambers, and control that keeps all the gears but the gear being driven on standby in neutral, together achieved a 28% reduction in friction torque relative to a conventional 5-speed AT (Fig. 18).

5.4. Fuel Economy

Multi-staging, wider range, expansion of LC direct drive range, reduction in friction torque, and heightened torque transmission efficiency achieved an 8% increase in fuel economy in US combined mode relative to a conventional 5-speed AT.

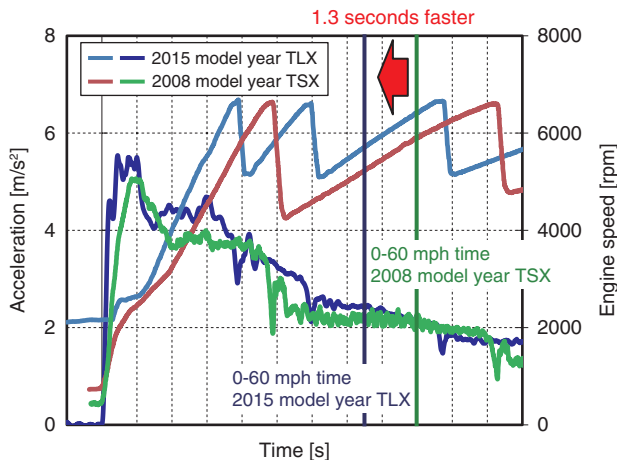


Fig. 17 Wide open throttle acceleration

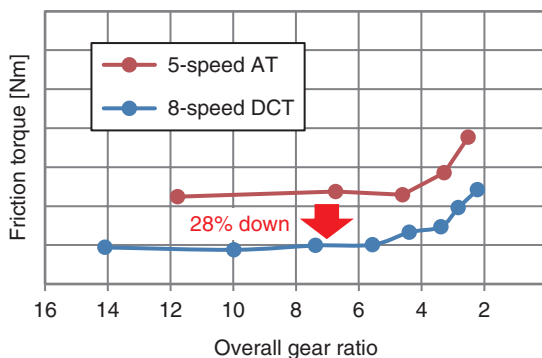


Fig. 18 Friction torque

6. Conclusion

An 8-speed DCT with torque converter was developed with the aims of a sporty driving feel, greater fuel economy, and compactness. The following results were obtained.

- (1) The adoption of a torque converter realized sporty driving characterized by powerful, smooth initial acceleration together with rhythmical gear shifting and a feeling of direct power. Compared to the 2008 model-year TSX, this model shortened the time taken to go from 0 to 60 mph by 1.3 seconds, achieving a 15% rise in driving performance.
- (2) An 8% increase in fuel economy in US combined mode was achieved relative to a conventional 5-speed AT.
- (3) The adoption of a structure with common gears in shifting across the entire gear train, a dual shaft structure, and an ultra-flat torque converter achieved an 8-speed transmission while also keeping the overall length of the transmission down to that of a 5-speed AT.

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