

Longitudinal 9-speed Dual Clutch Transmission for 2nd-generation NSX

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ABSTRACT

The world's first longitudinal nine-speed dual clutch transmission was developed for the second-generation NSX. Its purpose is to realize the design, acceleration performance, and dynamic performance that are appropriate in a supercar for the new era, as well as to provide smooth, comfortable driving on city streets and on expressways. By eliminating the shift mechanism for first gear and sharing the transmission gears, the total length was reduced 120 mm relative to these measures not being applied, achieving a rear overhang that is 35 mm shorter than other manufacturers' supercars with seven-speed dual clutch transmission. In order to deal with the higher power output, the optimal oil was respectively used for the clutch and gear rooms, while the adoption of a high-capacity dual wet clutch, high-strength gear material, and high-strength case material increased capacity to 550 Nm. In order to deal with high-load driving on the circuit and under other such conditions, the respective cooling and lubrication systems for the clutch and gear rooms were optimized by the use of four heat exchangers and a baffle cover that completely encloses the clutch. The gear ratio was optimized for each shifting stage, the rigidity of the shift fork was increased, and a double-cone synchronizer was adopted for second to fifth gears, thereby realizing high gear change response while retaining quiet cruising at high speeds.

1. Introduction

With the aim of giving form to drivers' universal desire to pursue the joy of driving control still further, the second-generation NSX was developed as a supercar for a new era with the keywords "New Sports eXperience" to realize unprecedented levels of driving control.

The second-generation NSX has a longitudinally mounted midship V6 3.5-L twin-turbocharged engine and a direct drive motor directly connected to the crankshaft together with a nine-speed dual clutch transmission (DCT) to drive the rear wheels. The twin motor unit (TMU) mounted on the front axle is combined with the SPORT HYBRID SH-AWD four-wheel drive system to deliver highly responsive acceleration performance that utilizes the high power produced by the system. Table 1 shows the specifications for the power train system mounted in the second-generation NSX. Figure 1 shows the layout of the components⁽¹⁾.

Conventional supercars have been equipped with a six- to seven-speed longitudinal DCT that realized overwhelming acceleration in circuit driving. The transmission for the second-generation NSX was required to produce a balance of further enhanced supercar performance with smooth, comfortable driving on ordinary public roads.

Table 1 Specifications of power train system

Power train system	SPORT HYBRID SH-AWD Maximum power 427 kW Maximum torque 646 Nm
Engine	Twin-turbocharged DOHC V6 3493 cm ³ 373 kW at 6500-7500 rpm 550 Nm at 2000-6000 rpm
direct drive motor	Water-cooled motor and generator directly connected to crankshaft 35 kW at 3000 rpm 148 Nm at 500-2000 rpm
Transmission	9-speed DCT
TMU	Twin traction motor and generator unit 27 kW at 4000 rpm × 2 73 Nm at 0-2000 rpm × 2

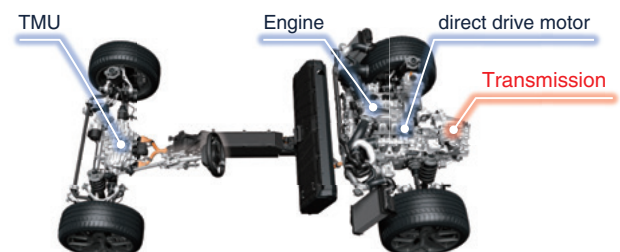


Fig. 1 Power train system components

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Realizing these aims necessitated a longitudinal nine-speed DCT that achieved a balance between greater compactness and added gear stages for optimal gear ratios at each shifting stage.

2. Development Aims

In developing the longitudinal nine-speed DCT for the second-generation NSX, the following items were defined as development aims.

- (1) Achieve a balance between a configuration with nine shifting stages and greater compactness.
- (2) Achieve the increased capacity to enable transmission of the supercar's high power output.
- (3) Achieve thermal feasibility during circuit driving and other such high-load driving.
- (4) Achieve a high level of instant launch, linear acceleration performance, and smooth, quiet cruising.

3. Basic Construction and Main Specifications

Table 2 shows the main specifications of the longitudinal nine-speed DCT for the second-generation NSX. Figure 2 shows a main sectional view of the DCT.

3.1. Parallel Multi-shaft Longitudinal Structure

The structure was designed so that the output from the engine and direct drive motor would work through the dual wet clutch (DWC) to transmit torque to the various shafts. A parallel multi-shaft structure was adopted for the transmission gears in which the drive gears of odd-numbered stages are located on the main shaft and those of even-numbered stages are located on the secondary shaft, with the input shaft and idle shaft placed in between, while the driven gear is located on the counter shaft and is shared⁽²⁾. The use of hypoid gears also made it possible to replace the output shaft at a right angle to give the transmission a longitudinal structure.

3.2. Close Ratio Configuration

First gear was configured with a low ratio to provide instant launch as SPORT HYBRID SH-AWD. Maximum shift range was configured with a high ratio to achieve quiet cruising at high speeds. The gear ratios of the seven stages between them were given a close ratio configuration that would retain acceleration in a power peak zone wherein the engine is kept in the high-speed range (6000 rpm) up to the maximum vehicle speed (Fig. 3).

3.3. Two Types of Oil

Two types of oil are used in order to obtain maximum performance from the nine-speed DCT. Two oil seals were positioned between the clutch case and the input shaft and another two between the input shaft and the main shaft. This structure was adopted to separate the oil in the clutch room from that in the gear room (Fig. 4).

Table 2 Transmission specifications

Transmission type		9-speed DCT
Torque capacity [Nm]		550
Maximum engine speed [rpm]		7500
Power capacity [kW]		373
Overall gear ratio	1st	13.754
	2nd	8.719
	3rd	6.370
	4th	5.116
	5th	4.341
	6th	3.720
	7th	3.156
	8th	2.677
	9th	2.272
Reverse		8.580
Ratio range		6.055
Overall length [mm]		633
Oil	Clutch room	ATF
	Gear room	Gear oil

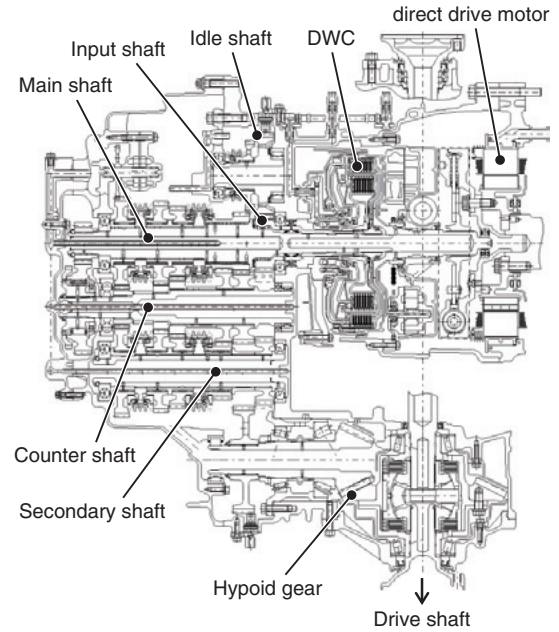


Fig. 2 Main sectional view of developed DCT

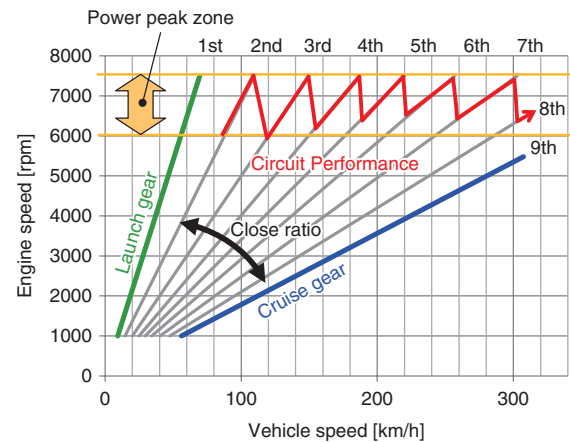


Fig. 3 Speed diagram of 9-speed DCT

A newly developed gear oil was adopted for the gear side to provide high viscosity and high oil film retention under conditions of high temperature and high surface pressure in order to support high power output. For the clutch side, however, an automatic transmission fluid (ATF) with an optimal blend of additives for superior oil properties was adopted in order to achieve a balance between DWC torque transmission performance and anti-judder characteristics (Fig. 5).

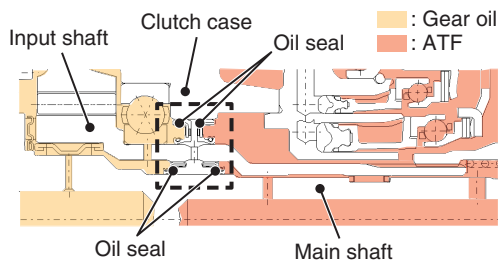


Fig. 4 Oil seal for oil separation

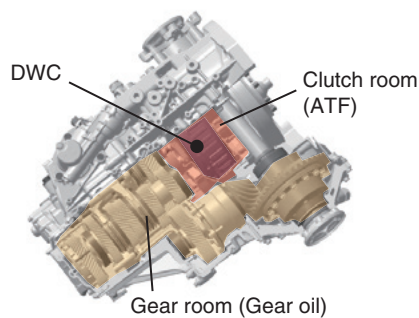


Fig. 5 Separation of clutch and gear room oil

4. Techniques Addressing Requirements

4.1. Added Gear Stages and Greater Compactness

It was necessary to reduce the total length of the longitudinal nine-speed DCT so that the limited overhang length would reduce yaw moment when turning as well as increase design freedom for the rear of the vehicle.

In order to limit the increase in total length caused by the addition of gear stages, the shift mechanism used in other shifting stages was eliminated from first gear. The adopted structure has a one-way clutch (OWC) shared by the first driven gear and parking gear. The fourth and fifth, sixth and seventh, and eighth and ninth gears were aligned and configured to share the driven gear on the counter shaft. The output drive gear and the reverse driven gear were configured to share the third driven gear (Fig. 6). These measures for a compact layout reduced the total length 120 mm relative to when the measures are not taken, while the adoption of a nine-speed system simultaneously

achieved a rear overhang that is 35 mm shorter than other manufacturers' supercars with a seven-speed DCT (Fig. 7).

4.2. Support for High Power

The nine-speed DCT was required to transfer the high power output from the engine and direct drive motor.

For the clutch, the DWC with torque capacity of 370 Nm used in the 2015 model year Acura RLX was used as the base and given greater capacity. The thickness was respectively optimized for the steel plates in the odd- and even-numbered stages, and the number of friction discs was increased. Combining this with optimized lubrication achieved a torque capacity of 550 Nm while retaining the former dimensions (Fig. 8).

In order to achieve high capacity without increasing total transmission length, high-strength steel was adopted for all the transmission gears and the module specifications were optimized. The durability of the hypoid gears was enhanced

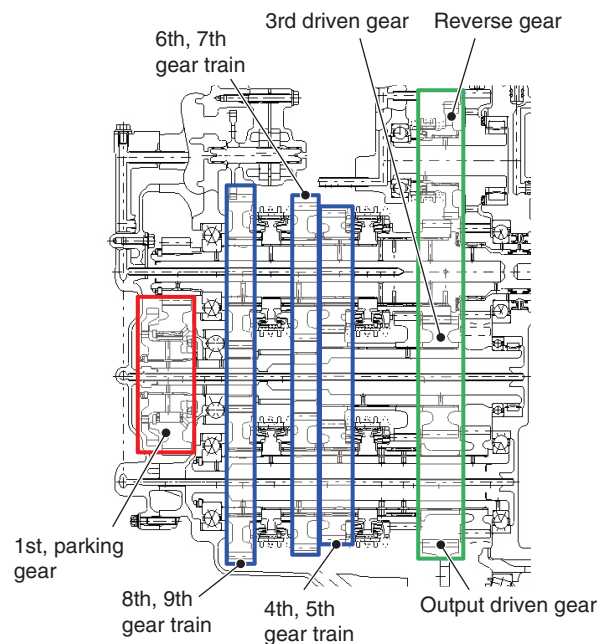


Fig. 6 Structure of gear train

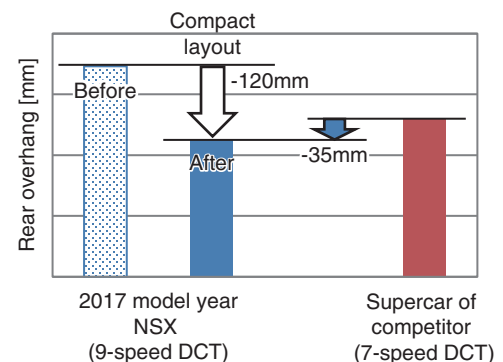


Fig. 7 Rear overhang

by polishing the tooth surfaces and applying precision surface processing. For the transmission case, a high-silicon aluminum material with superior abrasion resistance was adopted. These measures increased the fatigue strength of the transmission case by 20% relative to the 2015 model year Acura RLX.

The application of these techniques and the two types of oil described earlier together achieved the increased torque capacity of 550 Nm, capable of transmitting the high power output of a supercar.

4.3. Thermal Feasibility in High-load Driving

4.3.1. Cooling and lubrication systems

The clutches and gears were equipped with their respective cooling and lubrication systems in order to realize cooling performance matched to the severe use conditions that involve constant driving at high speeds as well as continuously alternating between acceleration and braking. Four heat exchangers were installed (Fig. 9), and the respective systems were optimized to provide cooling and lubrication appropriate to the level of heat generation in each part (Fig. 10).

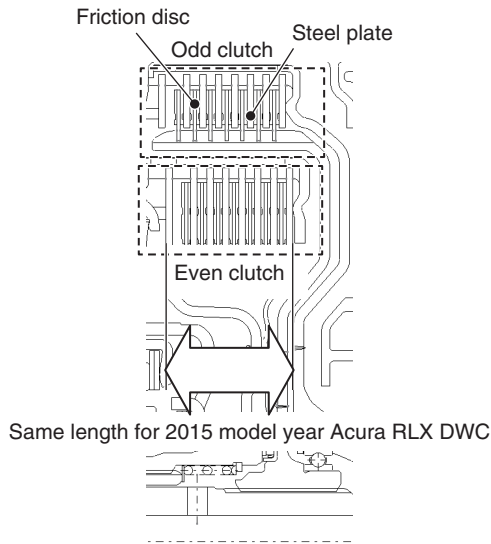


Fig. 8 High capacity DWC

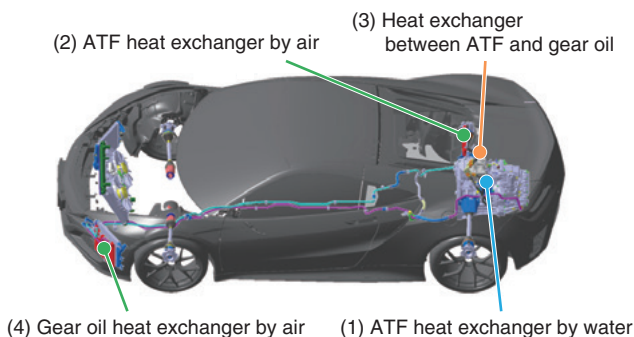


Fig. 9 Heat exchanger layout

On the clutch side, since higher heat is generated in the DWC when absorbing energy at high engine speeds, the system was structured to drive the oil pump in proportion to engine speed. A flow-regulating mechanism was adopted to optimize lubrication to the DWC temperature and operating state. In addition to conventional water-cooled (1) and air-cooled (2) heat exchangers, the system was also equipped with a heat exchanger (3) that exchanges heat between the ATF and gear oil to increase cooling performance. The water-cooled heat exchanger (1) and the heat exchanger (3) were given parallel circuits to reduce pressure loss. On the gear side, since more heat is generated when the vehicle is traveling at higher speeds, the system was configured to drive the oil pump according to engine speed. The air-cooled heat exchanger (4) was positioned at the left front of the vehicle to heighten cooling efficiency, and the system was configured to directly provide the meshing portion of the hypoid gears, where heat generation is especially intense, with oil that has been passed through the air-cooled heat exchanger (4).

4.3.2. Lubricating oil management

Aeration of the lubricating oil occurs due to the rocking that occurs during acceleration, deceleration, and turning, and due to agitation by the DWC and gears. It was necessary to limit this aeration because it reduces the discharge volume of the oil pump, which tends to reduce cooling efficiency. The breather tube, which limits the rise in pressure inside the transmission, also had to be kept from blowing out oil. In order to manage the lubricating oil to address these needs, the respective lubricating structures of the clutch and gear rooms were optimized.

For the clutch room, a baffle cover that completely covers the DWC was adopted in order to limit oil agitation due to DWC rotation and to facilitate the discharge flow of oil supplied from the DWC shaft core (Fig. 11). The shape of the baffle cover and the location of the oil drain were optimized in order to limit the rise of the fluid surface due to wobbling of the oil within a compact space. For the gear room, a forced lubrication structure that blows oil directly

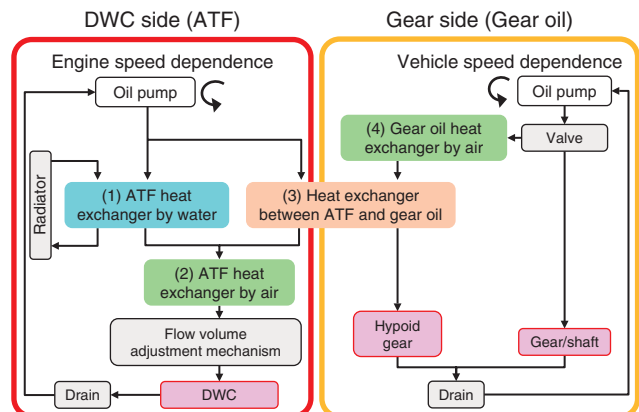


Fig. 10 Lubrication and cooling system

onto the meshing portion of the transmission gears was adopted (Fig. 12) in addition to the provision of oil to the gears through lubrication pipes inside each of the shafts, thereby ensuring a stable supply of lubricant to the gear tooth surfaces.

The use of these techniques achieved a high level of cooling performance and stable lubrication management, realizing thermal feasibility during high-load driving. As one example of the results, Fig. 13 shows the cooling effect during one lap at the Nürburgring Circuit. This confirmed that there is sufficient cooling performance to enable the nine-speed DCT to demonstrate its performance capabilities.

4.4. Heightening Shift Mechanism Response

As the shift mechanism realizes enhancement of acceleration performance as well as smooth driving, it demands high gear change response. In order to shorten the shifting time when changing gears, a high-response gear-shifting system was adopted that combines a high-capacity double-cone synchronizer, a high-rigidity shift fork, and a gear actuator (GA) (Fig. 14). These elements were also optimized.

A double-cone synchronizer was adopted to increase the capacity of second through fifth gears, because the energy absorbed during synchronized gear shifts is larger with

those shifts. With the goal of setting the gear shifting load at a higher level and shortening synchronization time, the material used for all the blocking rings from second to ninth gear was changed from the cold-rolled steel used in the 2015 model year Acura RLX to higher-hardness chromium molybdenum steel to enhance durability.

High-strength cast steel, which allows superior shaping flexibility, was used as the material for the shift fork. The rail and the shift fork portions were cast as a single piece (Fig. 15), and the resulting higher rigidity reduced the displacement of the shift fork tip when under load input from the GA. Optimizing the shape also enhanced the

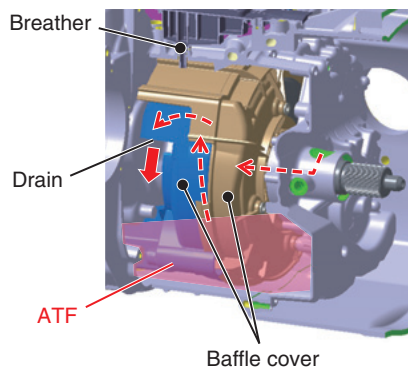


Fig. 11 Oil flow in baffle cover

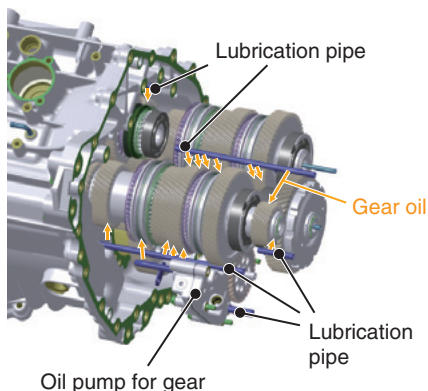


Fig. 12 Direct lubrication of gears

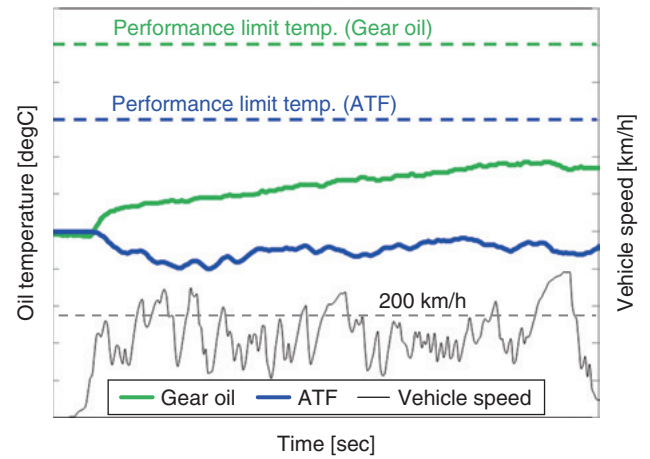


Fig. 13 Oil temperature behavior on circuit drive

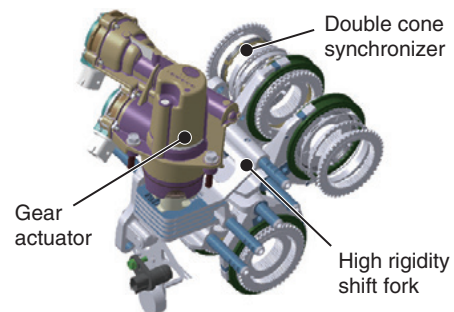


Fig. 14 High response gear shifting system

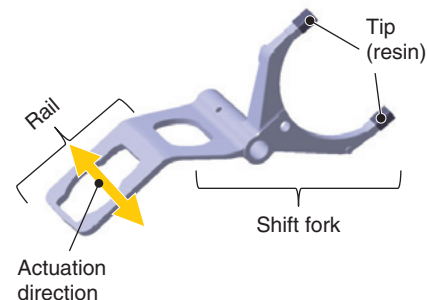


Fig. 15 High rigidity shift fork

balance of the load on the left and right tips of the shift fork during synchronization. Shortening the GA shaft length heightened rigidity, increasing gear shift system rigidity by 40% or more over the 2015 model year Acura RLX, and reducing load power loss at the shift fork tips with respect to the load input from the GA.

These techniques enabled the gear shift load during synchronization to be set even higher than in previous Honda models with a GA. In addition to increasing the synchronizer capacity, synchronization time was shortened by 65% (Fig. 16).

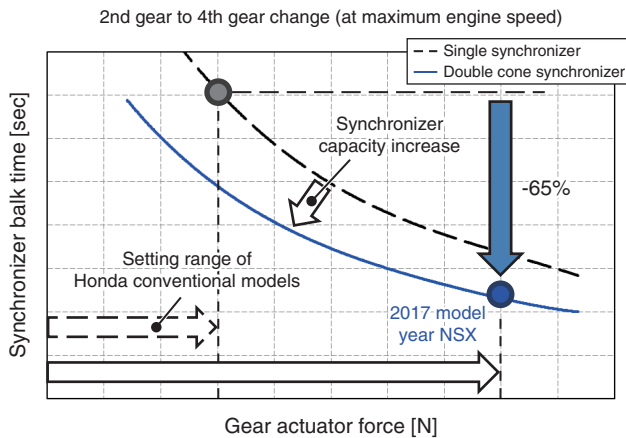


Fig. 16 High response gear shifting

5. Balancing Acceleration Performance and Quietness

5.1. Enhancing Acceleration Performance

The optimization of gear ratios described above realized a close ratio with a common ratio in second through eighth gears that is even lower than in the seven-speed DCT of competitors' supercars (Fig. 17), contributing to enhanced acceleration performance.

The combination of the high system power output of the SPORT HYBRID SH-AWD with the optimized gear ratios and high gear change response of the nine-speed DCT achieved instant launch and linear acceleration performance. Figure 18 shows acceleration at launch control. This reduced gear change time by up to 50% over that of the seven-speed DCT in rival supercars. These measures contribute to acceleration from 0 to 100 km/h in the three-second range, while also enhancing mid-range acceleration performance.

5.2. Quiet Cruising

Setting the nine-shift range at a high ratio reduces engine speed during high-speed cruising. Even when cruising at 100 km/h, engine speed is just 1800 rpm or less, which is on a par with the 2015 model year Acura RLX. Smooth and quiet cruising even at high speeds is ensured.

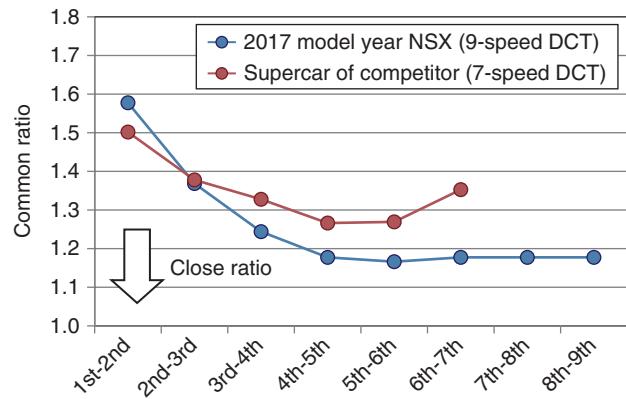


Fig. 17 Sport close ratio

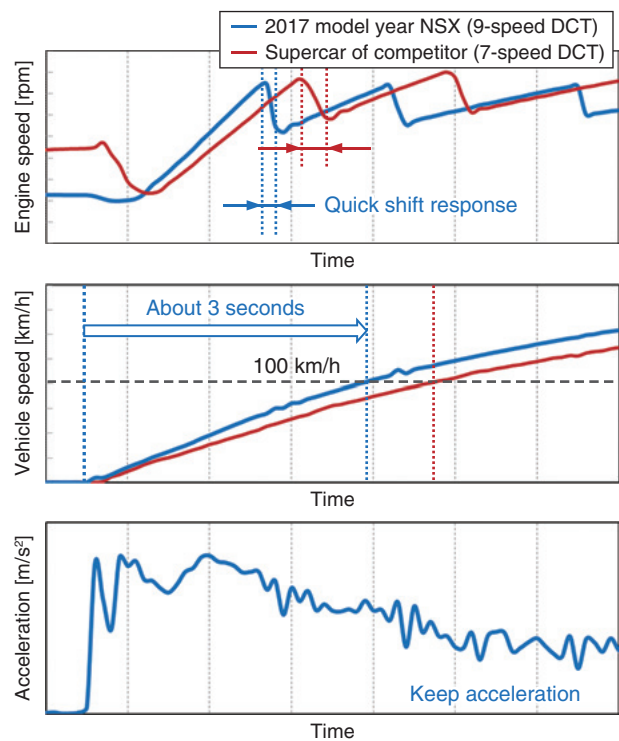


Fig. 18 Acceleration at launch control

6. Conclusion

A longitudinal nine-speed DCT for use in the second-generation NSX was developed and achieved the following results.

- (1) Elimination of the first-gear shift mechanism and sharing of transmission gears shortened the total length by 120 mm, and at the same time a nine-speed configuration was adopted, a rear overhang that is 35 mm shorter than the seven-speed DCT of other manufacturer's supercars was achieved.
- (2) Oil was optimized for the clutch and gear rooms, and

the adoption of a high-capacity DWC, high-strength gear material, and high-strength case increased torque capacity to 550 Nm.

- (3) The respective cooling and lubrication systems for the clutch and gear rooms were optimized by the use of four heat exchangers and a baffle cover that completely encloses the DWC, increasing thermal efficiency during high-load driving on the circuit and under other such conditions.
- (4) Optimized gear ratios for each shifting range, a high-rigidity shift fork, and a double-cone synchronizer for second to fifth gears achieved high gear change response as well as a balance between acceleration performance from 0 to 100 km/h in the three-second range and quietness with engine speeds at 1800 rpm or lower when cruising at 100 km/h.

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