

Hybrid System Heat Management that Contributes to High Performance for New NSX

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ABSTRACT

A hybrid system with three motors was developed to realize the high power train system power and vehicle dynamic performance that are the vehicle concepts of the new NSX. Efforts were made to enhance the cooling performance in order to simultaneously reduce the size and increase the power of each hybrid system component. To achieve high cooling performance compared to that of the conventional hybrid system, the direct drive motor is directly cooled by the engine cooling water, an oil cooler has been added to the Twin Motor Unit, the size of the dedicated radiator for the Power Drive Unit has been increased, and the Intelligent Power Unit uses an air conditioner cooperative battery cooling system.

As a result, thermal feasibility of the hybrid system during high-load driving was achieved. The power train system, which consists of the engine and three motor systems, achieved the high power of 427 kW. In addition, the motor assist of the hybrid system compensated the turbo lag, which is an issue for supercharged engines, enabling rapid response acceleration. Furthermore, the longitudinal and lateral driving force allocation control performed by the hybrid system realized a good balance between cornering performance and high-speed stability.

1. Introduction

It has been advocated for some time that issues such as environment, energy, and food should be addressed from a global perspective. Among the various environmental issues, reduction of both CO₂ emissions and dependence on petroleum are pressing issues, and automobile companies worldwide are making efforts to enhance automobile fuel economy.

A new power train was developed for the new NSX based on these premises. This new power train comprises a high power engine, a transmission, and a hybrid system consisting of three motors, a Power Drive Unit (PDU), and an Intelligent Power Unit (IPU). The high system power and torque of this newly developed power train enable to manifest rapid response acceleration performance. In addition, the SPORT HYBRID SH-AWD, which is a 4WD system consisting of three motors, performs longitudinal and lateral driving force allocation control that enables to manifest high maneuverability. Meanwhile, the hybrid system also realizes high fuel economy performance.

Figures 1 and 2 show the layout of the power train system mounted in the new NSX, and Table 1 lists the specifications. The twin-turbocharged V6 3.5 L engine has a longitudinal midship layout and drives the rear wheels using a direct drive motor directly connected to the crankshaft and

a 9-speed dual clutch transmission (9DCT). A Twin Motor Unit (TMU) that drives the right and left front wheels with separate motors is mounted on the front axle of the vehicle. An IPU with a high voltage battery and high voltage distribution parts is mounted behind the seats, and a PDU



Fig. 1 Overview of layout

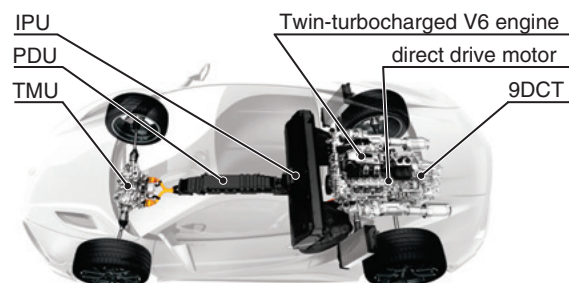


Fig. 2 Power train system components

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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	9DCT
TMU	Twin traction motor and generator unit 27 kW at 4000 rpm x 2 73 Nm at 0-2000 rpm x 2

that supplies and controls the power to the three motors is located below the center console between the seats. This realizes a layout with the main components close to the center of the vehicle.

Efforts have been made to achieve a layout with a low center of gravity while reducing the size and weight and increasing the average power of each component of the new NSX hybrid system. Achieving suitable cooling performance was an issue when increasing the average power. This paper introduces the vehicle systems used to enhance the cooling and power of the hybrid system mounted in the new NSX.

2. Hybrid System

The main components of the hybrid system are the direct drive motor, TMU, PDU, and IPU, as shown in Fig. 3. The direct drive motor is directly connected to the engine and performs power generation, regeneration, and driving. The TMU drives the right and left front wheels and performs regeneration using separate motors. The IPU mainly consists of a high voltage battery, and performs electric power charging and discharging. The PDU is connected between the three motors and the IPU, and performs AC-DC power conversion and control.

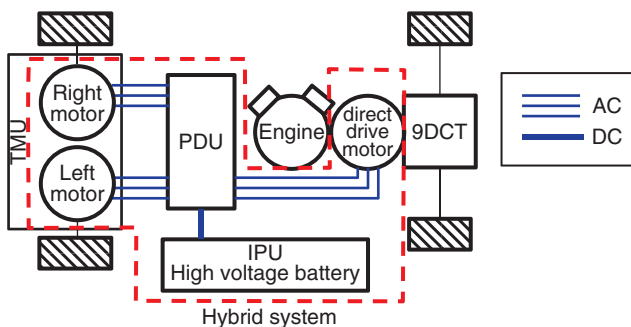


Fig. 3 Hybrid system components

2.1. direct drive motor

The direct drive motor is located between the engine and the transmission, and uses a structure with the rotor directly connected to the crankshaft (Fig. 4). This is to cooperate with the engine and make use of the linear torque characteristics of the motor, which compensates for the turbo lag and achieves rapid response acceleration. Cooling is realized by a water jacket for stator structure that uses the engine cooling water (LLC) to provide cooling performance as shown in Fig. 5. In addition, the insulator was changed from a conventional assembly type to an insert molding type as shown in Fig. 6 to reduce the thermal resistance to the stator core, which is the heat transfer path with the coil, which is a heat-generating location. Figure 7 shows the relationship between the average power and the average vehicle speed. Here, the driving mode, which includes the typical fuel economy modes of city driving mode and highway driving mode, is labeled City mode, and the high-load driving mode on a circuit is labeled Heavy load mode. The dots show the operating points of the developed system, and the cooling performance of the conventional hybrid system was set to include City mode. The developed system was confirmed to both enhance the average power by 40% compared to the conventional hybrid system and to satisfy the cooling performance in Heavy load mode. This enabled sufficient performance even during high-load driving.

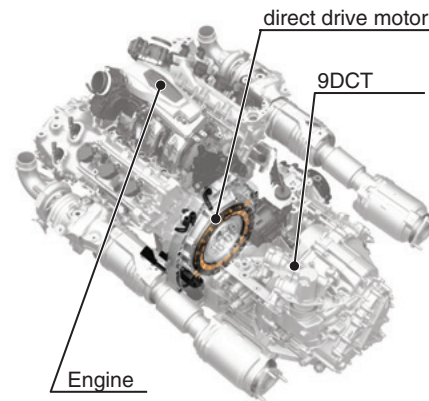


Fig. 4 Location of direct drive motor

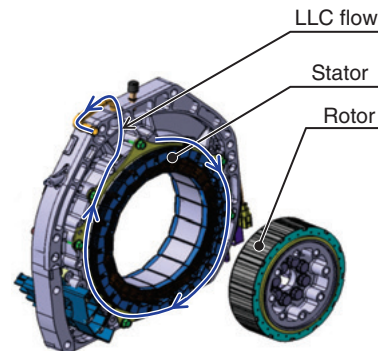


Fig. 5 Structure of direct drive motor

2.2. IPU

The high voltage battery needs high power and high capacity to realize high system power and enhance fuel economy. However, increasing the amount of batteries mounted leads to an increase in the vehicle's weight. Therefore, it is necessary to simultaneously increase the power and reduce the weight in order to enhance the vehicle dynamic performance. In addition to the conventional method of using the air inside the cabin to cool the battery cells, a system that introduces air from the air conditioner to cool the battery cell is also used to maintain an appropriate battery cell temperature and enhance power performance during high-load driving (Fig. 8). Also, a lithium ion battery cell and module were developed that are smaller and lighter in weight compared to the conventional hybrid system (Fig. 9). These technologies enhanced power by up to 15% compared to the conventional hybrid system. The developed system was confirmed to both enhance the average power by 80% compared to the conventional hybrid system and to satisfy the cooling performance during high-load driving in Heavy load mode.

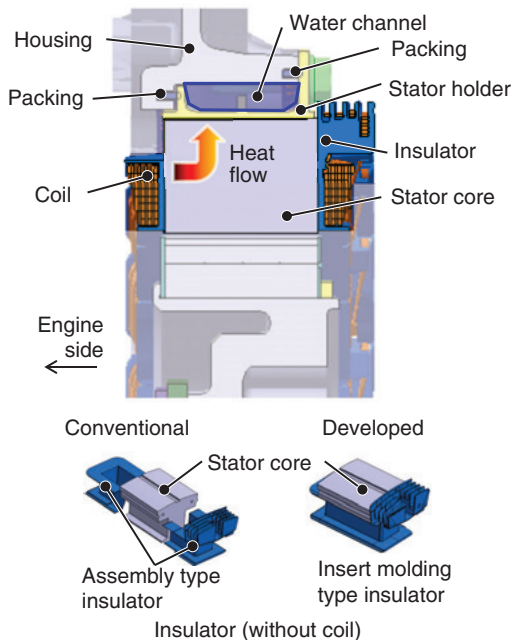


Fig. 6 Section view of direct drive motor

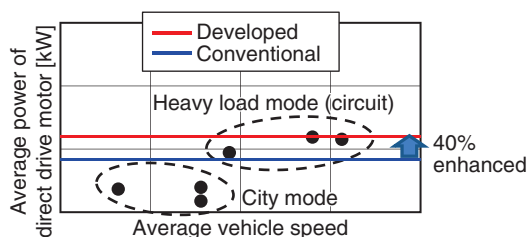


Fig. 7 direct drive motor performance

2.3. TMU

The TMU located in the front of the vehicle incorporates two motors and a gearbox, and can control the torque separately for the right and left front wheels during driving and also during regeneration. The yaw moment can be effectively generated by controlling the right and left wheel torque. This enables to achieve higher cornering performance compared to the mechanical SH-AWD, which uses the yaw moment produced by the difference in driving torque of the right and left wheels (Fig. 10).

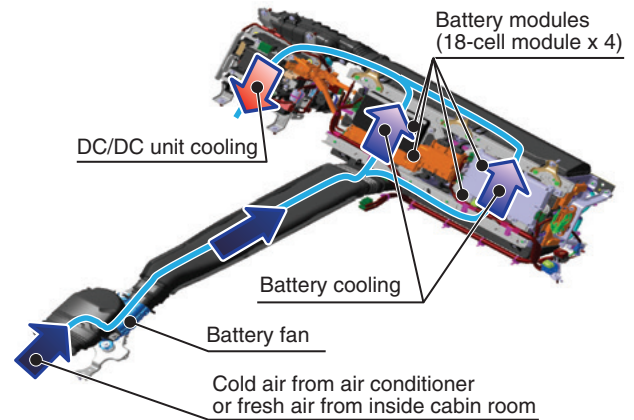


Fig. 8 Overview of IPU cooling system

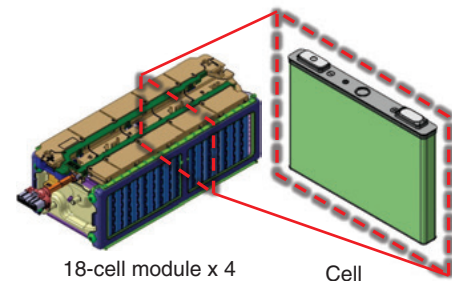


Fig. 9 Structure of battery module and cell

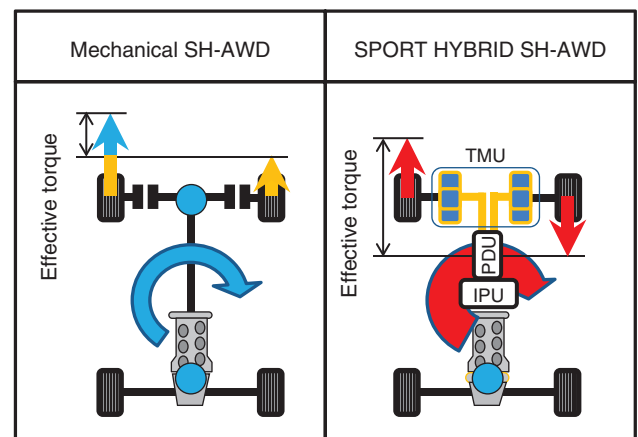


Fig. 10 Difference between SH-AWD systems

The high heat load is supported and cooling performance is provided by installing a TMU cooler (Fig. 11) and having the wind produced by driving flow to the TMU main unit. Figure 12 shows the structure of the TMU left motor, and Fig. 13 shows the average power enhancement results. Cooling uses the wind produced by driving, so the average power characteristics curve depends on the vehicle speed. The developed system was confirmed to both enhance the average power by 95% compared to the conventional hybrid system and satisfy the cooling performance when driving in Heavy load mode.

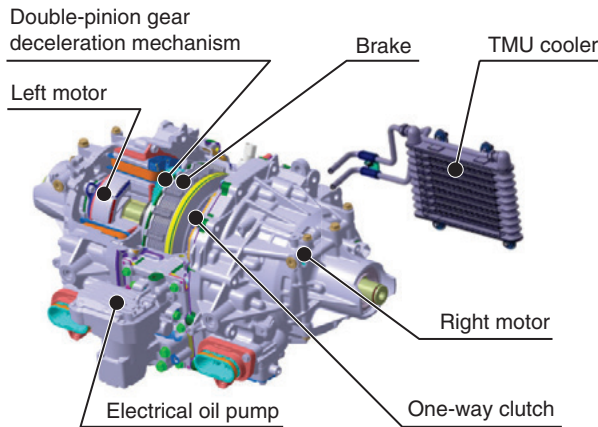


Fig. 11 Overview of TMU

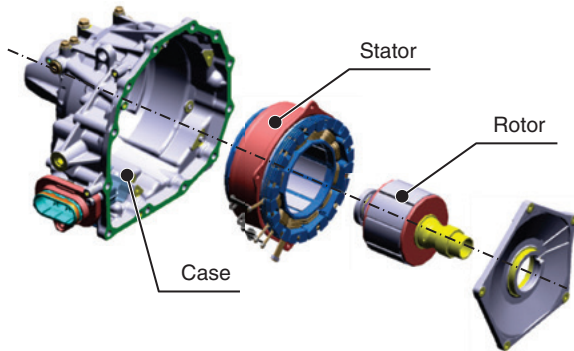


Fig. 12 Structure of TMU left motor

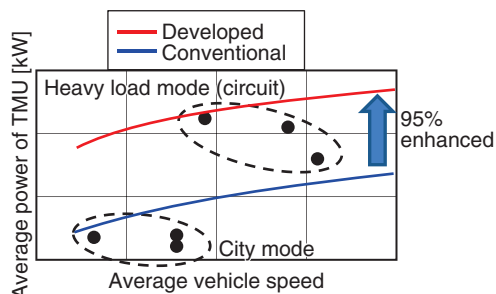


Fig. 13 TMU performance

2.4. PDU

The PDU controls the total three motors of the direct drive motor and the TMU (Fig. 14). Cooling capability was enhanced to support the increased inverter heat generation by increasing the size of the dedicated radiator (Fig. 15). The PDU dedicated radiator layout was modified to optimize the amount of air introduced to the engine radiator and air conditioner condenser in order to increase the utilization rate of the air introduced from the front bumper. Figure 16 shows the simulation results. The developed system was confirmed to both enhance the average power by 80% compared to the conventional hybrid system and satisfy the cooling performance when driving in Heavy load mode.

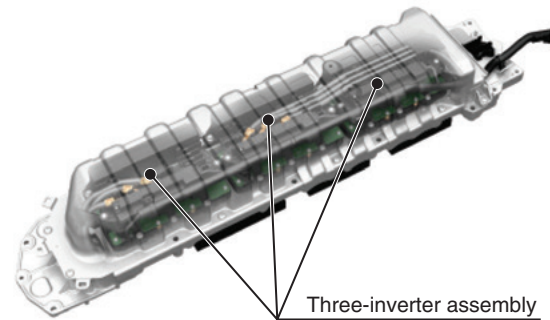


Fig. 14 Overview of PDU

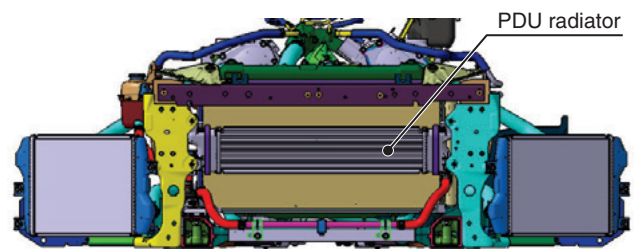


Fig. 15 Section view of PDU radiator

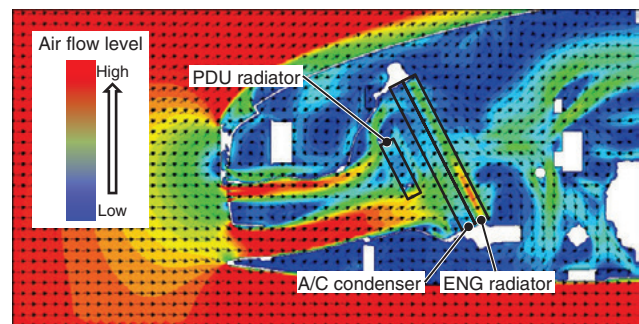


Fig. 16 Air flow for PDU radiator (simulation)

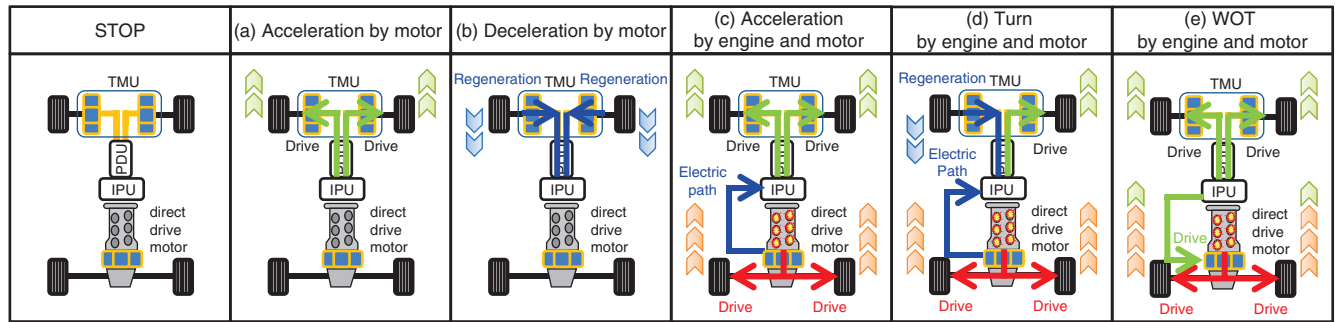


Fig. 17 System operation

3. System Operation

3.1. Normal Operation

Figure 17 shows the typical driving modes of the SPORT HYBRID SH-AWD system. In EV driving mode, the rear wheels are cut off from the engine and only the front wheels are driven by the TMU [Fig. 17(a)].

When decelerating, the TMU generates power by regenerative braking and charges the battery [Fig. 17(b)]. In hybrid driving mode, the engine directly drives the rear wheels, and the direct drive motor performs power generation and charging as appropriate in accordance with the battery charging status [Fig. 17(c)]. When turning, the TMU motor for the wheel on the outside of the turn is driven by the energy regenerated by the TMU motor for the wheel on the inside of the turn, and the yaw moment is generated by the previously mentioned difference in driving torque [Fig. 17(d)].

3.2. Wide Open Throttle (WOT) Operation

When high driving force is called for, the TMU and direct drive motor are driven using the electric power charged in the battery, and the engine and three motors produce rapid response acceleration [Fig. 17(e)]. At vehicle speeds of 200 km/h or more, the TMU is disengaged by a clutch to protect the motor from over speed. Figure 18

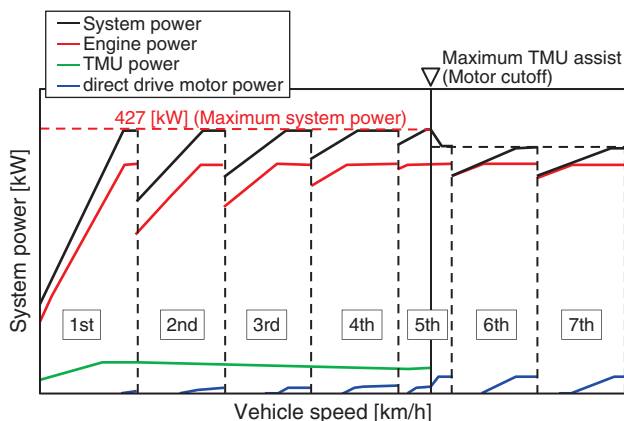


Fig. 18 System performance at WOT

shows the system power. This figure shows the vehicle speed and the power of each power train component during each transmission step at WOT, and shows that a maximum system power of 427 kW is achieved.

4. High-load Driving and Thermal Feasibility

4.1. Realization of Rapid Response Acceleration Performance

Figure 19 shows the hybrid system operating status when starting at WOT. The turbo lag compensation assist and steady assist performed by the TMU and direct drive motor enhanced the power rise during WOT acceleration by 57% (Fig. 20). This helps to enhance both acceleration from 0 km/h to 100 km/h and intermediate acceleration performance.

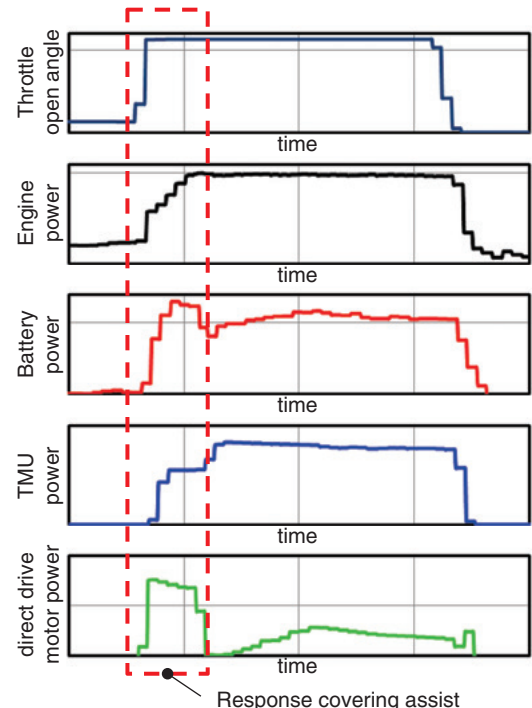


Fig. 19 Power of power train system

4.2. Realization of High Cornering Performance

The lateral driving force allocation control performed by the hybrid system realizes high cornering performance. Figure 21 shows the simulation results of US/OS characteristics relative to lateral acceleration during a 30R(R0) turn. Longitudinal and lateral driving force allocation control help to suppress understeer and increase the lateral acceleration limit, which as a result also enhances cornering performance.

4.3. Realization of Thermal Feasibility during High-load Driving

Enhancement of the cooling performance of each hybrid system component enabled driving without reducing the hybrid system power even during high-load driving. Figure 22 shows the effect of the hybrid system when driving in Heavy load mode as an example of the results. The enhanced rapid response acceleration performance and cornering performance described above were confirmed in simulations to reduce the lap time by 1.8%.

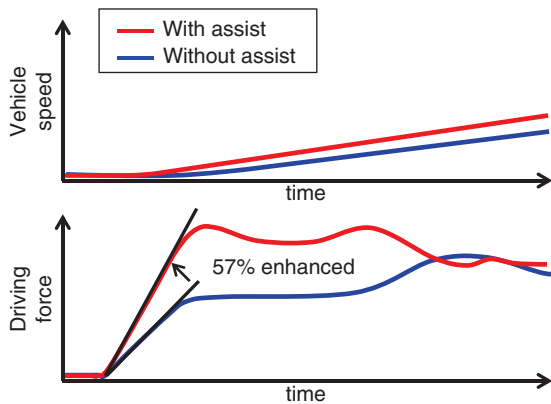


Fig. 20 Effect of motor assist on driving force at WOT

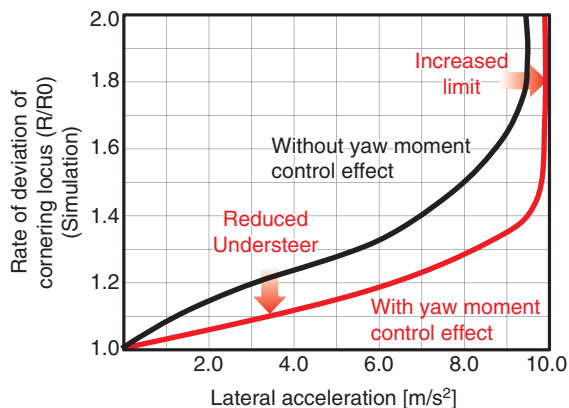


Fig. 21 Effect of hybrid system on US/OS Characteristics

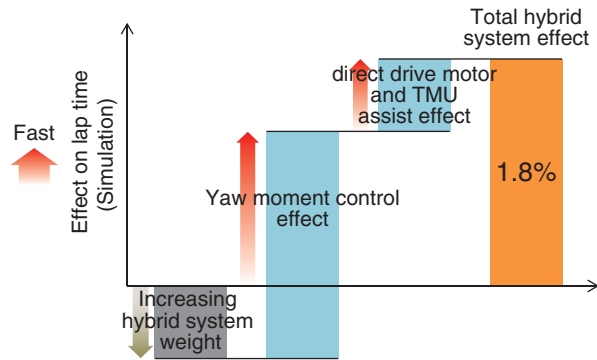


Fig. 22 Effect on lap time

5. Conclusion

A high-power, rapid-response power train was developed that achieves the following items in the hybrid system for the new NSX.

- (1) Thermal feasibility of the hybrid system when driving in Heavy load mode was achieved.
- (2) The combination of three motors and the engine achieved a maximum system power of 427 kW.
- (3) The assist of the direct drive motor compensated for the turbo lag of the supercharged engine and enhanced the power rise by 57% during WOT acceleration.
- (4) Lateral driving force allocation by the hybrid system achieved a good balance between cornering performance and high-speed stability.

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