1. ARIYA: new generation of flagship EV

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1. Introduction

Nissan Motor Co., Ltd. commenced mass production of EVs in 2010, globally ahead of all other companies. Based on over 10 years of market experience, Nissan has developed a new generation of EV: the ARIYA (Fig. 1). ARIYA embodies the new Nissan Automotive and Nissan Intelligent Mobility with the aim of being "a new generation of flagship EV that feels like the car of the future." With ARIYA, Nissan's goal is "to provide customers a blissful experience that only an EV can deliver."

Fig.1 ARIYA

2. Toward a new generation of flagship EV

ARIYA was developed to satisfy customers through integration of the latest technologies while fully utilizing the features of an EV. To simultaneously realize many values in ARIYA, new technological elements were developed and their integration was achieved at a high level using innovative system technology.

To start with, an innovative package was introduced through a new EV-specific platform to realize a spacious and noiseless interior, sufficient driving range, and stylish design. The infotainment technologies were revolutionized to offer abundant services and amazing usability, along with integrated vehicle control technologies to achieve high-power and stable driving performance. In addition, ProPILOT 2.0 was enhanced and a new remote-auto-park function was introduced.

The advancement of each of these technologies is explained in detail in the next chapter and brief explanations are provided below.

3. Innovative packaging with EV-specific platform

In most conventional EVs, the platform designs are based on internal combustion engine (ICE) vehicles. As such, they do not fully benefit from the features of small powertrains that are unique to EVs. To overcome this problem, a new EV-specific package was developed through a high-level combination of an EV-specific powertrain and mounting technologies to increase the interior space, reduce overhang at the front, widen the wheel base, reduce the minimum turning radius, achieve more stable control, improve driving comfort, extend the driving range, and achieve a quieter interior.

The means of achieving these individual aims are often conflicting. Hence, technological development of complex systems was achieved by integrating the following high-level elements.

3.1 Basic structure, interior space, and styling

To increase the height of the interior space, a holistic review of the underfloor structure was performed for battery storage. It was determined that the cross members be embedded in the structure such that the necessary battery capacity (explained later) is secured while providing temperature control system without

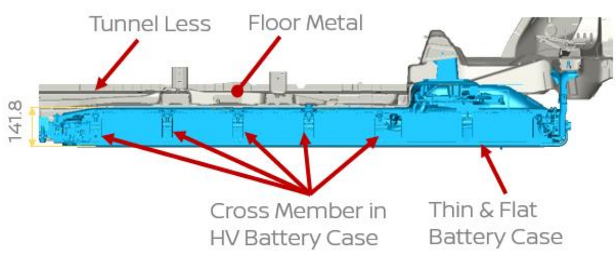

Fig.2 Subfloor structure

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compromising the strength and rigidity of the vehicle body (Fig. 2). The new structure enabled development of a body-integrated battery package with high rigidity, which allowed the mounting of an ultrathin large-capacity battery. Furthermore, the torsional rigidity of the entire vehicle body was improved by connecting the high-rigidity package to the front and rear parts of the body. Because the center of gravity was lowered by the subfloor position of the battery with the weight distribution being 50:50 between the front and rear of the vehicle, handling and ride comfort were optimized simultaneously.

Based on the reduced size of the power train, an air-conditioning system (HVAC) was placed in the motor room instead of the inside of the cabin. Because HVACs have large internal spaces in their structures, when placed in a motor room, they act as shock absorbers in the event of a crash. This enabled increasing the interior space while maintaining crash performance standards (Fig. 3). The additional interior space was used to increase the tire turning angle and thereby achieve a minimum turning radius equivalent to that of a B-segment car, despite the large cabin space of that of a D-segment car.

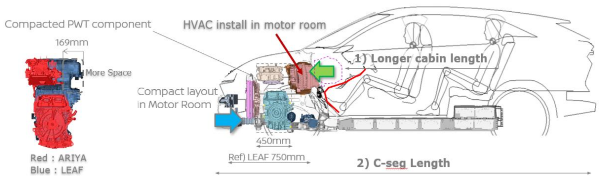

Fig.3 Layout of powertrain and HVAC

The interior cabin length was maximized by introducing an electric center console and minimizing the installment panel. The front and rear leg rooms were expanded owing to the flattened floor. This platform enabled increasing the effective length of the cabin interior to that of the D-segment level, whereas the overall body length was in the C-segment. Because of this platform, a short overhang and long wheelbase layout was possible for realization of a radical yet attractive design. The revolutionary interior and appearance are the major attractions of ARIYA that were enabled by the new EV-specific platform.

3.2 Long driving range

To motivate more customers to purchase ARIYA and to increase EV usage, the basic performance of the EV including driving range, battery charge performance, power consumption for heating/cooling, and usability in real situations must be more advanced.

In particular, advancements were made to reduce the general driving resistance and air resistance, which is the major cause of driving resistance, in addition to enhancing quick charging performance that is critical to highway driving in summer, heating performance, and battery low-temperature tolerance in winter.

3.2.1 Battery capacity

The driving ranges were set to B6- and B9-grade cars to allow a breadth of selection according to customer usage. The B6 grade is targeted for daily use, including commuting and shopping, whereas the B9 grade is targeted for weekend leisure activities, such as golf and camping. The battery capacities required for the expected driving ranges were estimated from data obtained during technological development, as explained below, and determined to be 66 and 91 kWh for the B6 and B9 grades, respectively.

3.2.2 Reduced air resistance

To reduce the air-resistance coefficient (Cd value), the roof shape was streamlined and an air curtain (a type of duct) was placed over the front mask to control airflow. In addition, a flat and full undercover was placed underfloor to control airflow (Fig. 4). Thus, the Cd value was reduced to 0.3 or less, which is outstanding aerodynamic performance for an SUV.

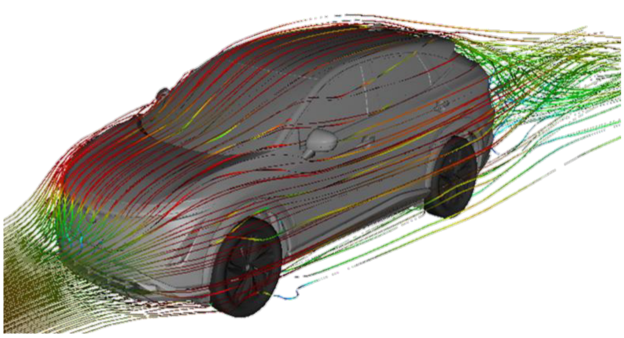

Fig.4 Air flow

3.2.3 Quick charging performance

Considering the quick charging conditions at the parking bays of highways, quick charging performance of 30 min was achieved for recovery from 10 to 80%. Charging speed is strongly dependent on the internal temperature of the battery. Therefore, a liquid battery temperature-control system was developed to achieve stable charging performance using thin batteries without the effects of air temperature and driving mode (Fig. 5). Based on expected future requirements, the allowable input power of the on-board charging device was set to 130 kW during development.

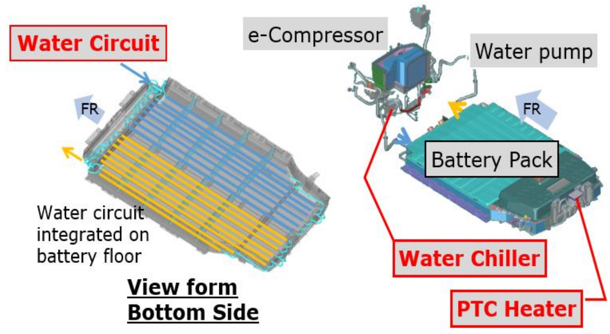

Fig.5 Temperature control system

3.2.4 Heating performance

Next to driving the most energy consumed by an EV is for heating in winter, when the air temperature difference between the inside and outside is larger than that in summer. Hence, efforts were made to increase driving range in winter by adopting highly efficient heat pump system to reduce energy consumption.

3.3 Quietness

EVs do not generate engine noise. The main sources of noise in an EV are the road noise between the road and tires, wind noise during high-speed driving, and motor noise. Road noise was reduced by using special tires containing noise-absorption materials, adapting double antivibration subframes, and thoroughly strengthening the rigidities of the body frame members. Wind noise was reduced by eliminating uneven surfaces and gaps to avoid generating turbulence. External noise was reduced by adapting sound-insulation glasses. At low speeds, when the load noise is small, a slight rotational motion or radial vibration of motor may be noticeable. A newly-developed motor with excellent vibrational properties at low speeds enables realization of a quiet interior space that is appropriate for a flagship EV.(*)

4. Innovative infotainment technologies

When using conventional on-board operation display devices and connected systems, the operations and display become complicated with increasing numbers of services and functions, and the menu selections become wider and deeper. The addition of new functions in complicated systems is time consuming, which makes it difficult to provide timely services. To overcome this challenge and minimize driver distraction, a new input system with high operability was introduced in ARIYA to allow the integrated use of two large displays comprising an IVI panel and a meter panel while reducing the operational hierarchy. Additionally, a new interface was developed for easy operation of the display device, where the two display panels could be used together via swipe actions (Fig. 6). Furthermore, a human-machine interface ("HMI") with high usability was realized through a voice recognition system that allows control of NAVI or air conditioning settings.

Fig.6 Display swipe

To ensure flexibility and rapid development of the connected service system underpinning these functions, the service server was separated from the system server and key function-integrating software was developed in-house. Simultaneously, firmware-over-the-air (FOTA) technology was introduced to update the on-board firmware wirelessly to enable continued offering of abundant services in a user-friendly and timely supply.

5. e-4ORCE: Innovation for integrated vehicle control

The highly desired 4WD was installed in ARIYA to offer additional value beyond ordinary 4WD functionality by integrating vehicle and powertrain controls. High-level integration of the following two advanced technologies was achieved in ARIYA. Namely, 4WD control technology used in GTR and ATTESA that controls torque distribution between the front and rear axles in accordance with driving conditions, and the motor-torque control technology used in LEAF for fast and high-precision control of the motor torque in milliseconds. This combination enables stable vehicle behavior under a variety of road conditions (snow, ice, rain, and dry), thereby providing a confident driving experience to customers.

The two motors placed at the front and back seamlessly produce flexible torque distribution between the front and rear by integrating driving information, such as acceleration, yaw rate, tire slip recognition, and conventional driving-force control. Vehicle behaviors can be controlled with high precision by integrating brake control of the four wheels to optimize the load weight on each wheel. For example, winding roads can be navigated smoothly by independent control of the front and rear torque. At the entrance of a curve, more torque is allocated to the rear, similar to an Front engine and Rear drive vehicle, to improve the turn-in ability. In the middle of the curve, the torque is distributed in a 50:50 ratio between the front and rear to maintain smooth movement. At the curve exit, more torque is allocated to the front, similar to an Front engine and Front drive vehicle (Fig. 7). In addition, the front and rear distributions of the regenerative brakes were optimized by the motors to provide a smooth and comfortable ride. Hence, e-4ORCE is an outstanding system that offers driver secure feel, comfort, and pleasure, in addition to excellent acceleration performance.

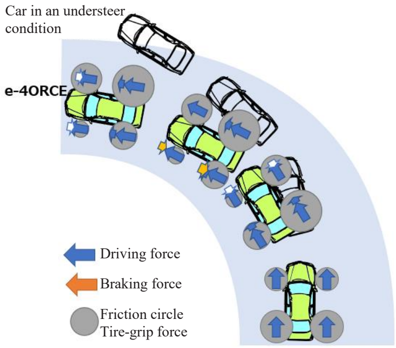

Fig.7 Operation of e-4ORCE

6. ProPILOT 2.0: Remote Auto Park

ProPILOT 2.0, which is installed in Skyline, has garnered much praise as a novel human–vehicle relationship that offers convenience, secure feel and comfort, along with being a “buddy” or ”partner.” Its functions were further enhanced and the vehicle location accuracy was increased using signals from the quasi-zenith satellite system.

In the past, there were system limitations in determining the current lane of the car on multilane highways. When using quasi-zenith satellite signals, the driving lanes can be precisely located by detecting vehicle positions within an accuracy of 50 cm. This significantly increases navigation accuracy, thus enabling smooth and accurate guidance for selecting and changing driving lanes at highway junctions. To further assist customer driving, a new technology called Remote Auto Park (RAP) was made available. Using this function, ARIYA can be remotely navigated forward and backward using a designated remote-control key (Fig. 8). Hence, it is possible to park ARIYA in a narrow space by first moving it forward using the RAP function for securing enough space to open the doors.

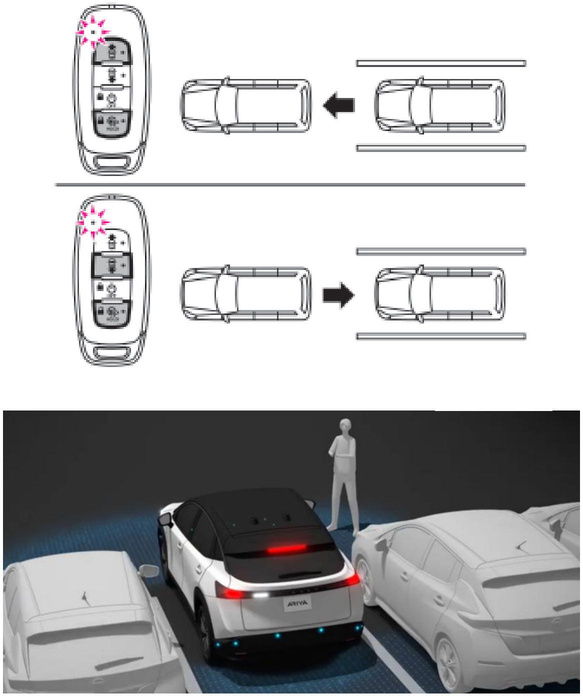

Fig.8 Remote Auto Park

7. Summary

Although ARIYA is a C-segment SUV, the newly developed innovative system technologies offer enough interior space as a roomy D-segment vehicle and noiseless comfort as an E-segment vehicle, which is appropriate for a flagship EV. The maximum driving range of ARIYA was 610 km in the WLTC mode. ARIYA offers user-friendly infotainment and abundant services through an integrated interface display and a connected service system that allows flexible information manipulation. Owing to e-4ORCE, ARIYA has outstanding drivability for all occasions, from normal driving to snowy conditions. The following chapters discuss several technological challenges that were not explained in this chapter.

ARIYA is equipped with the latest technologies of Nissan and is a icon of Nissan Intelligent Mobility. ARIYA is the next-generation flagship EV that represents the cars of the future. Nissan wishes that our passion will resonate with all users of ARIYA

*: Where required by law, the EV may be additionally equipped with an alert system that generates the necessary sounds and signals so that pedestrians can detect and recognize the vehicle.

Authors

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2. Development of EV-specific platform CMF-EV for high packaging efficiency

Masahiro Oonishi*

1. Introduction

The Nissan LEAF, which is a full-scale mass-produced EV released in 2010, has been accepted by customers for its high reliability, safety features, and comfortable driving experience that is typically offered by EVs. LEAF has pioneered the widespread use of EVs.

The high reliability and safety features developed for LEAF have been inherited and further advanced in the newly developed EV-specific platform (CMF-EV) for ARIYA. The target issues of vehicle packaging, driving range, and driving performance have been set to “exceed the expectations of our customers.”

This chapter describes the key points for realizing a large interior space, mounting a large-capacity battery, and achieving high driving performance.

2. Current situation of EV packaging

Our customers’ expectations for EV packaging can largely be classified under the following two features:

[1] Interior space that is large in the front-rear direction owing to the compact powertrain

[2] Completely flat interior floor from eliminating the exhaust system and propeller shaft

However, developing an EV that meets both expectations is more difficult than the customers can imagine.

A comparison of the overall vehicle length and effective interior length (distance from the accelerator pedal to hip point of a passenger in the rear seat, which is a representative index of the interior roominess in the front-rear direction) in different commercially available SUVs is shown in Fig. 1. It is seen that the benchmark lines of SUV EVs are inferior in terms of packaging efficiency in the front-rear direction compared to SUV ICE vehicles. If an EV is mounted with a high-capacity and high-voltage battery to secure sufficient driving range, the vehicle mass may increase significantly. Therefore, compared to ICE vehicles, the required crush stroke is higher for damage control during low-speed collisions and for securing passenger and high-voltage safeties during high-speed collisions, thereby offsetting the greater space allowed by the compact drive system.

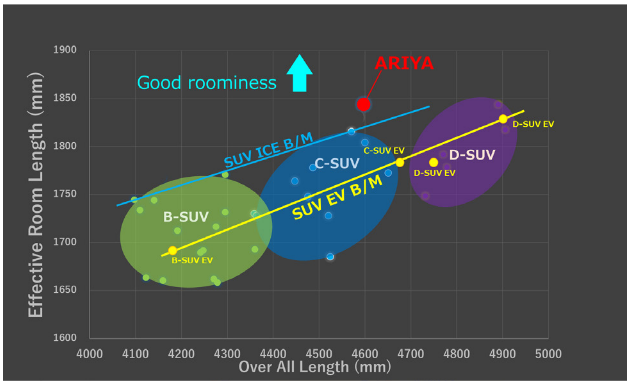

Fig.1 Comparison of overall vehicle and effective interior lengths between SUVs

In LEAF, it was not possible to meet the customers’ demand for a completely flat floor because the brake pipe, cooling water pipe, and high-voltage wiring harness were placed within the center tunnel.

3. Evolution of the novel EV-specific platform CMF-EV

The CMF-EV adopted in ARIYA has a breakthrough feature, wherein the air-conditioning unit is mounted in the moter room and has a higher packaging density owing to functional integration. Thus, both a completely flat floor and space efficiency (in the front-rear direction) exceeding those of the top benchmarked SUV ICE vehicles were realized (Figs. 1 and 2).

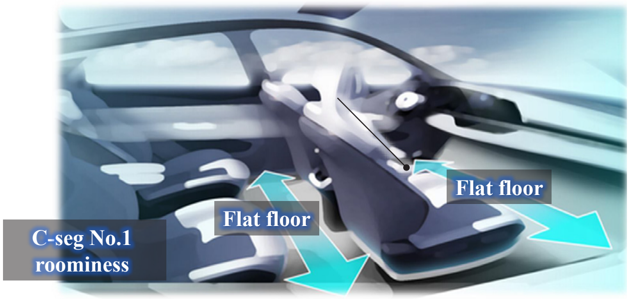

Fig.2 Realization of high space efficiency and completely flat floor

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The aforementioned functional integration were included under the premise of stiffness of the vehicle body frame structure from the beginning of the planning stage. Consequently, precise maneuvering performance, comfortable riding experience, and mass reduction, which are the expectations of the customers from an EV, have been realized simultaneously.

4. Layout of the air-conditioning unit in the motor room

The realization methods are described in more detail from this section forward. The position of the air-conditioning unit, which was previously situated in the instrument panel of the cabin, was relocated to the motor room to realize a thin instrument panel. This change was introduced during the world premiere of ARIYA and has been well known since then.

However, changing only the mounting position of the unit hardly contributes to improving the ratio of effective interior to overall vehicle length (i.e., packaging efficiency in the front-rear direction). This is attributed to the fact that as the interior space is elongated, the motor room housing the air-conditioning unit must also be extended.

The breakthrough realized in ARIYA is that in addition to the positional change of the air-conditioning unit, measures are provided to the structure so that the air-conditioning unit absorbs energy on impact. As shown in Fig. 3, the air-conditioning unit was previously mounted at the rear side of the dash panel (i.e., in a non-crushable zone). If the air-conditioning unit is relocated to the motor room and crush stroke is maintained, extending the motor room is necessary to accommodate the front-rear length of the air-conditioning unit (Fig. 4).

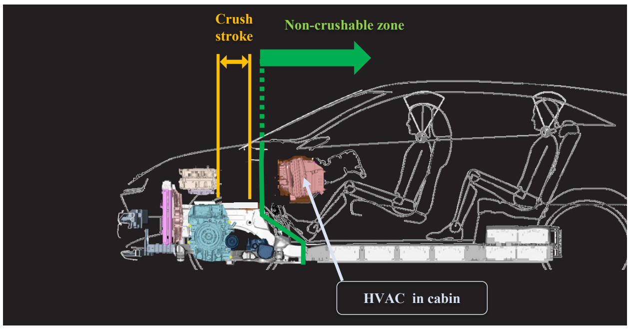

Fig.3 Relationship between previous air-conditioning unit placement and crush space

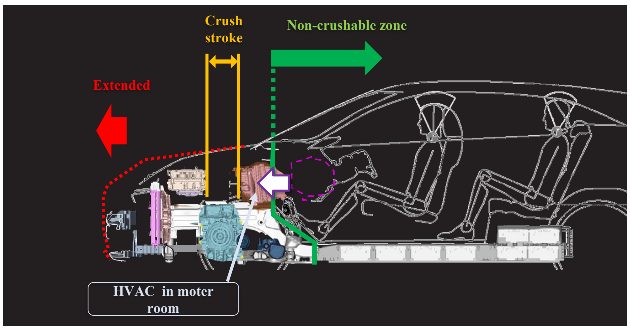

Fig.4 Relocation of the air-conditioning unit and extension of the motor room

For the CMF-EV adopted in ARIYA, the air-conditioning unit was built to be crushed so that the necessary crush stroke could be secured, and the front-rear length of the motor room was shortened (Fig. 5). The air-conditioning unit primarily comprises a heat exchanger, refrigerant pipes, blower fan, and duct. Because the components other than the heat exchanger and blower fan motor are made of resin or have hollow shapes, there is some allowance for crushing. Therefore, the Force-Stroke characteristic for collision was assigned to the air-conditioning unit when developing ARIYA by assuming that the air-conditioning unit body will be crushed to approximately 200 mm during a full-frontal collision. Of the air-conditioning unit components, the air PTC heater, which requires high voltage, was placed within the cabin (non-crushable zone) in consideration of high-voltage safety during collision.

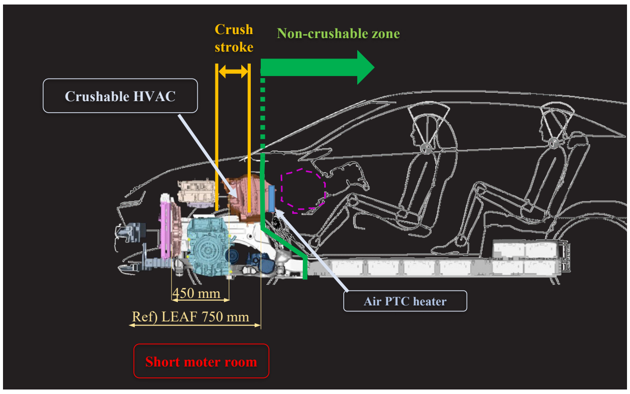

Fig.5 Crush space assuming crushing of the air-conditioning unit

A method for predictably crushing the air-conditioning unit during a frontal collision is described herein. Fig. 6 shows the layout diagram of the CMF-EV motor room. The air conditioning unit is mounted on the rearmost side of the motor room. The upper powertrain unit, which is an assembly of the battery charger, junction box, and DC-DC converter, is mounted on the front side.

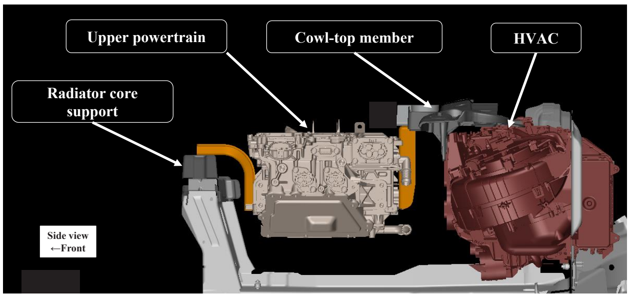

Fig.6 Layout of the motor room

During a frontal collision, the upper powertrain unit starts retracting from the intermediate stage of the collision event, and the maximum amount of retraction occurs at approximately the same time as when the air-conditioning unit is completely crushed. To achieve predictable crushing of the air-conditioning unit under various types of collisions, it is desirable for the upper powertrain unit to retract while maintaining the initial mounting angle (seen from the side view of the upper powertrain unit). The following measures were implemented to help control motion.

[1] Connect the front side of the upper powertrain unit to the vehicle body frame structure to stabilize the retraction motion during collision

[2] Detach the rear fixing bracket when the upper powertrain unit retracts to ensure that the retraction is not obstructed

As a structure that realizes the first measure above, the radiator core support member connected to the front side member was affixed to the front side of the upper powertrain unit. In addition, the allowable bracket deformation amount and deformation modes were specified.

To realize the second measure, a slit was introduced at the bolt fastening portion of the rear fixing point to enable the bracket to slide and come away only upon retraction input due to collision (Fig. 7). To ensure both secure fixation during normal driving and sliding during collision, the bracket stiffness, surface treatment, dimensional accuracy, and fastening torque are strictly controlled. By implementing the aforementioned measures, the space of the air-conditioning unit was utilized as a crushable zone. Thus, sufficient crush stroke was secured while realizing “large interior space in the front-rear direction owing to the compact powertrain”, as expected by the customers.

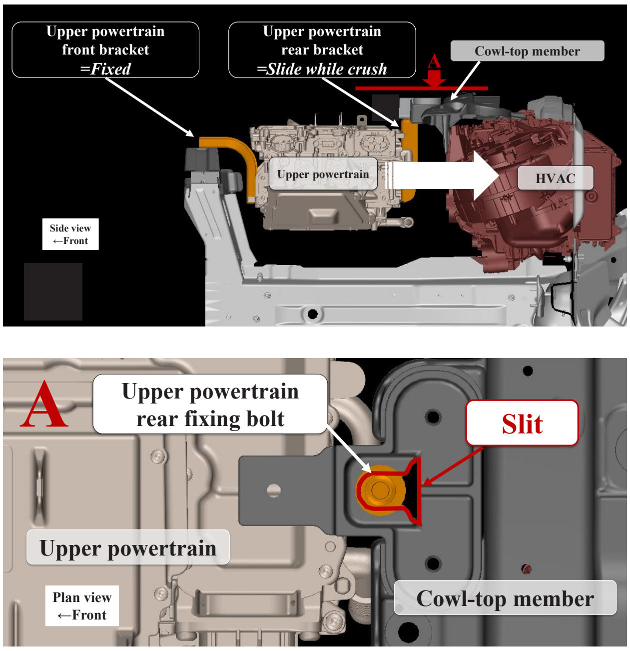

Fig.7 Unit behavior during frontal collision and slit structure at the fastening point

5. Space saving through functional integration and vehicle body stiffness

To mount a high-capacity battery, increase the cabin space, and realize a flat floor and high driving performance, functions were integrated to increase packaging density. Two major case examples are presented here.

The first is a cowl-top member that integrates the upper powertrain unit fixtures, air-conditioning unit fixtures, and strut tower bar. Previously, the upper powertrain unit was mounted on the member connecting the side members, and the air-conditioning unit was mounted on the steering member in the cabin, as shown in Fig. 8. An additional strut tower bar was added separately in vehicles requiring greater maneuverability.

In the CMF-EV, the functions of fixing the upper powertrain and air-conditioning units as well as the strut tower bar are integrated into a new cowl-top member made of aluminum. Thus, the space and mass necessary for the fixtures were reduced while increasing the structural stiffness around the strut tower (Fig. 8).

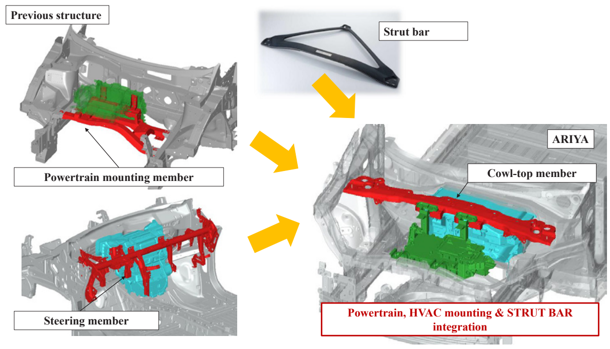

Fig.8 Functional integration using the cowl-top member

The second is a multifunctional frame for the high-voltage battery. Previously, the main functions of the high-voltage battery frame were to support the battery body and protect it from inputs, such as collisions and interference with road surfaces. While more details are described later in the chapter on development of the high-voltage battery, the CMF-EV uses aluminum extruded material for the battery frame. Using this manufacturing method, a water jacket for battery temperature control and a cooling water pipe connected to the rear motor inverter (for 4WD) were integrated in the cross section of the frame (Fig. 9).

Additionally, the high-voltage wiring harness connected to the rear motor inverter was changed to a bus bar and rerouted within the high-voltage battery pack, and the brake pipe was rerouted in the gap between the battery pack and side sill. Thus, removal of the tunnel was realized; additionally, a “completely flat interior floor from eliminating the exhaust system and propeller shaft” was realized in accordance with customer expectations from an EV.

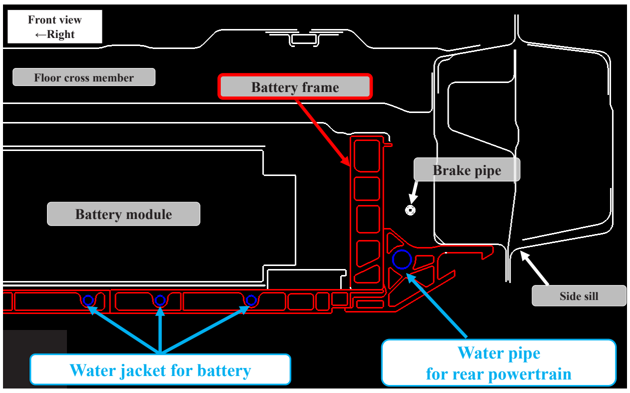

Fig.9 Integration of water pipe with high-voltage battery frame

The high-voltage battery frame is one of the main structural components, and its connections with the vehicle body frame structure and suspension members were strengthened. As shown in Fig. 10, the hot-stamped materials of the vehicle body floor (cross members of the floor and high-voltage battery) were rearranged in an alternating configuration in the front-rear direction. The cross members of the high-voltage battery are connected to the vehicle body side sill via the side frame and side rail. This construction helps protect the high-voltage battery during side collisions and increases the stiffness of the vehicle body frame structure.

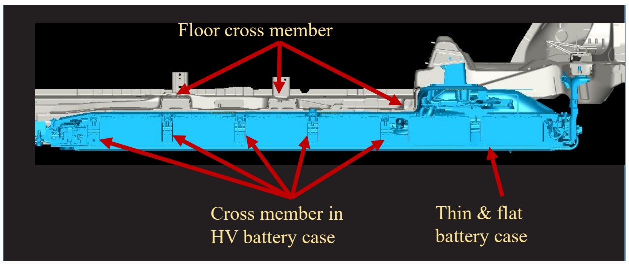

Fig.10 Positional relationship between vehicle body floor and high-voltage battery frame

The high-voltage battery frame was connected with both the rear fastening point of the front suspension member and the front fastening point of the rear suspension member via suspension pin stays. Thus, the lateral stiffness of the suspension member fastening point was increased and steering responsiveness was improved (Fig. 11). By utilizing the high-voltage battery frame as the main structural component, the cross-sectional area of the vehicle body cross member was reduced and a flat floor was realized; additionally, a vehicle body stiffness approximately 1.9 times higher than previous C-segment SUVs was secured. Thus, a low flat floor and dynamic performance, such as ride comfort performance, were realized simultaneously.

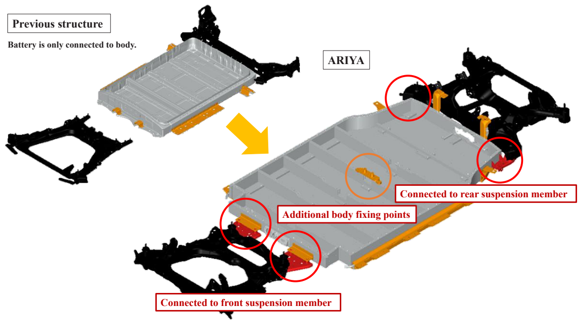

Fig.11 Strengthening connection between suspension and high-voltage battery

6. Summary

The CMF-EV adopted in ARIYA was developed for potential use in Renault vehicles. Renault's core development members, who are permanently stationed in the office at the Nissan Technical Center (Atsugi City, Kanagawa Prefecture), exchanged ideas with us on various technical issues and attended thorough discussions to formulate technical solutions and select the best options during the developmental activities.

During the development stage, the environment surrounding EVs changed drastically on a daily basis. However, there were no changes in our initial target of inheriting and furthering the high reliability and safety developed for LEAF as well as the target “exceed the expectations of our customers further” for vehicle packaging, driving range, and driving performance.

Although not mentioned in this chapter, we succeeded in evolving the ARYIA’S performance from LEAF in terms of the driving range, charging performance, and resistance to capacity decline of the high-voltage battery under actual driving scenarios, such as when using the air conditioner or under varying temperature conditions. In addition, we improved the driving experience unique to EVs (through e-4ORCE) as well as convenience using connectivity. Based on the developmental activities, we are confident that ARIYA will be a popular choice for customers not only as an EV but also as an automobile. We are looking forward to contributing to a more sustainable mobility by attracting and encouraging a wide variety of customers who have previously hesitated in purchasing EVs.

Authors

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3. Integrated interface display

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In recent years, smartphones have become daily tools for handling information and the volume of onboard infotainment information has increased steadily with changes in usage mode and user experience (UX). Further, with the advancements in driver-assistance technologies, the types of information, including sensing information from the surroundings and system conditions, have been changing. To reduce the burden of driving operations under such changes in the information environment, a new human–machine interface (HMI) was developed for easy access to the required information.

This chapter describes new technologies installed in ARIYA, namely an “integrated display package for combined visibility and operability” to support easy access to information and a “structured graphical user interface (GUI) for easy and intuitive handling of a large variety of content.”

1. Interface for combined visibility and operability

Various approaches have been considered for the integration of the infotainment and meter displays into a single information display area. During the development of ARIYA, the dead angle of the steering wheel was considered for determining the display location and its features (Fig. 1).

Fig.1 Integrated interface display

Meter information required for driving is displayed in front of the driver at a convenient distance for clear visibility, whereas the infotainment information is displayed at a distance conducive to high operability and within easy reach of the driver (Fig. 2). These two information panels are placed adjacent because the human visual field is approximately 1.5 times wider horizontally than vertically, and eye movements are easier in the horizontal direction (Fig. 3).

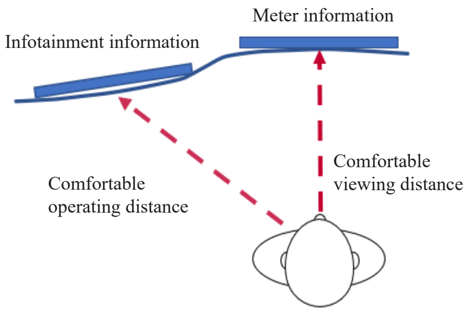

Fig.2 Layout of the information display

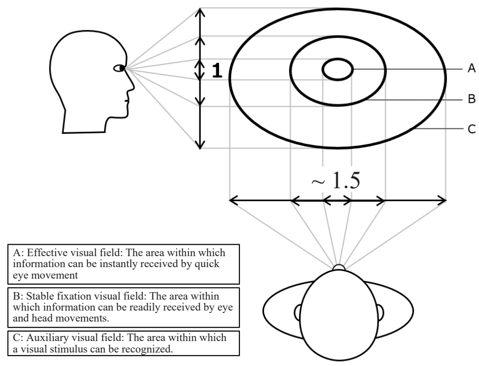

Fig.3 Characteristics of the human visual field

The panels were placed along an S-shaped curved surface, which was in harmony with the futuristic design of the cockpit interior (Fig. 4). The S-shaped display was manufactured as follows. First, a cover glass with multiple curvatures was fabricated via 3D hot forming technology (Fig. 5). Then, a flat liquid-crystal glass was bonded to the cover glass without distortion through optical bonding technology (Fig. 6).

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Fig.4 S-shaped display harmonized with the interior

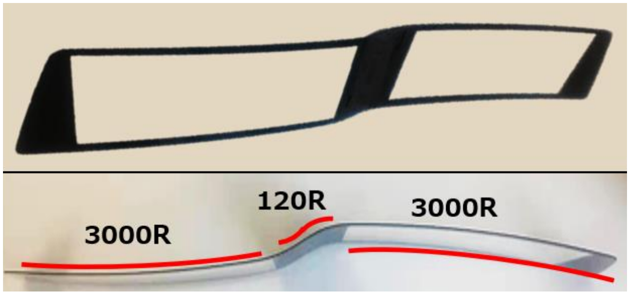

Fig.5 S-shaped cover glass

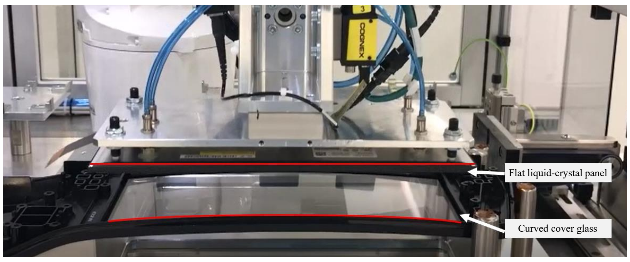

Fig.6 Bonding of curved cover glass

2. Simple and intuitive GUI

2.1 Infotainment information

Because humans have limited ability for processing increasing volumes of information, the number and positions of the displayed menu items were analyzed. The widget sizes (Fig. 7) and tile menus (Fig. 8) were enlarged and their numbers were optimized based on the recognizability and operability of the functions.

The arrangement of the menu items was optimized based on an evaluation of the ease of menu selection as a function of the number of menu items for different age groups. It was observed that short-term memory of a user decreased as the number of menu items increased. A 4-column × 2-raw configuration with a total of eight menu items showed a correct answer rate of over 90% irrespective of age group and was thus selected as the optimum configuration (Fig. 9).

In addition to basic operability, the display configuration allows customers to personalize a variety of content to their tastes and needs. The tile menu can be intuitively rearranged using drag-and-drop operations (Fig. 10).

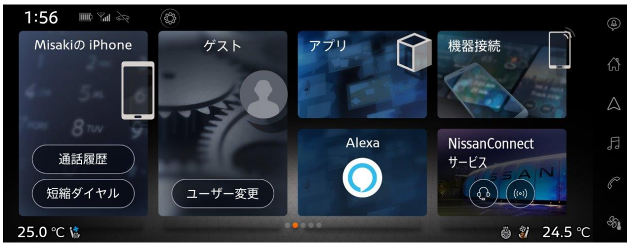

Fig.7 Home widgets

Fig.8 Eight-tile menu

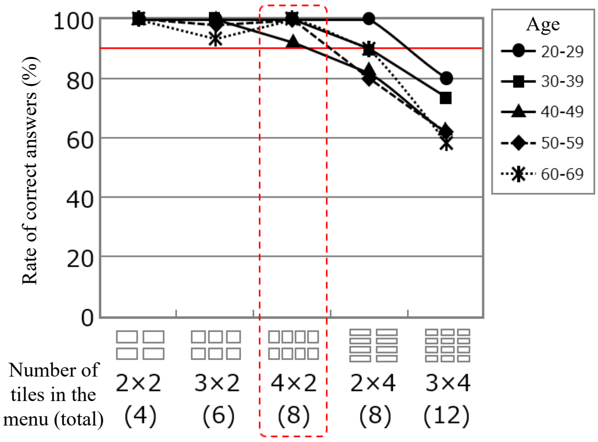

Fig.9 Ease of menu selection as a function of the number of menu items

Fig.10 Customization of home widgets

2.2 Meter information

The meter display consists of three basic zones (Fig. 11) and uses a simple mode, where the volume of information in each zone is restricted such that the desired information can be found easily. For example, the power gauge, instantaneous speed, and drivable distance are digitally displayed in separate zones, thereby allowing easy confirmation of the conditions of the vehicle (Fig. 12).

Fig.11 Conventional meter display

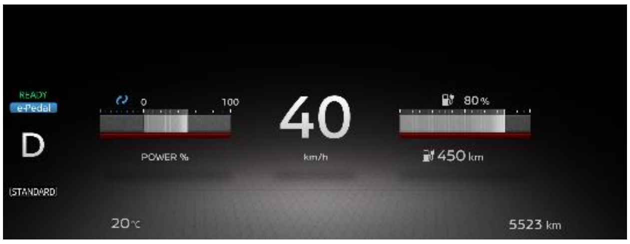

Fig.12 New simple-mode display adopted in ARIYA

2.3 Information communication between the displays

The infotainment and meter displays were synchronized via Ethernet communication and information could be transferred between the two displays instantly using intuitive swipe actions (Fig. 13). This function supports various usage modes, such as moving a map to the meter display while a passenger enjoys other content on the infotainment display.

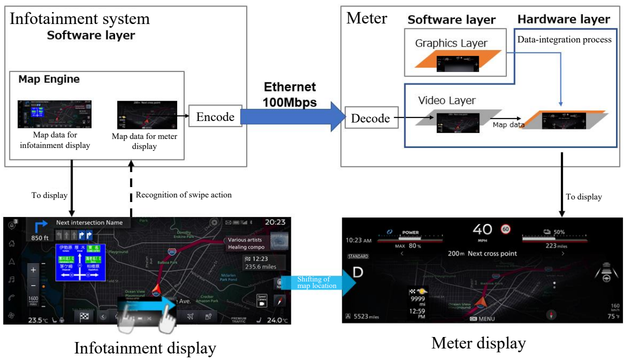

Fig.13 Information transfer between the two displays via Ethernet

2.4 User experience (UX) with emotional value

To provide emotional value to the customer along with high operability of the basic functions, new functions and interactive systems were developed with high interactivity and spatiality. Voice-animation expressions were used for voice recognition because of the excellent interactivity to enhance information recognition (Fig. 14). Home widgets offer new UXs, such as comfortable and enjoyable operations, by providing adequate space to tile menus and icons with parallax effects (Fig. 15).

Fig.14 Voice interaction display

Fig.15 Home screen with parallax effects

3. Summary

ARIYA has been equipped with an “integrated display package for combined visibility and operability” to enable easy access to information and a “structured GUI easy and intuitive handling of a large variety of content.” In addition, ARIYA offers great emotional value to customers through various applications and animations. In the future, the cockpit HMI can be further developed into a drive concierge.

Authors


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4. Development of new NissanConnect

Toshiro Muramatsu* Kazuhiro Funai** Masaru Tasaki**
Shintaroh Murakami* Hiroyuki Kamishima**

1. Introduction

Connected services, which connect the mobile phone network to the navigation system to provide a wide range of services, were started in the late 1990s. Nearly a quarter century has passed since Nissan launched its "NissanConnect (formerly COMPASSLINK and CARWINGS)".

Owing to technological evolution in recent years accompanied by the widespread use of the Internet, connecting "things", such as automobiles and household electrical appliances, to the Internet for better utilization (Internet of Things, IoT) has become popular. In 2019, Nissan updated its connected car system to the NissanConnect service, which provides new experiences to customers by connecting the vehicle and customer terminal seamlessly. The number of users of the NissanConnect service has increased rapidly (Fig. 1). The technologies developed through the dedicated efforts of the NissanConnect development team have been fully adopted in ARIYA to provide new and exciting experiences to customers.

This chapter describes the strengthened NissanConnect platform and the new voice recognition technology developed for the platform.

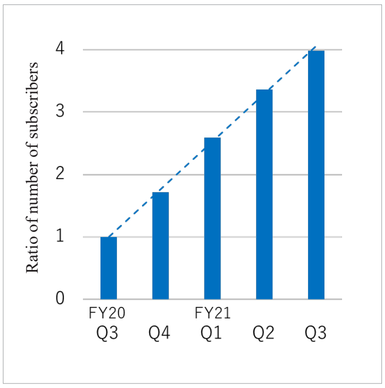

Fig.1 Increase of NissanConnect subscribers

2. NissanConnect system

An overview of the NissanConnect system is shown in Fig. 2. The vehicle is equipped with an in-vehicle infotainment (IVI) system comprising a display and graphical user interface (GUI) as well as a telematics control unit (TCU), which communicates with the cloud. Connections to the other electronic control units (ECUs) and sensors of the vehicle are via LAN. The TCU communicates with the cloud using a mobile phone network. The cloud system is accessible by call centers and third-party information providers that offer services and information to users. In addition, a dedicated app on a user's smartphone collaborates with the cloud system. The IVI, display, IVC, cloud system, and apps comprise the NissanConnect platform.

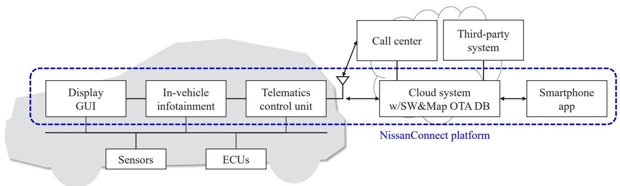

Fig.2 Overview of NissanConnect system

The cloud system consists of three main components: vehicle connection/vehicle information management, service logic/provision management, and software/map over-the-air (OTA) distribution management. The core parts of these components are common globally; hence, global deployment can be achieved quickly. The components may have portions that meet the unique needs of different regions. The system requires both robustness to provide stable service and flexibility to adapt to changing customer requests and peripheral IoTs. To realize these requirements, joint development was conducted with Microsoft Corporation to develop components requiring greater robustness (vehicle connection/vehicle information management and software/map OTA distribution management). In-house development was conducted for the service logic/provision

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management, which requires higher flexibility, for efficiency.

Fig. 3 shows the sequential overview of various services provided by this platform. For example, for the remote function that enables vehicle operation from an app, the user input to the app is used as the trigger to establish a communication path between the cloud server and TCU; subsequently, the commands are sent to the TCU. The TCU operates the vehicle according to the received command and sends the results to the app via the cloud system. In addition, for services that coordinate with third-party information when the vehicle is traveling, user input to the IVI is used as the trigger to convert the cloud system to a proxy, which subsequently connects to the third-party system for service provision. Hence, numerous services can be provided by configuring the functions on the NissanConnect platform.

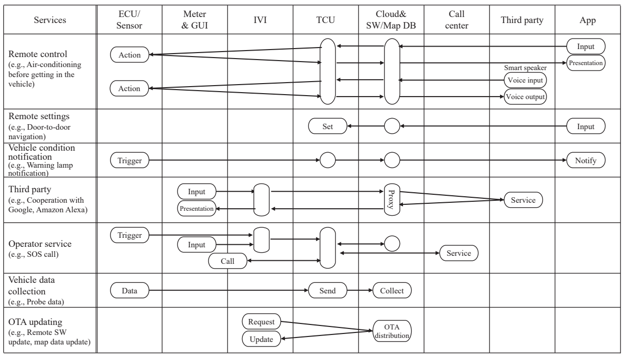

Fig.3 Overview of the NissanConnect service sequence

3. Voice recognition technology supporting CCS

Voice recognition technology is a method to reduce the burden of operating an in-vehicle device when driving. To date, the mainstream voice recognition method has been a standalone method, where a voice recognition engine is installed in the in-vehicle device. For ARIYA, we developed a dictionary database used exclusively by Nissan in addition to the standalone method. The off-board method was adopted for the dictionary database; thus, the database resides on a network configured on the platform. The off-board method was adopted because it is capable of accurately understanding the daily utterances used while driving and the intentions of such utterances.

Natural language speech is acquired using a microphone, processed via voice signal processing in the in-vehicle device, and further processed in the following order. Phoneme recognition, word/sentence recognition, and intention estimation (Fig. 4).

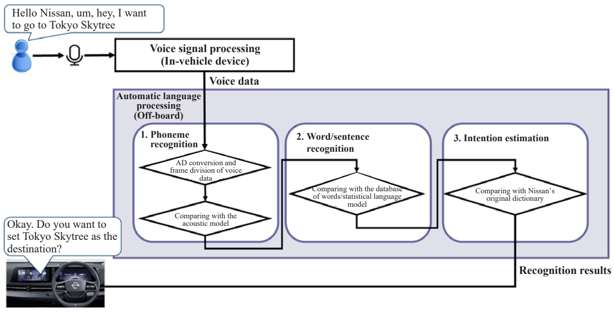

Fig.4 Flow of natural language recognition processing

3.1 Phoneme recognition

The voice signal acquired by the microphone undergoes AD conversion and is sequentially divided into frames of equal lengths. Then, each frame undergoes frequency spectrum analysis to obtain the acoustic features. Subsequently, phonemes are recognized by comparison of the obtained acoustic features with the acoustic model, which is created by statistical processing of human voice.

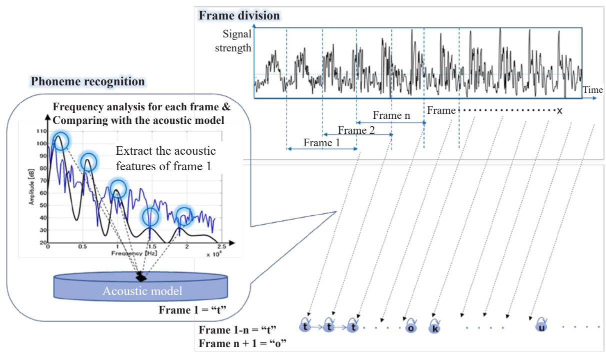

Fig.5 Phoneme recognition

3.2 Word/sentence recognition

Comparing the chronological connections of phonemes with the database of words, the words in the voice signal are obtained. In addition, a statistical language model in the form of parameters obtained by learning the probability of shifting from one word to another is used for comparison when selecting the final candidate for "the most probable word combination result." For example, given the input "I want to go to tou . . . kyou skytree," it is possible to recognize an accurate sentence "I want to go to Tokyo Skytree."

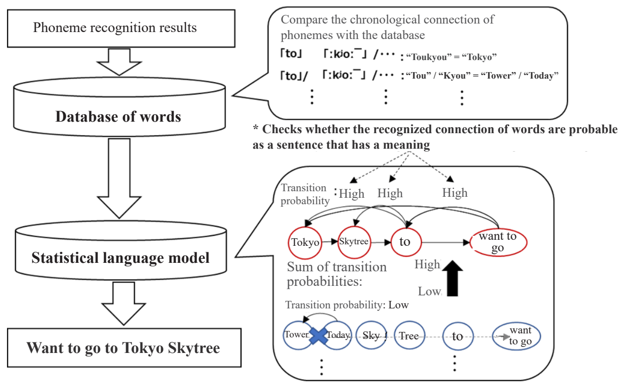

Fig.6 Word/sentence recognition

3.3 Intention estimation

To estimate the intention of an utterance made during driving, it is necessary to process and remove unnecessary words (e.g., “Um…,” “Hey”) and extract only the necessary words (e.g., Tokyo Skytree + want to go). In addition, synonyms of “want to go to” (e.g., “go to,” “set the destination at”) need to be recognized. There may also be cases where the uttered sentences are not grammatically correct. To separate these factors and secure sufficient intention estimation performance in the driving environment, Nissan’s original dictionary database was developed. The database contains learned data from approximately 3,000 utterance patterns collected in actual driving environments. Using this dictionary database and narrowing the database to only the necessary words allowed a voice recognition rate achievement of approximately 85% for ARIYA compared to approximately 70% for systems manufactured by other companies.

Fig.7 Intention estimation

4. Summary

We are at the beginning of an era wherein automobiles have become a part of the Internet, and we are creating new value using the NissanConnect platform. The voice recognition technology described herein has the potential to offer new experiences, such as dialog-type services, including the virtual personal assistant (VPA). Once again, we deeply consider the meaning and significance of our principles “What is important is the value for the customer,” “Is there competitiveness in that subject?” and “Only the customer knows the correct answer” to actively develop leading services for the future.

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5. High-capacity lithium-ion battery for ARIYA

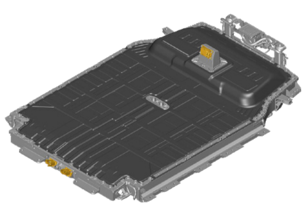
Junji Katamura* Kentaro Hatta* Keisuke Wakabayashi*
Masanori Takagi* Naoto Todoroki*

1. Introduction

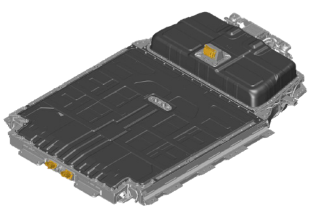
Electric vehicles (EVs) have been deployed globally in recent years, and there is demand for a longer driving range. The driving range depends primarily on battery performance. Therefore, it is important to increase the amount of energy within specified battery size, it is important to increase the energy density per unit volume. A newly developed EV-specific platform is adopted in ARIYA to realize a flat and large interior space; thus, the requirement for the battery layout design is to fit within a limited space.

On the other hand, from the viewpoint of improving convenience, there is a high demand for quick charging performance to ensure that a greater amount of energy can be stored in a short period of time. To meet these demands, a temperature control system that appropriately controls battery temperature is essential. However, the battery temperature control system significantly lowers the volume efficiency of the battery pack, and the control system has a large impact, particularly in the thickness (height) direction.

The newly developed battery pack has improved energy density per battery pack thickness (approximately 2.3 times that compared to the LEAF E+), even though it is equipped with a temperature control system. Consequently, top level volume energy density and quick charging performance (for EVs) have been realized while improving interior comfort. This article describes the development of the high-capacity lithium-ion battery mounted in ARIYA.



B6 grade (66 kWh)



B9 grade (91 kWh)

2. Technology for low and flat floor in the cabin

As mentioned above, the newly developed EV-specific platform was adopted in ARIYA to realize a flat and large interior space. This required designing a thin and flat battery structure. The main technologies developed newly for this requirement are described herein.

2.1 Thin cooling mechanism

Typically, a temperature control system that uses LLC(Long life coolant) is adopted in battery EVs (BEVs). In this system, a plate is placed at the bottom of the battery pack. The LLC is cooled using a chiller, heated using a heater, and supplied to the plate to control battery temperature.

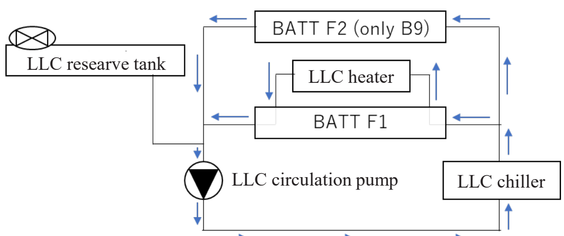


Fig.1 Diagram of the battery temperature control system

To uniformly cool/heat the battery modules arranged within the battery, the LLC must be supplied uniformly across the entire of the lower plate. However, the space within the battery must be watertight and separate from the LLC flow channels. Therefore, three structures, namely the lower plate, LLC flow channel mechanism, and protection cover, are necessary, as shown in Fig. 2. In ARIYA, these structures are integrated to realize a thin battery pack (Fig. 3).

*Powertrain and EV Energy Storage Technology Department

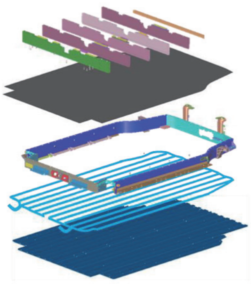


Fig.2 Battery cooling structure of other companies

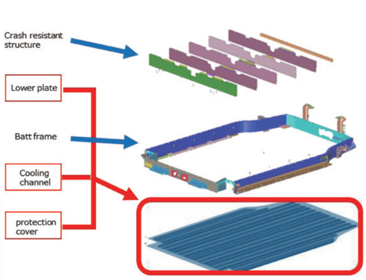


Fig.3 ARIYA cooling structure

2.2 Battery floor manufactured by aluminum extrusion

Aluminum extrusion method was adopted to manufacture the battery casing to integrate its lower plate, LLC flow channel mechanism, and protection cover. A cross-sectional structure was established such that the LLC flowed inside the extruded lower plate. In this manner, the lower plate and cooling plate were integrated to realize a cooling mechanism with reduced thickness (Fig. 4).

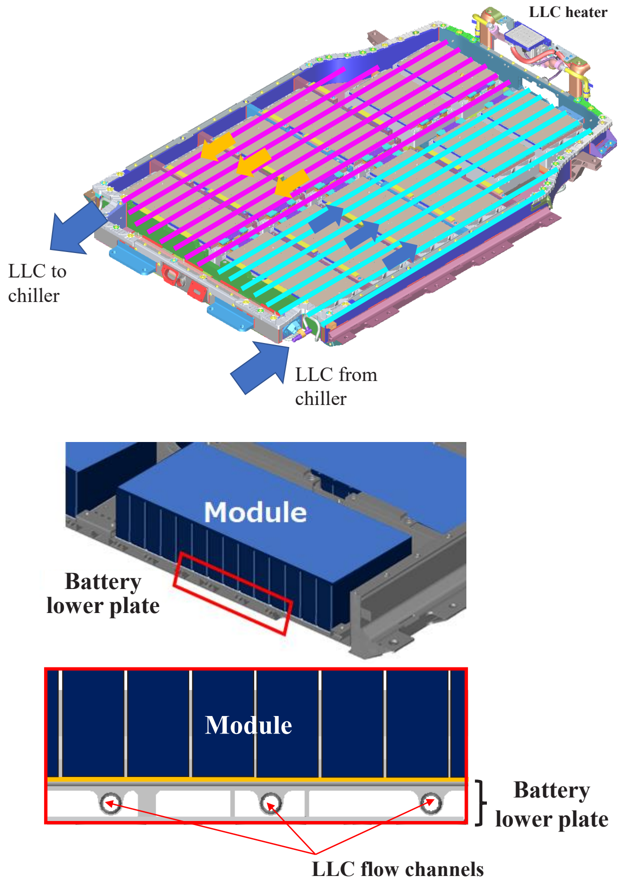


Fig.4 cross section of battery lower plate with LLC flow channels

The cross section in which the LLC flows is structured such that the flow channel is in contact with the upper plate on which the battery module is mounted. A hollow space is formed between the flow channel and lower plate side to increase the heat-insulating property and cooling efficiency (Fig. 5).

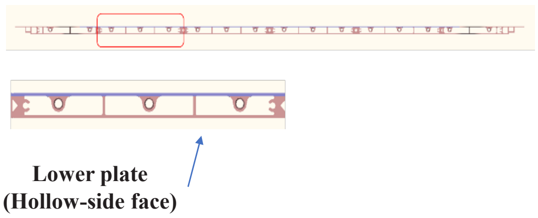


Fig.5 LLC flow channel cross section

To realize a thin and flat battery layout design, the battery modules are arranged in a thin and wide layout (Fig. 6). Therefore, the space between the battery pack peripheral frame and battery modules is narrow, which results in very little crush allowance during collisions. To solve this problem, multiple cross members are placed within the battery pack to realize high resistance against impact.

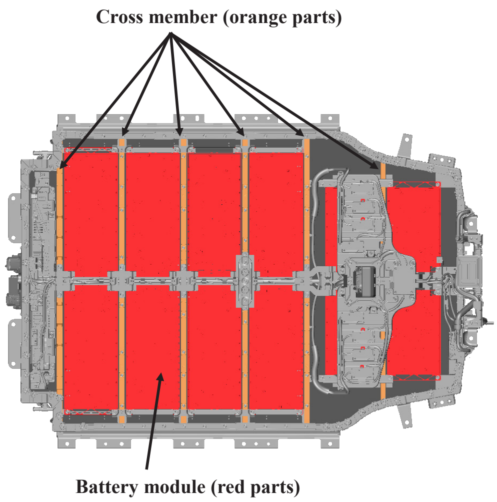


Fig.6 ARIYA battery layout

3. Balanced evolution of the trade-off performance

Although our previous battery development activities were based on balancing high-level performances, we have improved the balance further in ARIYA. The main battery performances that provided value to customers were compared among ARIYA, LEAF, and other existing technologies; the comparison results are summarized in Table 1. Balanced evolution of the battery performance was realized in ARIYA, which is a trade-off relationship. The representative items are described here.

Table 1 Comparison with existing technologies

Value for our customers	Battery performance	Natural heat dissipation (LEAF)	Temperature control by fluid (Existing technology)	Thin temperature controlling mechanism (ARIYA)
Interior space	Battery pack thickness	BASE	△	○
Driving range	Energy	BASE	×	○
	Mass	BASE	×	△
Price	Number of components	BASE	×	△
	Structure expansibility	BASE	←	○
Convenience	Consecutive charging	BASE	◎	◎
	Low-temperature charging	BASE	◎	○

3.1 Convenience improvement

The thin cooling mechanism described in the previous section was instrumental in realizing a flat and large interior space unique to EV-specific platforms. Additionally, it helped realize quick charging performances in various types of environments. Fig. 7 shows the amount of energy stored in 30 min of quick charging at ambient temperatures of 40°C and –5°C. It was possible to achieve excellent and quick battery charging performance in ARIYA under various types of environments by appropriately controlling the battery temperature (heating during winters and cooling during summers).

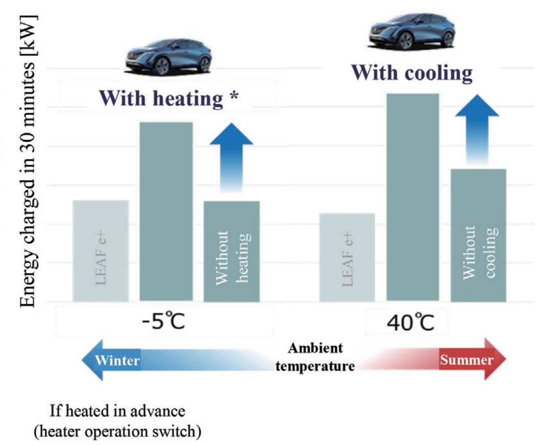


Fig.7 Quick charging performance

Fig. 8 shows the quick charging performances of Nissan EVs assuming a situation where the vehicles are driven for long durations and mainly on highways, with repeated high-speed traveling and quick charging. In LEAF E+, the battery temperature increased with the number of quick charges, and the charging speed tended to decline from the second quick charge onward. However, the battery temperature is controlled appropriately in ARIYA; therefore, the charging speed did not decline even with repeated high-speed traveling and quick charging, thereby enabling comfortable long-distance driving.

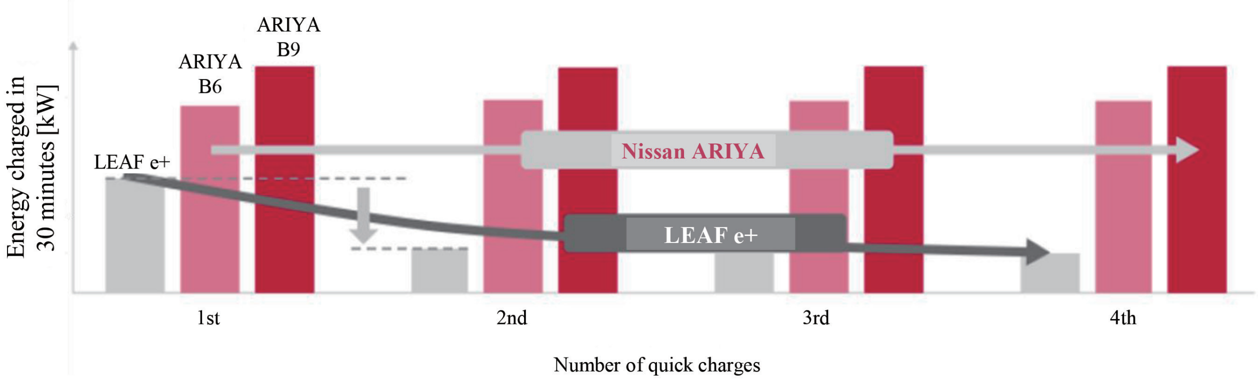


Fig.8 Transition in the amount of energy charged with repeated high-speed traveling and quick charging

3.2 Battery structure for high expansibility and fewer components

The battery floor structure fabricated by aluminum extrusion enables a thinner battery and realizes high expansibility to various types of vehicle specifications. Because the battery casing is extruded in the front-rear direction of the vehicle body, simply changing the extrusion length enables the application of the battery casing in vehicles with different wheelbases. Thus, the number of specifications was reduced. Even in the two-story-structured B9 grade (91 kWh battery specification, in contrast to the one-story-structured B6 grade (66 kWh)), where the battery modules are arranged in the space below the rear seat to obtain high energy capacity, the basic structure of the first-story portion can be standardized (Fig. 9). As noted previously, integrating the lower plate and LLC plate of the battery casing enables an approximately 60 % reduction in the number of components. These technologies can promote high competitiveness.

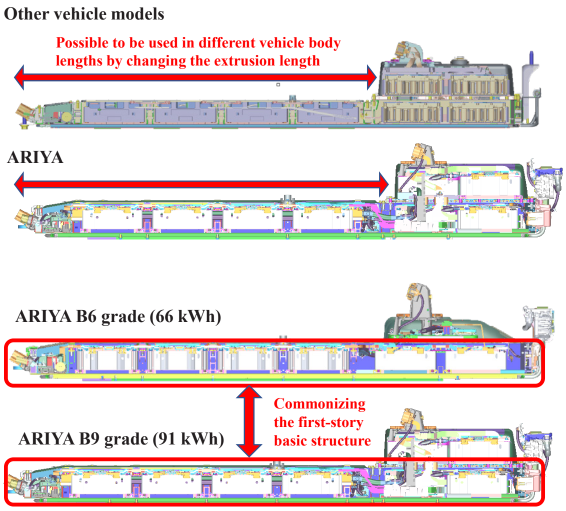


Fig.9 High expansibility to other vehicle models

4. Summary

The battery mounted in ARIYA has a newly developed thin structure and is equipped with a temperature control system. Thus, a flat and large interior space that is unique to EV-specific platforms was realized. Moreover, improved energy density per volume as well as high quick charging performances under various types of environments were realized.

To promote the widespread use of EVs, we will continue to improve the chemistry of lithium-ion batteries while maintaining their high performance and reliability, improve the energy density, and develop batteries with greater competitiveness.

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6. Newly developed motor to realize ARIYA's performance

Takahito Okubo* Hiroki Wada**

1. Introduction

One of the concepts realized in ARIYA is providing the feeling of being in a lounge. The key points of the lounge concept are ensuring a high level of quietude as well as smooth acceleration and deceleration without abrupt shocks, in addition to the design and quality of the interior, such as the seats. This chapter describes how these requirements were met. The main focus here is on the motor, which has been completely redesigned for ARIYA.

2. Overview of the newly designed motor

In ARIYA, EESM[*2] was adopted instead of the IPM (SM)[*1], which was adopted in LEAF, NOTE, and SERENA E-POWER. Although the EESM is similar to the IPM in that three-phase AC is supplied to the stator by PWM control, the EESM does not use permanent magnets in the rotor and instead uses electromagnets operated by DC. Thus, appropriate amounts of current can be selected for the rotor and stator based on the driving load, thereby leading to improved efficiency as well as reduced vibration and noise. However, the heat generated increases owing to the supply of electric current to the rotor, and securing torque responsiveness is an issue (as described in the next section).

An expanded view of the EESM used in ARIYA is shown in Fig. 1. For comparison and reference, a similar view of the IPM of LEAF is shown. An eight-pole rotor structure is adopted in the EESM in ARIYA. The DC generated in the PEB[*3] is supplied to the rotors via a brush system. The amounts of DC for the rotor and three-phase AC for the stator are calculated in the PEB according to the torque instruction values based on the driving force requirements. The current values are controlled such that an optimum combination can be achieved. Direct oil cooling is used to cool the motor.

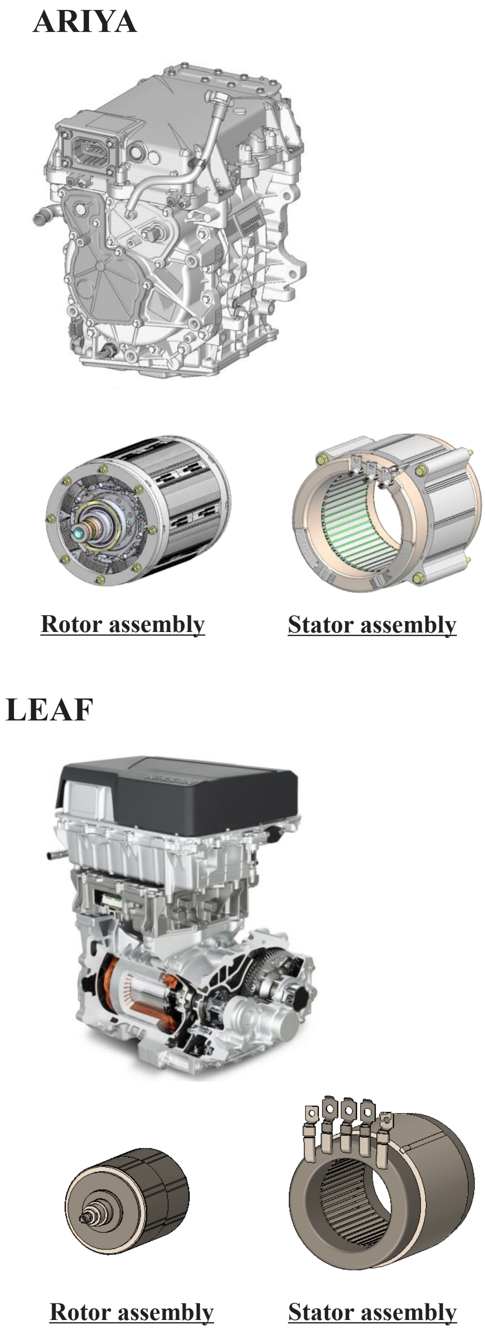


Fig.1 Motors used in ARIYA and LEAF

*Powertrain and EV Engineering Division **Powertrain and EV Electrical Technology Department

3. Value realized by ARIYA's motor

3.1 Realizing quietness

Compared with combustion engine and hybrid vehicles, there is no generation of engine noise in a BEV [*4]. Therefore, the road and wind noises are more prominent. Moreover, there are instances where high-frequency noise generated by the motor and inverter are issues that are never observed in combustion engine vehicles. In ARIYA, several measures are implemented in the vehicle body to suppress the road and wind noises heard by passengers. Further, measures are provided to suppress the high-frequency noise generated by the motor. By implementing these measures, the overall quietness was improved.

The high-frequency noise generated by the motor, whose main component is the electromagnetic excitation force, changes according to the torque and number of revolutions. The magnetic force of the rotor is constant in an IPM; therefore, the torque is controlled only by the current supplied to the stator. Thus, the electromagnetic excitation force is proportional to the supplied current. However, in the motor used in ARIYA, the current is controlled for both the stator and rotor, the electromagnetic excitation force is reduced, particularly in the low-torque area. Further, a higher level of quietness is realized in scenarios where the driving force requirement is not large, such as during gentle acceleration and cruising (Fig. 2).

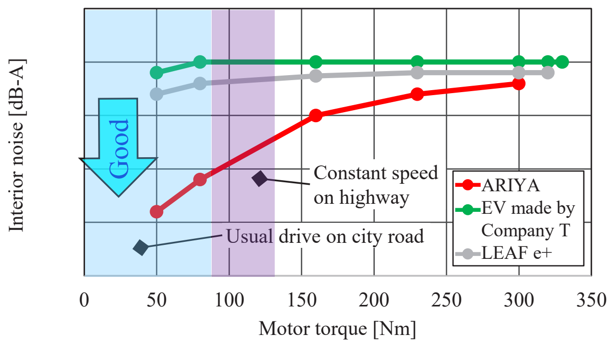


Fig.2 Comparison of interior noise

3.2 Improving electrical energy consumption

The induction voltage generated between the rotor and stator in the IPM increases with the increase in the number of revolutions. In such cases, the output is usually secured in the high-revolution regime by measures, such as field-weakening control; however, this may simultaneously worsen the efficiency. Owing to a similar mechanism as that for high-frequency noise, the magnetic force is constant for the IPM. Therefore, the magnitudes of the induction voltage and field-weakening current are determined uniquely according to the torque and number of revolutions. In ARIYA's motor, the magnetic force of the rotor can be changed by changing the supplied current. Accordingly, the rotor and stator currents are controlled such that the induction voltage is suppressed while the required torque is exerted. Thus, the decline in efficiency is reduced even when driving at high speeds (Fig. 3).

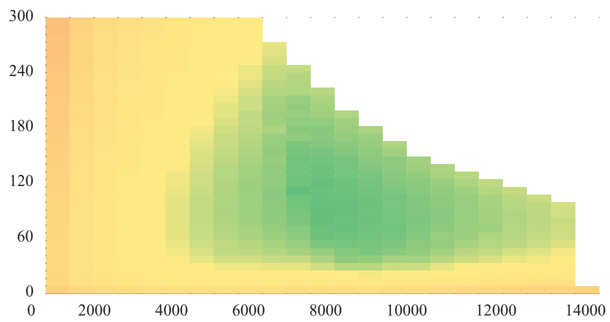


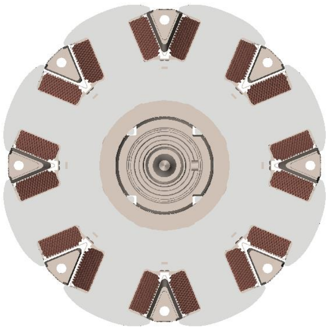
Fig.3 Efficiency

4. Characteristics of ARIYA's motor

4.1 Structure of the wound rotor

EESM, as the name suggests, is structured to supply DC to the rotor that acts as an electromagnet. Therefore, the rotor has a wire-wound structure. The rotor developed for ARIYA has eight wire-wound poles. Renault, which is Nissan's alliance group, has adopted an EESM in ZOE that has four wire-wound poles. To obtain higher outputs, the rotor volume was increased and the number of poles was increased to eight to secure the necessary electromagnetic force and torque responsiveness.

Moreover, the number of revolutions is higher in ARIYA. To realize this feature, the aforementioned measures have been implemented for increasing the output and additional measures are provided in the rotor structure. The cross section of the rotor and a magnified view of a portion of the cross section are shown in Fig. 4. After winding the wire on each of the eight rotor poles, wedge-shaped slots were inserted between the poles to suppress wound-wire deformations due to centrifugal forces. Therefore, the stability of the wound wire shape is crucial. When commencing the motor production process for ARIYA at the Nissan Intelligent Factory, a fully automatic wire-winding machine capable of winding eight rotors at once was introduced to ensure sufficient production capacity. In addition, collaboration was undertaken with the Production Engineering Division to realize uniform and stable wire-winding shape between rotors.



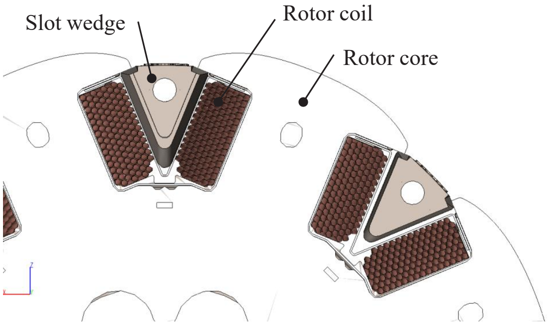


Fig.4 Structure of the wound rotor

4.2 Improved cooling performance via oil cooling

Because the EESM is structured to supply electrical current to the rotor that acts as an electromagnet, the heat generated by the rotor is high. Therefore, a direct oil-cooling method was adopted in ARIYA. The configuration of the oil-cooling circuit is shown in Fig. 5. The oil that accumulates in the oil pan below the motor is pumped using an electric pump, transferred through the channels in the motor casing, and sprayed over the stator and rotor. For the stator, oil is supplied from the outer periphery primarily to cool the core. For the rotor, the supplied oil cools the front and rear coil end portions, and oil is simultaneously supplied to the bearings and oil seals to ensure lubrication.

The oil circulates only inside the motor, and the generated heat is discharged to the water-cooling circuit of the vehicle side through a heat exchanger attached to the side of the motor. The discharge quantity of the oil pump can be varied according to the temperatures of the stator and rotor. Thus, the electrical power consumed by the pump is suppressed.

Additionally, the oil is used to cool the high-voltage components. Therefore, oil that can achieve stable performance from very low to high temperatures while ensuring electrical insulation performance was selected. In addition, a maintenance-free system that requires no replacement or replenishing of the oil is realized.

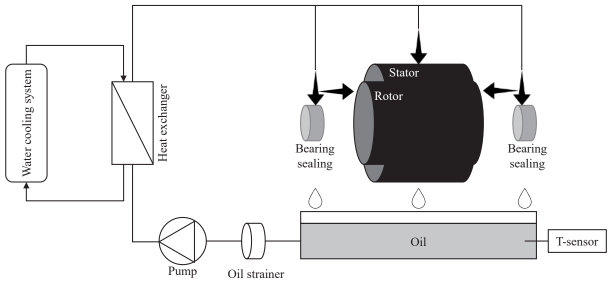


Fig.5 Oil-cooling circuit of the motor

5. Summary

Electric drive technology is rapidly evolving along with the acceleration of electrification trends. In addition to IPMs, which have been widely used previously, an EESM has been developed for ARIYA with sufficient performance and mass-production quality. Thus, we are now able to provide the technology most suited for meeting customer demands regarding vehicle performance. Furthermore, we are able to reduce the cost and supply risks of rare-earth materials.

In future, we intend to further utilize the characteristics of EESMs. For example, in vehicles that have drive motors at both the front and rear ends, during low loads (e.g., when cruising), the electric current supply to the stator/rotor can be turned off for one of the motors to effectively improve electrical energy consumption.

Terminology

*1 IPM (SM): Interior permanent magnet synchronous motor, which is an embedded-magnet-type synchronous motor.

*2 EESM: Electrically excited synchronous motor, which is an external-field-type synchronous motor.

*3 PEB: Power electric box that mainly integrates the inverter function with the peripheral circuits and power source branching function.

*4 BEV: Battery electric vehicle, which is an electric vehicle driven primarily by the energy stored in an externally charged battery.

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7. Nissan's "e-4ORCE" : Proposition for evolution of electric AWDs
— Aiming for a more exhilarating and confident driving experience

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1. Introduction to "e-4ORCE"

Starting from ARIYA, Nissan will be adopting "e-4ORCE," which is a novel technology for controlling electric all-wheel drives (AWDs). The "e" in "e-4ORCE" indicates the electric drive of EVs. Whereas, the "4ORCE" (read as 'force'), which combines the physical power and energy with the "4" of four-wheel drives, indicates the will to control the power or force of the tires of four-wheelers.

In recent years, electric AWDs mounted with two high-power motors, one each at the front and rear, have been increasingly adopted by companies to meet the demands for higher vehicle dynamics and environmental performance. Compared to previous mechanical AWDs, Nissan considers that electric AWDs have very high technological potential because of their "good acceleration" and "high ultimate performance levels", and because they can achieve better vehicular motion "quality" even in daily usage environments. The "e-4ORCE" technology is an attempt to unleash the potential of electric AWDs and improve the quality of vehicular motion. This section describes the "e-4ORCE" technology.

2. Overview of the "e-4ORCE" technology

The previous AWD system, which was mounted with combustion engines, realized power generation at the combustion engine and its mechanical distribution to the front and rear wheels via the connected propeller shaft (Fig. 2). Therefore, there may be mechanical delays when transferring power and mechanical limits to the resolution of power distribution. Unlike electric motors, it is difficult for combustion engines to control their outputs with high responsivity. Therefore, it is difficult to achieve total driving force control of the order of 0.1 s.

The basic configuration of "e-4ORCE" is an electric AWD. As electric AWDs are mounted with independent electric motors at the front and rear (Fig. 1), it is possible to distribute driving force to the front and rear tires with high responsiveness and accuracy. The technological aim of "e-4ORCE" is to realize the full potential of electric AWDs to ensure that drivers feel secure when operating the vehicle regardless of the environment, and the vehicle posture can be controlled such that all passengers can feel comfortable.

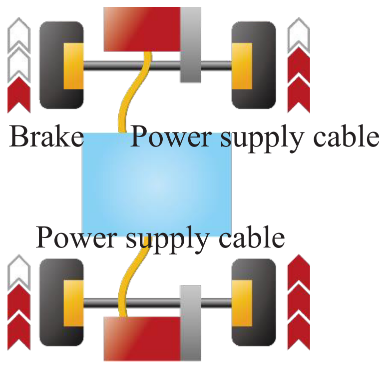

Fig.1 Diagram of e-4ORCE AWD system

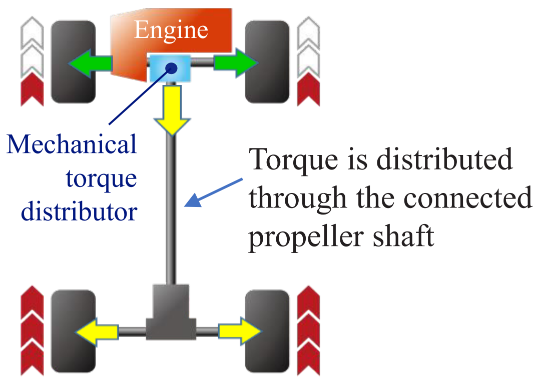

Fig.2 Diagram of previous AWD system

When a vehicle body is supported by four wheels, the load applied to each wheel changes constantly owing to the road surface and vehicular conditions. Additionally, the frictional force limit of each tire changes according to the load on the wheel (Fig. 3). The key criterion here is to achieve control such that the load is distributed to all tires, with good balance including some margin, and within the limits of the tires.

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Fig.3 Tire friction circle and resultant force

In front-wheel drive vehicles, the turning and acceleration/deceleration functions are integrated at the front tires; thus, there is little room for margin. In four-wheel drive vehicles, the turning and acceleration/deceleration functions are optimally shared between the front and rear wheels (Fig. 4) to achieve stability by preventing each tire from exceeding its limit. In the ultimate limiting behavior, the load is distributed such that the maximum value (edge of the friction circle) of each tire is optimally used.

Below the limiting behavior, load distribution is controlled loosely yet carefully within the limits of each tire. Thus, smooth and easy-to-maneuver vehicle motions that are impossible in mechanical AWDs can be realized. In addition, the left/right brakes are controlled according to the situation, and the braking force is utilized in situations other than deceleration to improve turning performance.

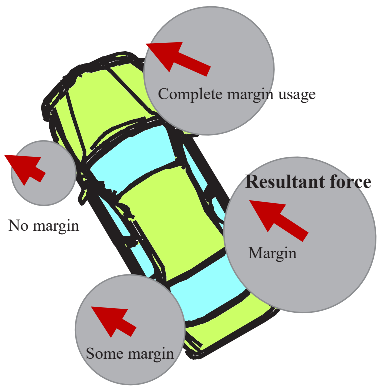

Fig.4 Relationship between the friction circle and resultant force of the four wheels

These technologies have been created and developed by crossbreeding, combining, and further advancing the technological and empirical genes developed by Nissan over the years. These technologies include the AWD technologies, such as the Advanced Total Traction Engineering System for All Electronic-Torque Split (ATTESA E-TS) 4WD system, Intelligent 4 × 4 system, and knowledge gained for electric drive control through LEAF and E-POWER (Fig. 5).

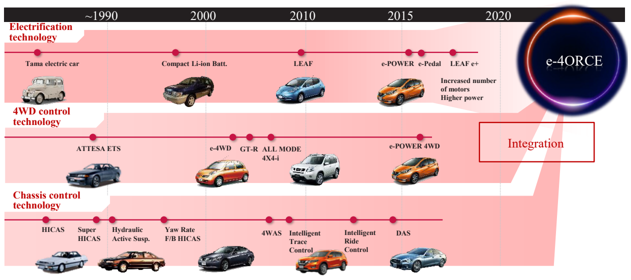

Fig.5 History of e-4ORCE

3. Customer experience offered by "e-4ORCE"

— An exhilarating and confident driving experience —

Given the premise of an electric AWD configuration, the target of "e-4ORCE" is to fully unleash the high potential of the electric motor of a vehicle to a level that has never been achieved by conventional combustion engine vehicles or electric AWDs manufactured by other companies. This includes excellence in handling maneuverability; sense of security regardless of the type of road surface; and comfortable riding experience for all passengers.

3.1 Excellence in handling performance

In general, accelerating a vehicle along a curve causes the vehicle to deviate outward with respect to the normal line of travel. Therefore, the driver must operate the steering wheel further or decrease the speed (understeer). This phenomenon occurs because a portion of the limit value of the friction circle determined by the load on the wheel is used for acceleration, which weakens the turning force. In accordance with the road surface and driving conditions, the "e-4ORCE" technology distributes the driving force to the front and rear wheels so that optimal tire gripping is achieved based on the fluctuating loads on the wheels. In normal driving mode, the front/rear torque distribution is close to 50:50. Moreover, the distribution is changed automatically to an optimal ratio within the range of 0:100 to 100:0 without driver effort based on the road surface and driving conditions. In addition, curve turning performance is improved during deceleration by combined control of regenerative braking by the front-rear motor and the hydraulic brakes of the four wheels (Fig. 6).

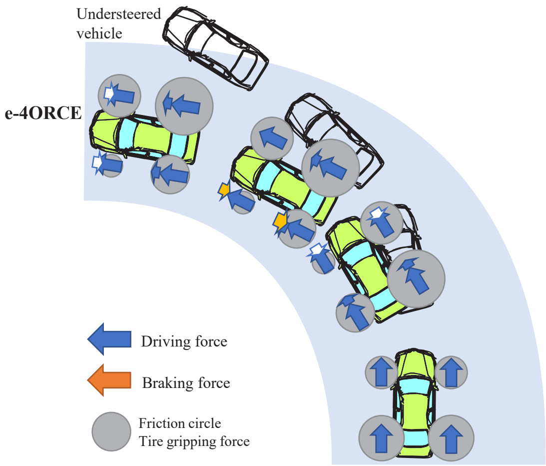

Fig.6 Comparison between e-4ORCE and understeering

This sophisticated control exerts its effects, particularly when turning a curve. Because the vehicular motion is guided by the steering operation of the driver, it is expected that steering correction can be minimized. We hope that the drivers can enjoy a smooth and highly stable driving experience enabled by the "e-4ORCE" technology.

3.2 Sense of security on various road surfaces

The technologies for independently controlling the front/rear motors and brake control developed by Nissan over the years enable excellent driving performance even on constantly changing and slippery road surfaces with snow, compacted snow, ice, ruts, or wetness.

Fig. 7 shows the turning acceleration stability data as a case example of achieving a sense of security. This data graphically compares fluctuations in the steer characteristic when pressing the accelerator for 4 seconds up to full throttle after stabilizing the turning condition to a constant 40R at a vehicle speed of 25 kph. The steer characteristic is an index of the degree of further steering required to align the vehicle with the travel line when the vehicle deviates outward from the target line. If the road surface is covered by snow, the frictional force will be low and surface will be uneven. Therefore, the size of the friction circle fluctuates constantly, and the travel line may deviate both outward and inward; thus, stabilizing the steering condition will not be easy. Even on such snowy road surfaces, ARIYA's "e-4ORCE" causes very little fluctuation in the steer characteristic, thereby enabling stable driving. Compared to the AWD SUVs of competitors that have high-power motors (green and blue lines in Fig. 7), the fluctuation in steer characteristic was approximately 1/9 for ARIYA. Moreover, the fluctuation achieved was small and approximately 1/3 when compared with the top benchmarked AWD SUV mounted with a conventional combustion engine (orange line).

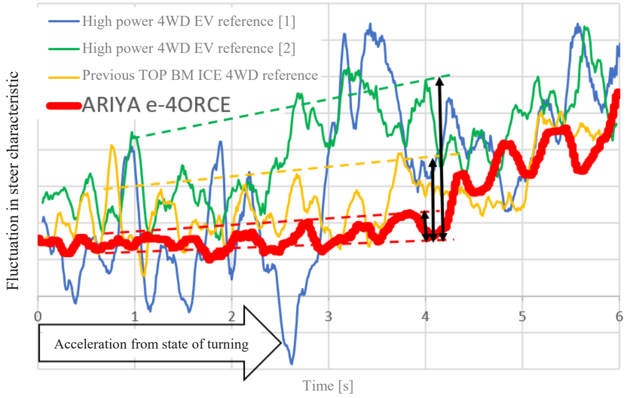

Fig.7 Turning acceleration performance on a snowy surface

A high level of sense of security can be experienced through this high stability, regardless of the situation, road surface, and driver. In addition, this reliability may bring joy to skilled drivers when driving on snowy and frozen road surfaces during winter.

3.3 Comfortable riding experience for all passengers

Control of the regenerative brakes by the motor also contributes to a comfortable riding experience. Even if the vehicle is an EV, applying regenerative brakes to front-wheel drive vehicles can cause a substantial tilting feeling to the passengers because only the front motor is used when braking; thus, the rear of the vehicle is raised when decelerating (referred to as pitch behavior) (Fig. 8).

In the "e-4ORCE" technology, the regenerative brake of the rear motor is used in addition to that of the front motor. Thus, there will be lesser vibration even when the road is congested, thereby resulting in a comfortable riding experience. When accelerating and decelerating, fluctuations in the vehicle posture are suppressed by the optimal control of the motor (right side of Fig. 8). Because the vibrations of the vehicle body are minimized, a smooth and comfortable riding experience is available to both the driver and passengers in other seats.

(Adopted for the first time in NOTE E-POWER 4WD)

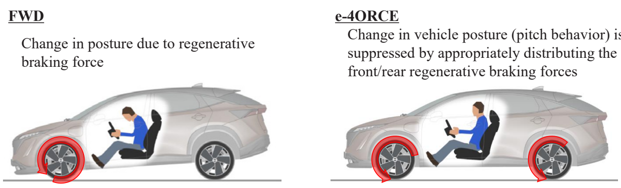

Fig.8 Tilting of the vehicle

4. Summary

The principle behind the development of "e-4ORCE" was to allow the system to achieve control naturally such that the driver would not notice the operation of the system. It is expected that anyone riding in a vehicle equipped with "e-4ORCE" technology for the first time would feel that the vehicle can be maneuvered naturally and comfortably without great effort.

For our long-time customers who have continued to choose Nissan vehicles, we hope that the "Nissan way" can occasionally be felt when driving the vehicle. We hope that the "Nissan way, but redefined" can be felt by our customers. The "e-4ORCE" technology was developed with the aim that our customers will find it indispensable in their vehicles once they have experienced it and that they would become used to the sense of security it provides.

Because ARIYA provides stable steering operation with very little fluctuation in the steer characteristic, the vehicle can be handled confidently, even though it has the power equivalent to a sports car. Moreover, the "e-4ORCE" technology has potential for further development to enable enhanced performance for sports cars.

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