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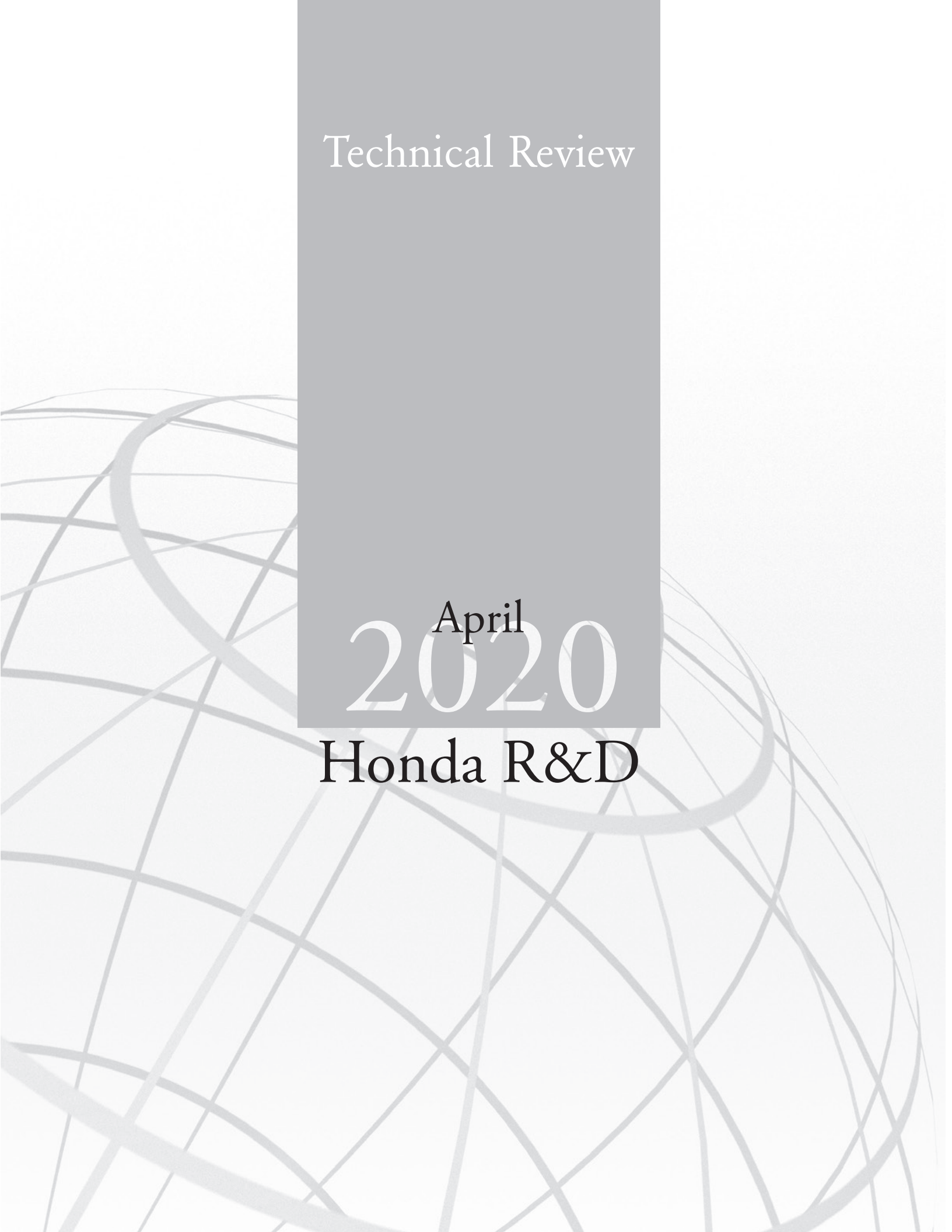
Comment on the Cover

I created the cover image for this issue with “Mechanism of Light Weight Sound Insulation Material Using Thin-film Cells” as the motif.

In creating this cover image, I learned that from every microscopic perspective, things have a necessary form derived from calculations, and I realized that fruits are produced by each technology. Knowing this, a product changes into a special thing when you take it in your hand. With this cover image, I want to communicate my wonder at things that were previously simply symbols having changed into blocks of meaning.



Automobile Center
Atsushi SASAKI

The background features a light grey wireframe sphere on the left side, composed of intersecting curved lines. A solid grey vertical bar runs down the center of the page, serving as a backdrop for the main text.

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Development of Electrical Systems for 2018 Gold Wing -Idling Stop System and Honda SMART Key System-

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ABSTRACT

The 2018 Gold Wing represents the first full model change in seventeen years. It was developed with a broad age range and a variety of use scenes in mind. TBW control was combined with the DCT-equipped model to achieve an idling stop system, the first time ever for a large Honda motorcycle. The Honda SMART Key system was made compact enough for a motorcycle by integrating the tire pressure monitor into the control unit. With these technologies, advanced functions designed for usage unique to motorcycles was achieved.

1. Introduction

The 2018 Gold Wing described in this paper represents first full-model change in seventeen years with a broad age range and a variety of use scenes in mind⁽¹⁾. In the electrical equipment system, cooperative control of Throttle By Wire (TBW), Dual Clutch Transmission (DCT), and Integrated Starter Generator (ISG)⁽²⁾ is developed to create the first idling stop system for large Honda motorcycles (for the DCT type only). Furthermore, to enhance convenience in daily use, the Honda SMART Key system including the tire pressure monitor (Tire Pressure Monitoring System: TPMS) was created uniquely as a single unit. This paper describes in outline the idling stop system, Honda SMART Key system, and TPMS.

2. Idling Stop System

For automobiles, the idling stop system has come to be widely applied mainly for the purpose of improving fuel economy. With the growth of automobiles equipped with the system, the collateral effect of vehicle quietness is obtained by reducing engine noise and vibration. The application of this system to Gold Wing aimed at providing high quality feel. Additionally, in order to enhance quietness at restart, the helical gears were applied to the ISG driving gears used for starting the engine, and mechanical noise was reduced compared to the existing configuration of the

starter motor and spur gear.

However, there were two sets of technical issues in applying idling stop system to Gold Wing.

2.1. Issues Relating to Application to Large Motorcycle

When a motorcycle comes to a stop, the rider may take a variety of postures such as gripping the front or rear brake lever, stepping only on the rear brake pedal while supporting the motorcycle with one foot, or standing with both feet without applying the brakes.

Therefore, in the case of a motorcycle, the very act of opening the throttle grip is detected and judged as the rider's intention to start the motorcycle. Unlike in the case of an automobile, the time period from releasing the brake to opening the throttle grip cannot be used to prepare for engine start. Therefore the transition from idling stop to engine start had to be completed within a short time interval to help prevent rider discomfort.

2.1.1. Time lag when starting

Currently, the use of idling stop system is expanding on scooter type models within the small motorcycle category. Such a bike is easy to support with the hands and feet, whereas Gold Wing is heavy and large. Therefore, it is necessary to satisfy the starting performance responding to gripping the throttle, which is expected by a rider in situations such as starting in the middle of a slope. In order to realize this, the earliest possible generation of the driving

¹ Honda Motor Co., Ltd.

force, that is, the earliest engine start is required. Also, when starting the engine while opening the throttle grip, if the rate of grip opening causes a difference in engine start time, this will cause the variation of the time lag until the vehicle starts to move. In order to help prevent rider discomfort, it was necessary to create a control method that was able to realize a consistent time lag at the start.

2.1.2. Reduction of unexpected driving force

When riders feel that the generation of driving force is delayed, they tend to open the throttle more. Accordingly, it is necessary to reduce the sudden driving force caused by the additional throttle opening.

2.2. Issues Addressing Methods -Combination with TBW Control-

In order to address the two issues described in the preceding paragraph, we tried to solve the issues by combining with the TBW control (Fig. 1).

During the initial operation time to start the vehicle, the throttle opening after operation by the rider was fixed

to a preset value. Consequently, until the vehicle starts, the engine speed is not affected by the throttle opening performed by the rider. The engine speed is controlled by the control unit until right before the vehicle is accelerated for a start, and until the vehicle starts to accelerate. In addition, the engine speed is controlled according to a fixed rising sequence. By adopting this method, stable engine start is realized.

After cranking at a constant speed when starting, the control unit carries out control in accordance with the following procedures:

- (1) Raise the engine speed to the idling speed after the engine is started (I in Fig. 1).
- (2) Raise the engine speed gradually to follow the value that corresponds to the actual throttle grip opening. At this time, the engine speed is suppressed to help avoid sudden increase (II in Fig. 1).
- (3) In the DCT system, the oil pressure in the clutch is raised to the required value beforehand by using the cranking start time as the starting point for control. By doing so, the time to engage the clutch is reduced (III in Fig. 1).

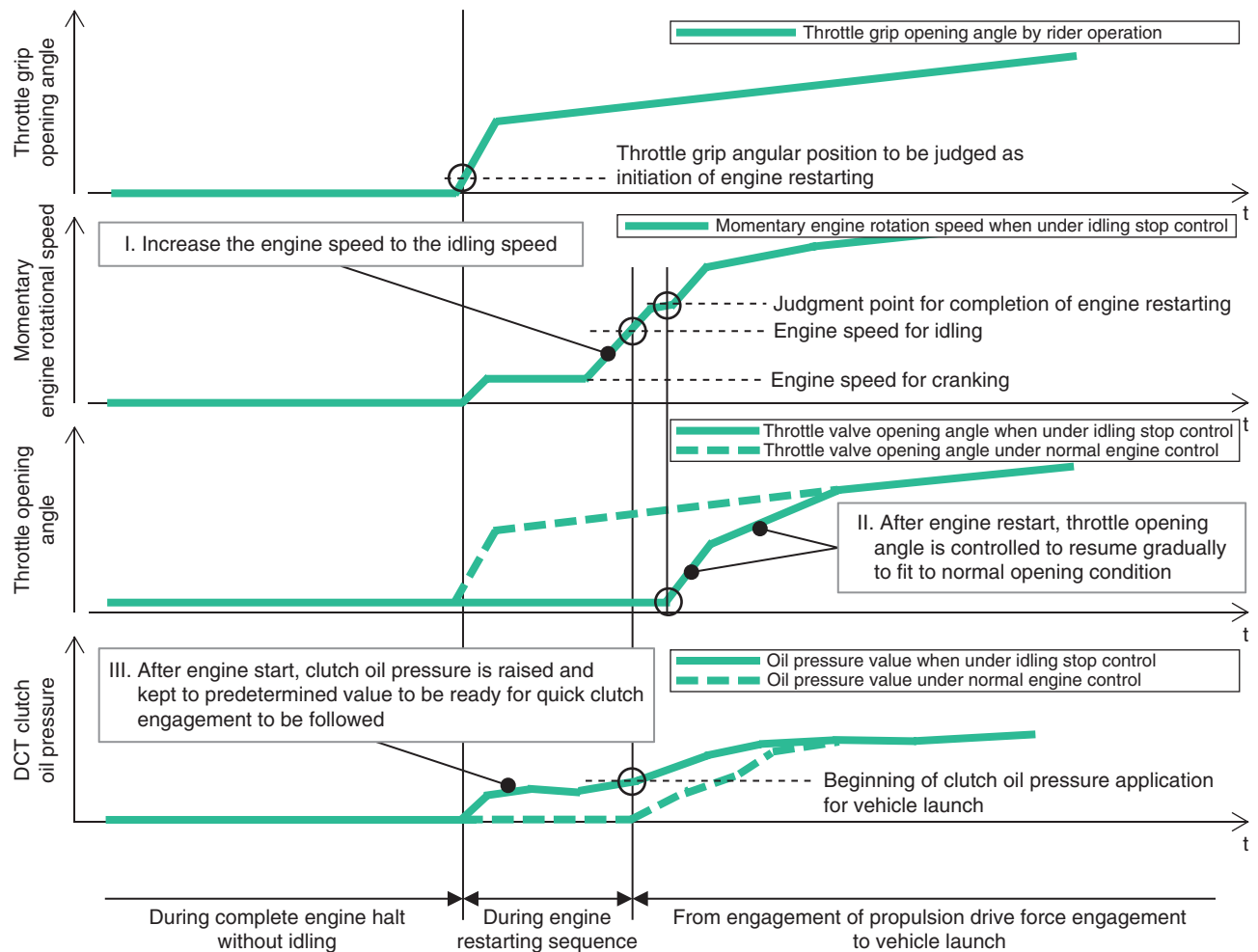


Fig. 1 Vehicle launching control sequence when started from idling stop condition

With the controls described at (1), (2), and (3) above, it is possible to start with a little time lag compared to the rider's intention to start and moreover, with reduced speed variation. By repeating the sensory evaluation and settings, the continuity of the driving force from the idling stop state through the engine start to the vehicle starting to move becomes smooth without causing any discomfort, thus achieving the desired high-quality start.

3. Honda SMART Key System and TPMS

Since a motorcycle is ridden with gloves on, not having to use a key is more beneficial than in the case of an automobile. This chapter describes the features of the Honda SMART Key system and the TPMS system, both of which share the same control unit.

3.1. Function of Honda SMART Key System

3.1.1. Ignition operation

With Honda SMART Key carried by the rider, the ON/OFF operation of the ignition and handlebar locking/unlocking is possible by rotating the main switch at the front end of the center panel. The engine is started by pushing the starter switch placed on the switch housing of the right handlebar. The push operation for the ON/OFF of the ignition to start and stop the engine is widely adopted for automobiles. However, it was not applied to a motorcycle due to the FMVSS123⁽³⁾ regulation stating that ignition OFF must operate in counterclockwise direction. Therefore, for the main switch, the rotary and momentary structure was adopted, and the counterclockwise rotation operation to turn the ignition OFF was applied (Fig. 2).

From the state of the handlebars being locked, turning the main switch in the clockwise direction releases the handlebar lock. Then, each time the switch is rotated in the clockwise direction, the ignition comes ON, and then the accessory mode is engaged. During the accessory mode, in order to help avoid the battery going flat, the mode turns OFF automatically after 60 minutes when the

communication with the Honda SMART Key is enabled, and 30 minutes when the communication is disabled. The exterior design of the Honda SMART Key is shown in Fig. 3.

3.1.2. Handlebar lock and unlock

The electric handlebar lock "Electric Steering Lock (ESL)" was adopted for the first time for Honda motorcycles (Fig. 4). While stationary, the handlebar is locked by rotating the main switch in the counterclockwise direction and steering the handlebar. In the locked state, turning the main switch in the clockwise direction will unlock the handlebar.

Generally, handlebar lock is achieved by fixing the steering system including the whole unit from the top bridge to the area around the front wheel with the handlebar steered to the left or right. Therefore, for this operation, both



Fig. 3 Appearance of Honda SMART Key



Fig. 2 Main switch layout

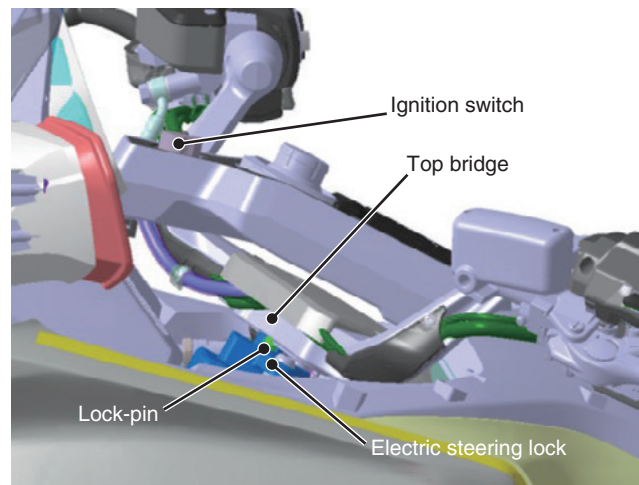


Fig. 4 ESL layout

hands are required, steering the handlebar with one hand while rotating the key with the other hand to look for the position to lock. In order to make it possible to operate with one hand, this model has adopted the mechanism where during the lock operation, the lock pin is pushed against the top bridge until the handle bar is steered and the pin fits in the insertion hole to complete the locking procedure (Fig. 5). Furthermore, a mechanism has been added to notify the rider by a buzzer and indicator to complete the operation, if the locking or unlocking process is interrupted midway.

3.1.3. Quick start operation (ignition ON operation)

In addition to the existing operability, in order to realize the same ignition operability as the smart system for automobiles, the quick start mode was adopted which enables the rider to start the engine while seated. By long pressing the engine starter switch with the brakes applied when the handlebar is locked or the ignition is OFF, the engine starts and is ready to launch as soon as the gear is shifted. In case such as the brake is not applied during the quick start mode, the engine starter inhibitor is engaged which will prohibit the engine to start and maintain the ignition ON state.

3.1.4. Illumination function

The function to light the ignition knob when a rider approaches the vehicle is installed (Fig. 6). When a rider with a Honda SMART Key approaches the vicinity (about 2 meters) of the vehicle, the knob glows for 30 seconds. Since this function continuously searches for the Honda SMART Key and the power is consumed during standby, this function is enabled for 3 days only to maintain the battery state of charge for starting the engine. Also, an LED entry light for lighting the feet is installable as an option (Fig. 7). These functions contribute to make riders or passengers feel welcome.

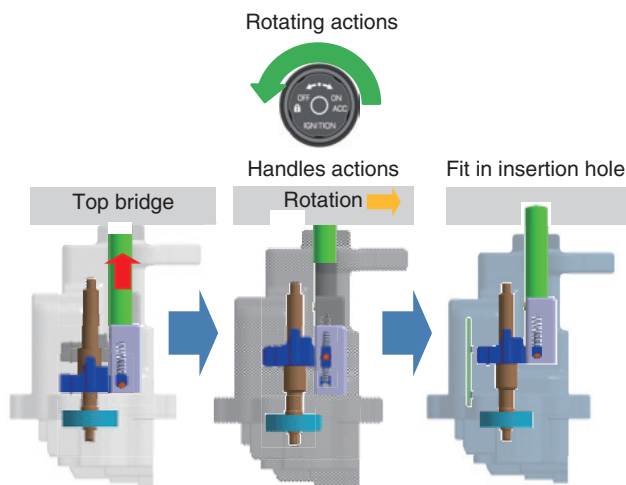


Fig. 5 ESL operation detail

3.1.5. Honda SMART Key authentication OFF mode

Honda SMART Key has the function to switch ON and OFF the authentication for the Honda SMART Key system when the wing mark button in the middle is long pressed. The LED light flashes once by long pressing the button for 1 second to switch the authentication OFF, and the light flashes 3 times by long pressing once more for 1 second to switch the authentication ON. This is effective to reduce the power consumption during standby, or to help avoid unintentional authentication when the bike is parked outside near the window and the key is placed inside near the window.

3.1.6. Opening and closing of trunk and saddlebag

In the previous model, the lock was released when the latch knob was pulled by hand, which required a heavy operating load. To enhance the experience, a mechanism has been adopted which allows the lock to be released by an actuator pulling the latch when a rider carrying the smart key presses the open switch near the trunk or saddlebag.

When a smart key is within communicable range, locking is done by closing the trunk or saddlebag. Since there is no operation to lock the key by closing the door like an automobile, the lock is automatically unlocked when the smart key is not nearby, and the rider or user is made aware



Fig. 6 Entry light image of ignition switch

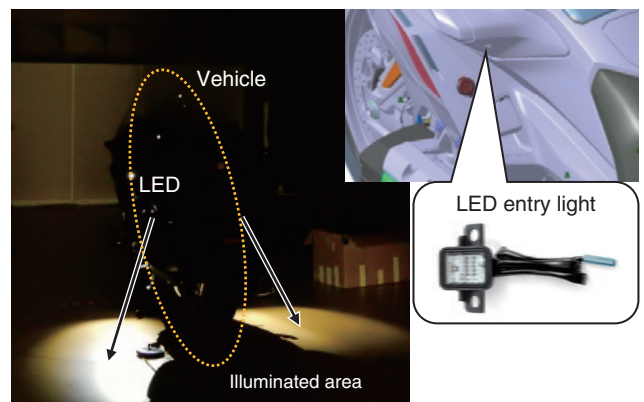


Fig. 7 Optional entry light image

with the lid not being closed that the locking operation had failed. However, if the closing is desired even in such a case, it is possible to close the lid forcibly by retaining the closed state while the opening actions are performed 5 times continuously.

3.2. Integration of Honda SMART Key System and TPMS

TPMS has been installed from the previous model for North America as a standard equipment. It detected reduced tire pressure and gave warning to the rider with an indicator, blinking or lighting up depending on the reduced air pressure. For the new model, in addition to these warning, the numerical value of the tire pressure is shown for the Gold Wing Tour model, which is equipped with a trunk with a large weight difference between empty and fully loaded condition. Moreover, the number of units is reduced by using the same frequency as Honda SMART Key system and by integrating the receiving function. In this model, the signal receiving process to detect the location of the Honda SMART Key and to receive the tire pressure value transmitted by the TPMS sensor is performed under the same frequency. In order to achieve this, it was necessary to realize systems whose communications do not interfere with each other.

3.2.1. Smart key location search communication

In the Honda SMART Key system, when the ignition is ON, the location of the smart key is being searched by periodic communication with the smart key. In the case of automobiles, the search communication of the smart key is performed as a warning that the smart key is taken outside the cabin with the ignition ON and the door or the trunk is closed. This is because the situation where the smart key is taken outside the cabin with the ignition ON is considered to be the case that the key is carried out by a person after the door is opened. It is assumed that the possibility of dropping the smart key outside the vehicle while driving is low for

automobiles. However, in the case of motorcycle that has no cabin, it is assumed that it is possible to drop the key while driving. Moreover, the rider may leave the vehicle momentarily to get a forgotten item with the ignition ON and even come back without the smart key. Therefore, it is necessary to monitor the situation where the rider does not have the smart key when riding and give a warning to the rider.

3.2.2. Compatibility of signal receiving processes for smart key and TPMS

In smart key location search communication, the system processes reception at regular intervals that can be determined reliably not long after the time the smart key is dropped or left behind. On the other hand, the communication with TPMS is performed in a different period from the smart key search process, and the transmission period is constant and decided by the sensor which is a restriction that cannot be changed. Therefore, it was necessary to develop a processing method for those two signals having different periods to be compatible without interfering with each other.

The signal from TPMS sensor is transmitted from front and rear wheel multiple times each at regular intervals of few minutes during driving, and it is necessary to receive the signal without fail. For this reason, the smart key must be searched when the signal from the TPMS sensor is not being transmitted.

Accordingly, a function that predicts the signal transmission timing from the TPMS sensor based on the previous reception timing and the known cycle has been provided. The process of searching for the smart key is performed based on the timing decided by this prediction. In addition, the key will be searched at the next earliest possible timing when communication is possible. In this way, two communication functions were realized with the same control unit (Fig. 8).

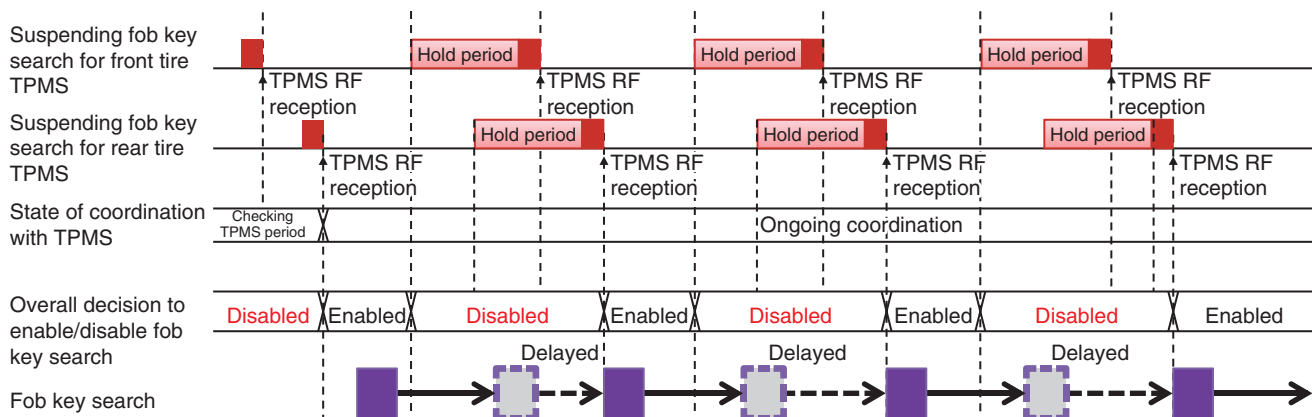


Fig. 8 Suspending fob key search in coordinated control process

4. Conclusion

The idling stop system for a large motorcycle has been realized in the DCT-installed model for the very first time for Honda. Accordingly, the two issues of reducing the time lag at vehicle launch and suppressing the unexpected driving force have been resolved by combining with TBW control.

In addition, the Honda SMART Key system including ESL has been adopted, in consideration of the motorcycle specific possibility of losing or misplacing the key, in order to enhance the convenience of riders. Moreover, it has contributed to downsizing by integrating the TPMS functions into the same control unit.

The adoption of these technologies has contributed to the realization of these advanced functions in consideration of the motorcycle specific ease of use that were required for the development concept of the new Gold Wing.

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- (3) FMVSS123: Standard No. 123; Motorcycle controls and displays: Table 1 - Motorcycle Control Location and Operation Requirements

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Development of Electrical Systems for 2018 Gold Wing –Infotainment and HMI–

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ABSTRACT

An infotainment system incorporating state-of-the-art features suitable for flagship models was developed for the 2018 Gold Wing. The system incorporates Apple CarPlay, which has been adopted for motorcycle use for the very first time, enabling hand operation while riding. As for the Human Machine Interface, operation load and stroke were designed especially for motorcycles, bearing in mind the exposed environment and operation with gloves. The result of all this is the latest infotainment system created specifically for motorcycles.

1. Introduction

Gold Wing, which made a full model change for the first time in seventeen years since 2001, was updated with equipment to make riding the Honda flagship model more enjoyable⁽¹⁾. One significant feature is the enhanced infotainment system, including audio function⁽²⁾. Electronic equipment, such as smartphones, have advanced greatly since a minor Gold Wing model change in 2012, and it was high time for a complete update. This paper describes the world's first use of Apple CarPlay (Apple CarPlay is a trademark of the Apple Inc.) in motorcycles, voice input via Bluetooth, and the restructuring of Human Machine Interface (HMI) to match vehicle multi-functionalization.

2. Infotainment System

The conventional audio unit and navigation system were redesigned to work with smartphones. Infotainment system functions were expanded to include hands-free phone and Bluetooth audio, as well as Apple CarPlay, all functions usually found in automobiles.

The issues we faced when applying these to a motorcycle were making the entire system small enough to fit into the space available and being able to operate the HMI system without releasing hands from the handlebar. This chapter describes the system constructed for a motorcycle, the issues we faced when connecting the system to smartphones, and the solutions to those issues.

2.1. System Configuration

The system first used in the 2001 model was updated and functions enhanced several times in the ensuing seventeen years (Table 1).

We assumed that the system would grow in size as functions of the developed model were enhanced, so we reviewed system configuration to see if we could simplify it as a way to control the added size and weight of the enhancement.

The previous system was complicated. It had three systems: a meter and audio unit as its core, with navigation unit systems added to the 2006 model. These systems were connected by voice, video signal, serial communication and control signal lines (Fig. 1). In this latest development project, the system was configured as two units consisting of the navigation system built into the head unit and meters with a built-in LCD monitor (Fig. 2). In addition, the unit size and the number of harnesses have been reduced by consolidating data input and output in the CAN bus. The transmission of the video signal has been digitalized to enhance noise tolerance and use thinner wires. Moreover, the head unit has been waterproofed and can be positioned with a greater degree of freedom. These changes made it possible to put the head unit in the space above the rear fender, contributing to overall high-density, compact vehicle packaging.

The rod-type radio antenna previously attached to the trunk was downsized and stored in the saddleback. Differences in specifications with and without trunks have

¹ Honda Motor Co., Ltd.

Table 1 Major updating points of electrical features

Model year	Major changing points
2003	- Complete redesign of audio system in accordance with full change of model
2006	- Vast scale minor changes including installation of navigation system (the first generation) - Addition of power amplifier and changes in operation switches
2008	- Addition of XM radio (satellite radio service receiver) to navigation system for US market
2009	- Change of audio unit outer configuration and separation of switches in accordance with addition of air-bag equipped model option
2012	- Re-designing of audio unit and navigation system (the third generation) - Change of installation location of audio system - Termination of CD changer adoption - Addition of audio connectivity with iPod and USB inputs (iPod is trademark of Apple Inc.) - Addition of navigation route information installation capability by SD card

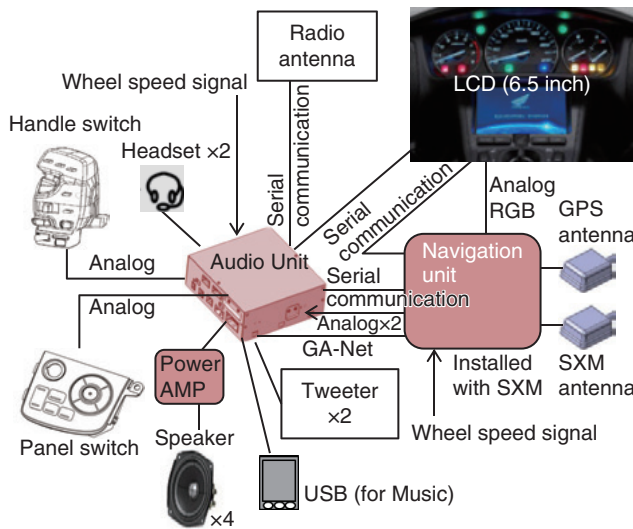


Fig. 1 Connection conceptual diagram of 2012 model

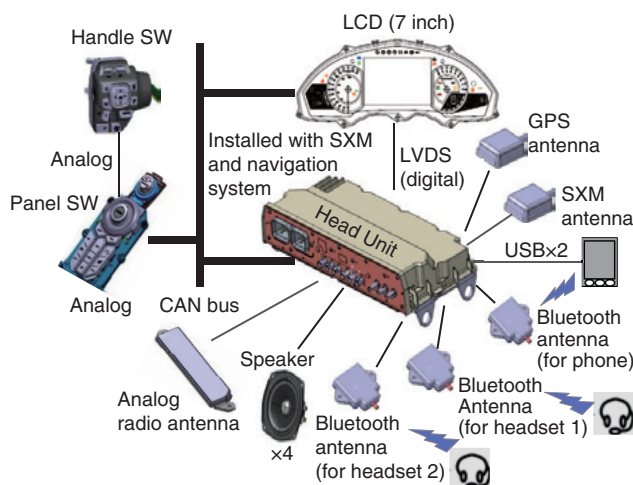


Fig. 2 Connection conceptual diagram of 2018 model

Table 2 Comparison of infotainment system structure

2012 model		2018 model	
Unit	Feature	Unit	Feature
Audio unit	Speed pulse Input	Head unit (audio and navigation)	CAN
	Serial communication (to meter)		LVDS
	Serial communication (to navigation)		AM/FM antenna input
	GA-Net		SP out × 4ch
	Analog I/O × 2		Bluetooth antenna input × 3
	Switch I/O × 2		GPS antenna input
	AM/FM antenna input		SXM antenna input
	Headset × 2		USB
	SP out × 6ch		
	USB		
Navigation unit	GPS antenna input	Navigation unit	GPS antenna input
	SXM antenna input		SXM antenna input
	Speed pulse Input		USB
	Serial communication (to meter)		
	Serial communication (to audio)		
	Analog RGB out		
	GA-Net		

been eliminated, which contributes to a better styling. The structure of the two systems are shown in Table 2 for comparison.

2.2. Smartphone Connection System

This was the first system for motorcycles in the

world that used Apple CarPlay (Fig. 3). Our goal was to link smartphones to the vehicle system to make it more convenient to use smartphone functions.

By adopting Apple CarPlay, immediate response to application updates is now possible, enabling continuous enhancement for user convenience. In addition, since navigation is provided via GPS apps with online connection, users always have the latest map information.

By adopting Apple CarPlay, the system can be operated either using 2-system switches or by voice via a Bluetooth headset, making it possible for the rider to use it without letting go of the handlebars.

The first system entails making necessary commands while riding using direction arrow and Enter keys installed on the handlebar switch.

The second system for switch operation uses the interface dial located on the center panel, and deals with the detailed operations and settings that are not necessary while riding. The switches for the two systems are shown in Fig. 4.

Vocal input is made via the Bluetooth headset. Both hands and feet are used to operate a motorcycle, so vocal input is one of the most suitable ways to operate a system

and it can be done intuitively. Apple CarPlay makes it possible to search for destinations on a map, select music stored on a smartphone, make calls and write and send messages. These are the first voice-operated input and output functions for motorcycles using a Bluetooth headset to correspond to the Hands-Free Profile (HFP) with a sampling frequency of 16 kHz. With it Honda has achieved high-resolution voice input and enhanced vocal recognition accuracy.

3. HMI

New functions have been added with each Gold Wing model change, and the number of switches has increased accordingly. Over the years, switches that could not fit on the handlebars were installed on the body panel and elsewhere. In our development, we added many more new functions and decided to completely rethink the concept of motorcycle switches. Switches were removed from the body panel and concentrated on the center panel. Photographs of the instrument panel of an earlier model and the latest Gold Wing model are shown in Fig. 5.

3.1. Reorganization of Switches

A major premise when developing the operation system was that each function be operated accurately. To do

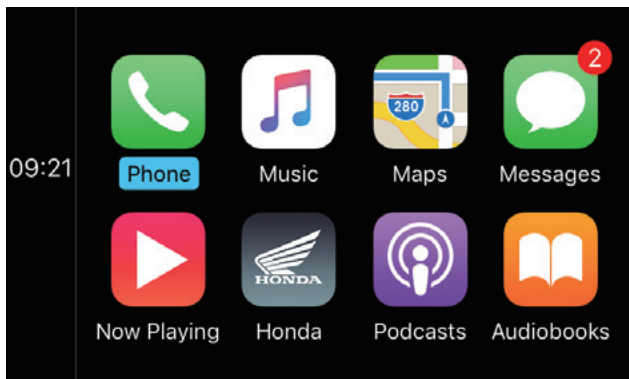


Fig. 3 Apple CarPlay main screen

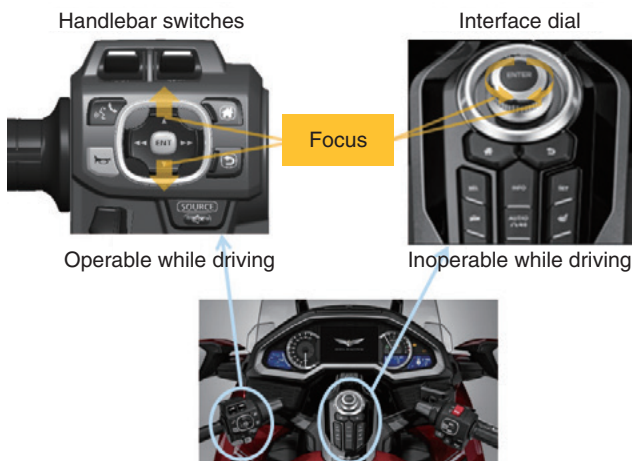


Fig. 4 Operational switches



Fig. 5 Arrangement of indicators and control switches (upper side: previous model, lower side: developed model)

this, the display had to be easy to see and understand, the layout of switches organized according to function, and all operated with minimum movement of fingers.

In the past, all functions for audio and navigation for Gold Wing were configured to be operated directly by the switches arranged on the panels at the lower sides of the meters. Since the switches were all visually recognizable, the arrangement was excellent in terms of being easy to understand.

As we mentioned earlier, the many functions added to Gold Wing 2018 meant that there could not be a designated switch for each function. For the developed model, the role of each switch was reviewed according to function. First, the importance of each switch was organized into a matrix based on frequency of use and operation necessity while riding (Fig. 6). Then, each function was scored. Based on these results, functions were divided into those operated by switch and those that could be displayed in a menu on the LCD (Fig. 7).

Top priority was given to the group of functions that were evaluated as important and used frequently, such as audio volume and raising and lowering the electronic screen. They are operated directly by switches arranged on the handlebar area (Fig. 7 A). Functions, such as the heater

and odometer/trip-meter switch, which were determined not necessarily used while riding, and functions not used continuously while riding and therefore have a low use frequency are positioned as panel switches (Fig. 7 B). Further, functions designated as neither important nor frequently used are now items that can be selected from a menu on the LCD screen, available at a certain stratum (Fig. 7 C).

3.2. Limiting Larger Switches

To make a switch unit structure smaller and a harness finer, adoption of switches that could be used in conjunction with minute electric currents was examined. The study resulted in adoption of a rubber contact-type switch that can secure load and keystroke necessary for contact (Fig. 8). In addition, the whole substrate was sealed for better waterproofing.

3.3. For Switch Operability

Many motorcycle riders wear gloves while riding. It is not easy for them to feel a switch via the extra layer, so it is important for switches to be able to provide gloved fingers with textural feedback. Building this feedback into the design is important to help ensure switches are operated

			Degree of importance			
			4	3	2	1
			1. May lead to injury or fatality 2. May lead to breakdown of drive system 3. If not properly functioning, causes irritation of users 4. May be against regulations	1. Crucial loss of function 2. If not properly functioning, causes discomfort of users	1. Partial loss of function	1. Practically no impacts
Frequency of use	4	Everyday	Legislated functions Cruise-control DCT, Hazard lamp A	Infortaimnet control Motorized screen level adjustment Reverse	Heater control HOMELINK B	
	3	Once a day				
	2	Once a week	B	Trip meter control	Screen brightness adjustment C	Beep sound setting
	1	Once a month	Fog lamp		HSTC level adjustment Language settings	Bluetooth device registration

Fig. 6 Classification of switches depending on criticality and frequency of use

	Classification	Display top	1st layer	2nd layer
A	Frequently checked up daily	Includable (to be operated without manual)	Prohibited	Prohibited
B	Checked up frequency is not high. To be able to operate without manual when item is set as custom setting.	Includable	Includable (to be located as permanent item)	Prohibited
C	Checked up frequency is not low. To be able to operate without manual after once referred to manual.	Includable	Includable	Includable

Fig. 7 Classification of information items displayed on LCD panel

as intended. However, there is a limited amount of space for installing switches. We put a great deal of effort into switch operability using gloved fingers and methods of help preventing erroneous operation. The methods we used are described below.

3.3.1. Right handlebar switch

Accelerator Angular Position Sensor (APS) is located on the right hand edge of the right handlebar switch housing. The cruise control lever is near the throttle grip below the APS to be able to set the motorcycle speed and increase/decrease the set speed while holding the throttle.

The mode button to switch the riding mode is positioned at the front of the APS mounting. The mode button was shaped like a lever to make it easy to operate with the index finger (Fig. 9). However, the lever shape resulted in leverage coming into play, reducing the operating load to about 2.3 N which was too small. Accordingly, a ball plunger was adopted to increase the load to about 3.5 N which is necessary for toggling. This resulted in a click sensation that could be fully transmitted to a gloved hand (Fig. 10).

3.3.2. Left handlebar switch

The turn signal switch, the switch used most frequently

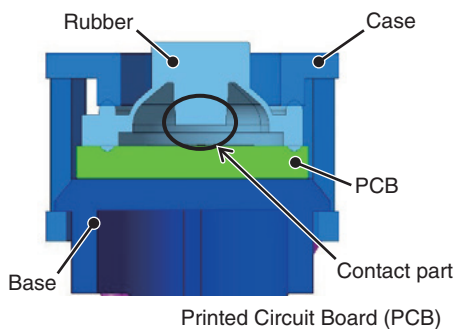


Fig. 8 Rubber dome contact

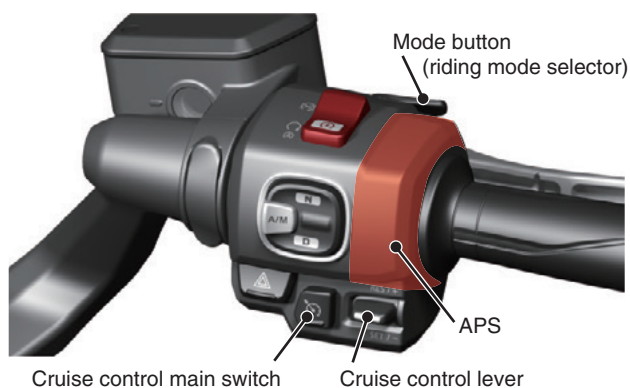


Fig. 9 Locations of cruise control switches and riding mode selector (on right hand grip)

while riding, was given the highest positioning priority. The turn signal switch knob unit was inclined by 10° to make it easy to put a finger on the knob when preparing to turn left (Fig. 11).

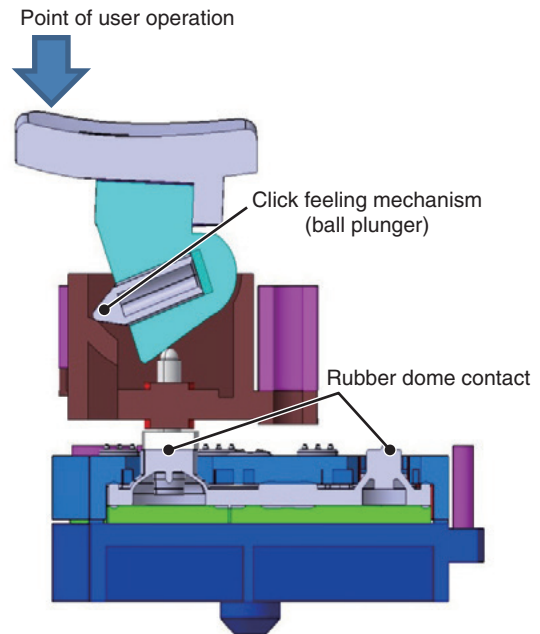


Fig. 10 Click feeling mechanism

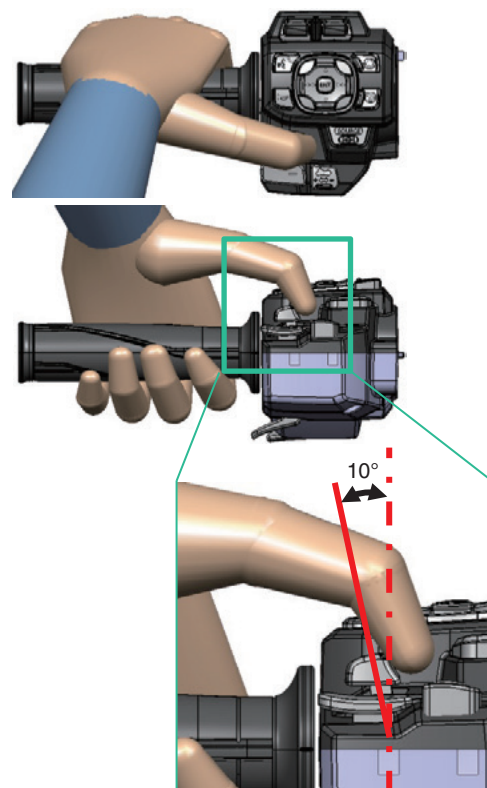


Fig. 11 Turn signal switch

The windscreen adjustment lever and the voice volume adjustment lever are adjoined above the switch housing. Since the shape and operating direction of the two levers are the same, a separator is installed between them to help prevent operation error (Fig. 12).

3.3.3. Switch on center panel

The interface dial is installed on the center panel (Fig. 13). The angles between clicks are set to 22.5° so that a click sensation is transmitted to the gloved hand when the dial is rotated. This angle is twice as large as that commonly used for automobiles. A sophisticated operation feeling is achieved by providing the optimum load value. The force-stroke characteristic chart of this switch and the dial switch of automobiles is shown in Fig. 14. The figure shows the operation feel with the operation torque on the vertical axis and the operation angle on the horizontal axis.

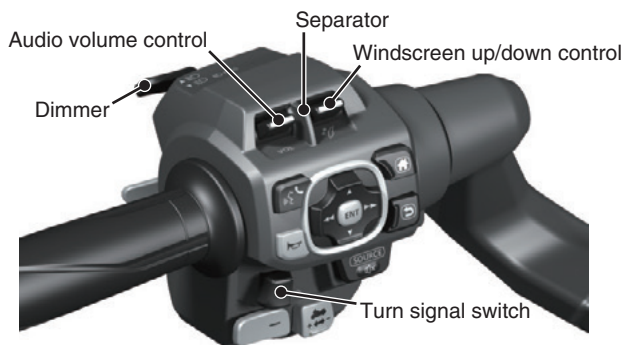


Fig. 12 Turn signal, volume, and windscreen up/down controls



Fig. 13 Interface dial

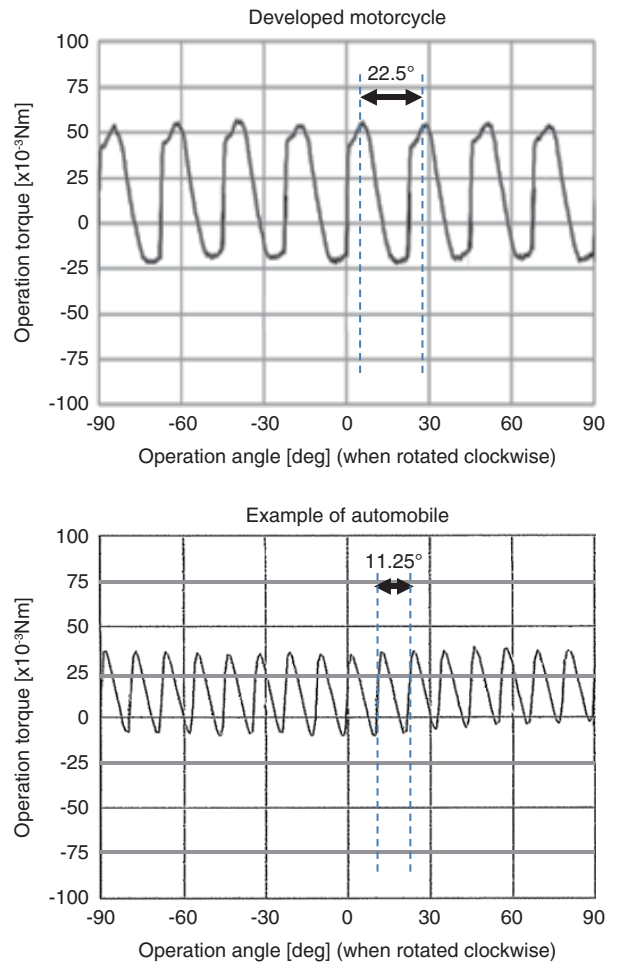


Fig. 14 Comparison of Force-Stroke characteristic of center console rotational switches between developed Gold Wing and automobile

4. Conclusion

We have described the Gold Wing infotainment system, which uses Apple CarPlay and represents a unique function of the model, as well as the restructured HMI.

- (1) The latest infotainment system has been achieved using Apple CarPlay, which operates in connection with smartphones, and adopted measures geared specifically to the distinctive motorcycle operation system and the Bluetooth headset.
- (2) To deal with the increase in switches due to new functions, switches were positioned in different stratum depending on frequency of use, etc., and HMI was restructured along with the new handlebar switches.

By adopting these technologies, it was possible to provide the latest infotainment system and multi-function vehicle system as an HMI that takes aspects unique to motorcycles into consideration.

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Yutaka KIKUCHI



Takuya OSANAI

Development of Low-cost Card-edge ECU for Small Motorcycles

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ABSTRACT

In the development of ECU this time, the transfer molding of semiconductor manufacturing method and the card edge connector technology were applied to the ECU of electronic fuel injection system. In the ECU, whole components, except for the edge connector terminals, are sealed with resin. This ECU is transfer-molded using an epoxy resin specifically developed and mold die with a new mechanism. Furthermore, we developed a waterproof card edge connector to be mated with this ECU. Multi-contact terminals and vibration suppressing mechanism were applied to get a stable contact state. These enabled the equivalent vibration resistance as before and the detachability to the ECU in narrow space. With those measures, the developed ECU achieved more than five times higher productivity and 20% cost reduction compared to the conventional products.

1. Introduction

To cope with the global warming issues, Honda has been applying electronic fuel injection systems to small motorcycles since the beginning of year 2000 to reduce exhaust emissions and to enhance fuel economy. The steadily growing small motorcycle market is calling for further enhancement of production efficiency and cost reduction from the fuel injection system.

Figure 1 shows the structure of a conventional ECU. The printed circuit board (hereafter PCB), on which the electronic components and the male connector are mounted, is filled in the plastic case with the thermoplastic resin for protection from the outside environment. This ECU is mated with the waterproof female connector, and mounted in the small space between the engine and the frame body of the small motorcycle.

Upon the careful analysis of the component parts, the material, and the production processes of the said structure being in use from the early days of application of electronic components to motorcycles, we found a potential to enhance productivity in the male connector soldering process and the resin filling/hardening processes, and thought that the structures should be renewed for further cost reduction.

Figure 2 shows the newly developed card edge ECU and the connector. In this ECU, all parts except the edge connector terminals, which is an integral part of the PCB, are transfer-molded using the epoxy resin. This structure

requires no male connector, plastic case or filling resin. The edge connector terminals and the molded ECU serve as an alternative male connector.

This structure is recognized as an option of future ECU for automotive having an integrated mechanical/electrical systems and effective for productivity enhancement and cost reduction⁽¹⁾, and some practical applications are already seen in some areas⁽²⁾. However, none has ever realized high production efficiency and low cost while maintaining the performance and durability necessary for our motorcycles. We therefore started this project to satisfy such requirements.

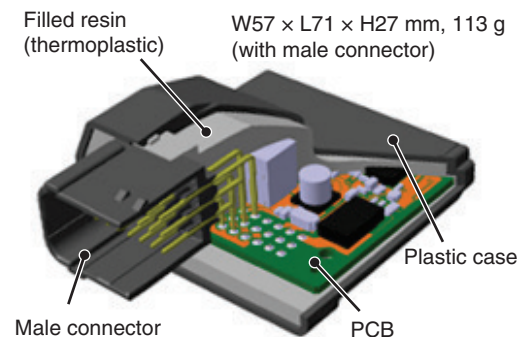


Fig. 1 Conventional ECU

¹ Honda Motor Co., Ltd.

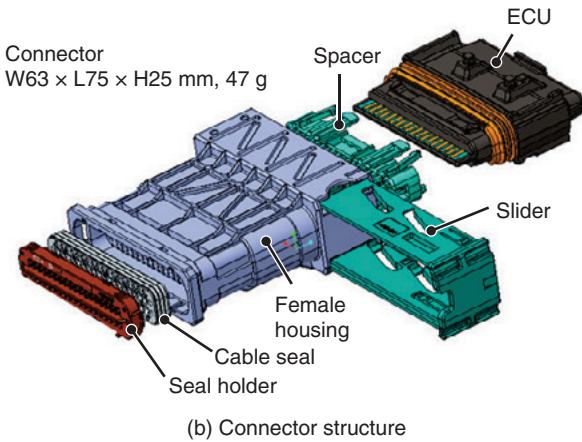
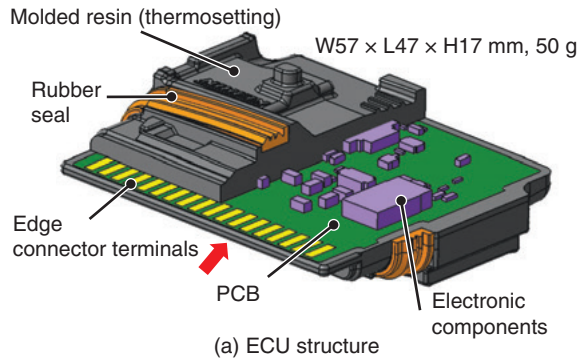


Fig. 2 Developed ECU and connector

2. Features of New Technology

Described hereafter is a comparison of the transfer molding and the card edge connector applied to the newly developed product with the conventional technology.

2.1. Resin Molding

Figure 3 shows the features of the two major resin molding methods; the transfer molding and the injection molding.

The transfer molding is such a method that uses the thermo-setting resin and free of deformation even when reheated after the molding. This method is applied to electronic components typically represented by the semiconductor package molded at low temperatures and low pressures using a low-viscosity epoxy resin. Figure 4 shows an example. Though silicon chips and bonding wires having a diameter of several tens microns are contained in the package, this method allows molding without causing damages to such vulnerable parts. However, the low viscosity resin tends to cause leakage from the mating surfaces of the die, which is not suitable molding of a complex shape. In many cases, a simple shape is molded using a horizontally split dies.

On the other hand, the injection molding using the thermo-plastic resin is applied to many kinds of electronic components and industrial products. Using a high viscosity resin, a complex shape can be molded. However, the high molding temperature and pressure cause damages to the electronic component itself and/or the soldered joint if the electronic components are directly molded. Taking into account such characteristics, we chose the transfer molding as the method for the direct molding of electronic components.

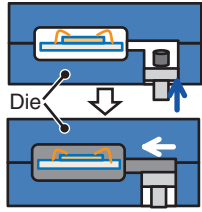
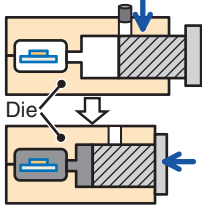
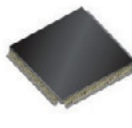
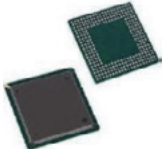
Item	Transfer molding	Injection molding
Outline	Low-viscosity resin is transferred into die while being heated by die	Melting resin, which is heated in cylinder, is molded with high pressure
Schematic of process		
Material properties		
Resin type	Thermosetting resin	Thermoplastic resin
Viscosity	Low	High
Molding conditions		
Pressure	< 10 MPa	30 MPa <
Temperature	< 180°C	250°C <
Cycle time	< 5 minutes	< few minutes
After cure	2-5 hours	None

Fig. 3 Comparison between transfer molding and injection molding

Code	TO220	QFP *	BGA *
External view			

* QFP: Quad Flat Package, BGA: Ball Grid Array package

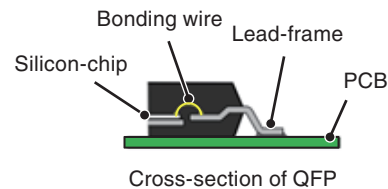


Fig. 4 Example of semiconductor packages (top) and internal structure (bottom)

2.2. Connector

Figure 5 compares features of the card edge connector and the conventional connector used in automotive applications.

The card edge connector was of such a design standardized by IEC603 in 1980's, referred to as "Edge-socket connector," and used for internal connections of communication devices, etc. Compared to the connectors of a through-hole type or a surface mount type, this design features the simple male connector structure. The edge connector terminal functions as a male connector terminal, and the molded ECU serves as a male connector housing. As the edge connector terminal is formed in the PCB production process, there is no need of male connector mounting on the PCB. Furthermore, as the surface area the edge connector occupies on the PCB is minimal, the PCB size can be reduced by approximately 20%. Due to these features, the card edge connector is advantageous from the standpoints of number of parts, production efficiency and downsizing.

On the other hand, due to its simple structure, the vibration resistance is low. Also, there is no waterproof structure. Moreover, the damages the female terminal sustains at the time of mating is an issue. Accordingly only a few examples are seen in the applications to automotive subjected to vibrations exceeding 98 m/s^2 and requiring repetitive attaching and detaching. We tried to solve these issues while maintaining the advantages of the card edge connector.

3. New Technology Applied to Card Edge ECU

Among the new technologies applied to the ECU, described hereafter are the waterproofness, the sealing of sheared end of PCB, the substitution to the ceramic capacitor, and the multi-piece molding.

3.1. Waterproof Structure

The rubber seal is wrapped around the molded ECU and the ECU is mated with the card edge connector. The watertightness in the edge connector is adequately maintained by having the rubber seal adequately compressed at the time of mating [Fig. 2 (b)].

As mentioned earlier, the ECU is transfer-molded with the horizontally-split, simple dies. At that time, the low viscosity epoxy resin tends to leak from the die mating surfaces, sometimes causing protrusion such as burrs and/or steps on the parting lines at the sides of the molded part (Fig. 6).

To help secure the waterproofness corresponding to IPX7⁽³⁾ necessary for the motorcycle ECU, we have found that the height of such a protrusion should be less than several ten microns (Figure 7 shows the relationship between the protrusion height and the waterproofness). As the waterproofness is not required in general semiconductor packages alone, there used to be no ways for realization of such a level of precision. It was therefore necessary to increase die-alignment accuracy in addition to the preciseness of the die used in the semiconductor production.

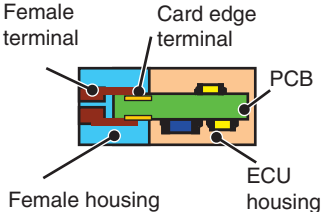
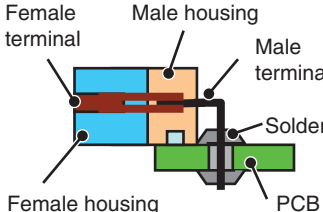
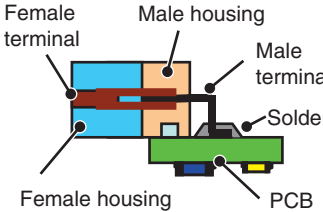
Name		Card edge type	Through hole type	Surface mount type
Structure	Terminal			
	Contact type	Pressing	Pinching	Pinching
	Male terminal	Non-existing (PCB)	Copper alloy	Copper alloy
	Connection PCB	Unneeded	Flow soldering	Reflow soldering
	Occupancy area	Small	Large (both-sides)	Medium (single-side)
Housing	Female terminal	Copper alloy	Copper alloy	Copper alloy
	Male side	Non-existing (ECU housing)	Existing	Existing
	Female side	Existing	Existing	Existing
	Height	Low	High	High
Connector cost		Low (male connector less)	Medium	High

Fig. 5 Comparison of automotive connectors

Moreover, it is necessary to control the protrusion height because it changes in the mass production due to die deterioration, etc. Accordingly, the shape of the areas near the protrusion is designed flat as Fig. 6 (b) shows. The flat part serves as a reference surface, allowing high precision measurements and easy removal of excessive protrusion.

In addition, both ends of the rubber seal are also designed flat shape as Fig. 6 (a) shows with the wide protrusions provided to hinder misalignment from twisting or turning when mating with the ECU. On the other hand in the ECU side, the ribs are provided to hinder falling off of the rubber seal. These new design considerations help secure waterproofness that satisfies the requirements

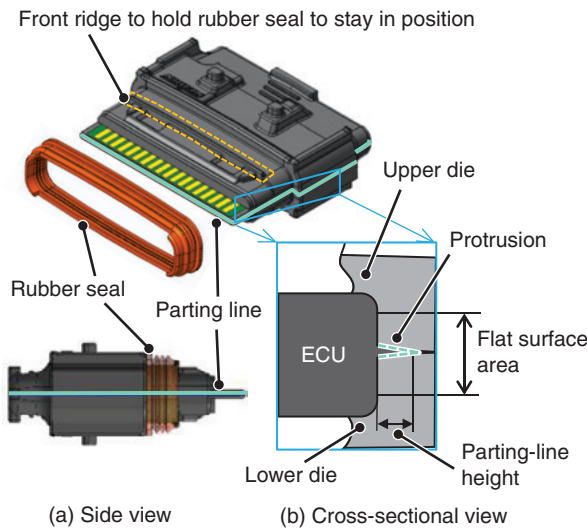


Fig. 6 Rubber seal straddling over parting line

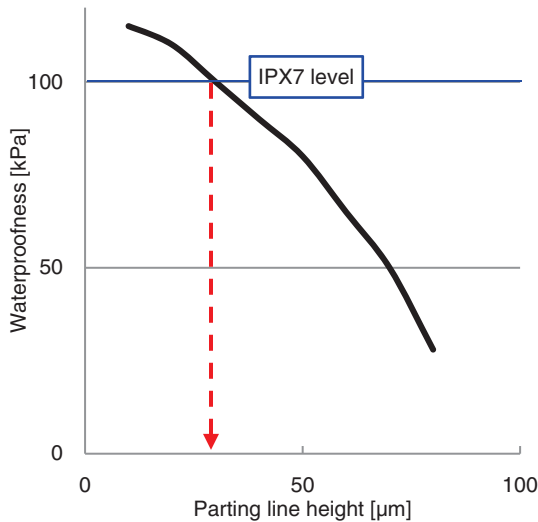


Fig. 7 Parting line height vs. waterproofness

corresponding to IPX7 even after repetitive attaching and detaching.

3.2. Sealing of Sheared End of PCB

Described hereafter is about the second issue. While the card edge connector having the simple structure as shown by Fig. 8 (a) is employed for enhancement of ECU production efficiency, there is an issue, which is the exposure of the sheared end of PCB that comes on the front end of connector terminal [Fig. 8 (b)]. If water, oil, dust or other contaminant adheres on that end of an ECU when removed for maintenance, the contaminant eventually penetrates the inner layer of the PCB, causing ECU malfunction.

To deal with this issue, such a structure is considered necessary that protects the sheared edge of PCB from an exposure to the atmosphere when the ECU alone before mated with the connector. Our solution to this issue is that the independent movable insert die is added to the simple die, horizontally split, transfer molding die to allow the resin to cover the sheared end. Figure 9 shows a cross sectional view at the time of transfer molding. The picture shows the conditions when the cavity is filled with the epoxy resin after setting the PCB in the die. The areas near the sheared surface of PCB are held by the movable insert die. The PCB near the runner is held by the support pins. The resin transferred by the plunger passes through the sides of edge connector and reaches the sheared end of PCB (Fig. 10).

One thing to note is that as the terminals are used for electric conduction from the female terminals, there should be no damage such as scratch, deformation or adhesion

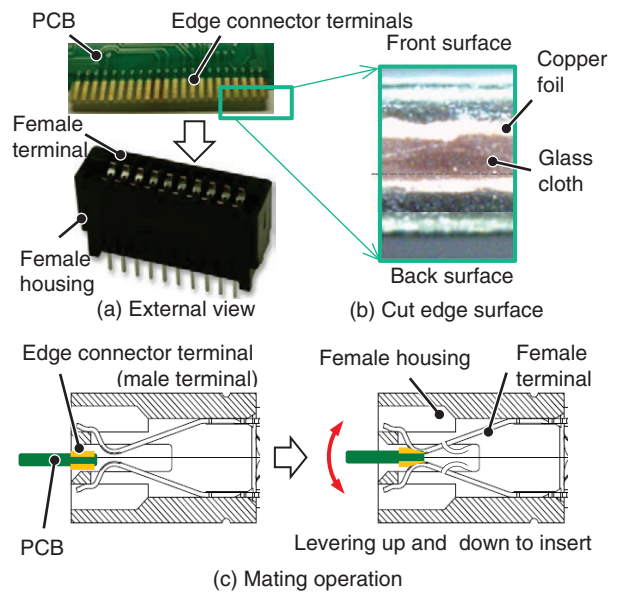


Fig. 8 Overview of card-edge connector

of resin during the molding. It is therefore necessary to pinch and cover that part with dies when molding. As the thickness of PCB has a manufacturing tolerance exceeding 0.1 mm, the additional die that only pinches the edge connector terminal is incorporated to deal with the thickness deviation. This die has a movable insertion die to allow control of pinching load depending on the thickness of PCB⁽⁴⁾. This technology allows sealing of sheared end of PCB to help secure waterproofness of ECU alone.

3.3. Substitution to Ceramic Capacitor

While it is mentioned in Section 2.1. that the transfer molding is less damaging to electronic components, the only remaining issue is such a possibility that the epoxy resin penetrates into the electrolytic capacitor, causing a change of its property. Figure 11 (a) shows the cross section of electrolytic capacitor before molding. On the other hand, after molding, the epoxy resin penetrating into the capacitor lifts the sealing plug, causing the electrolytic foil to deform as shown in Fig. 11 (b). Under such conditions, the electrical characteristics cannot be satisfied.

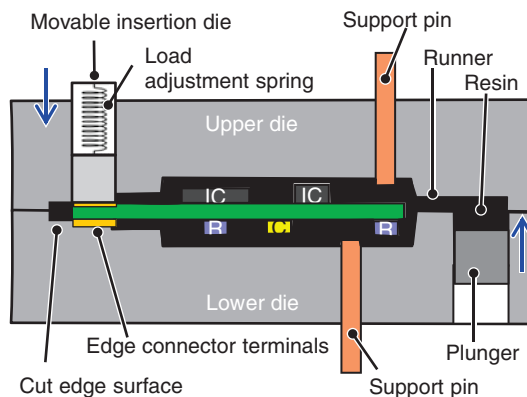


Fig. 9 Transfer molding dies

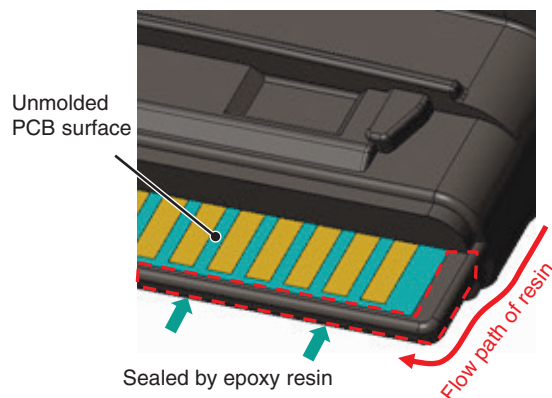


Fig. 10 Sealed PCB cut edge surface

Described hereafter is the role of electrolytic capacitor.

In small motorcycles, there are switches and connectors having contact points in the power supply route from the battery to the ECU. In such electrical devices for automotive, the contact is momentarily lost when subjected to an impact or vibration from outside, sometimes causing an interruption of electric current. The electrolytic capacitor stores necessary electric energy to operate the ECU functioning when the electric current is interrupted.

In the power supply system of small motorcycles, the momentary interruption of contact in the connector used in the conventional ECU is the longest, requiring an electrolytic capacitor to deal with it.

As the newly developed card edge connector is compliant as per ISO8092, the length of momentary interruption is reduced to less than 1 μ s. Accordingly, the new design allows substitution of the electrolytic capacitor to a small-capacity ceramic capacitor, eliminating the electronic component vulnerable to damages at the time of molding.

3.4. Multi Piece Molding

The most effective way to enhance ECU production efficiency is the multi-piece molding.

The transfer molding used in the production of semiconductor packages is such a high-productivity manufacturing method that produces more than several hundreds of integrated circuits at a shot of molding of silicon chips placed in the die cavities. To take the same advantages for the ECU, it is necessary to realize a multi-piece molding to produce as many pieces as possible per shot.

However, as the ECU is far more bulky than the semiconductor package, the conventional method used for semiconductor production cannot be applied as it was.

We therefore considered adoption of the multi-cavity molding method used for molding of large IC such as the power device. It is such a method that places a number of single-piece molding dies in the press die. The pod and the plunger are provided in each die. Using this method

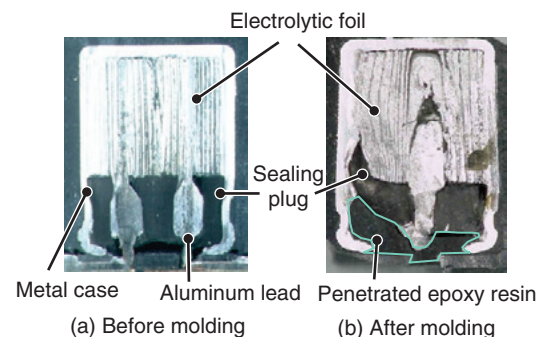


Fig. 11 Electrolytic capacitor deformation

as a basis, pods adequate for molding of large ECU are additionally provided, and placed parallel in the molding die⁽⁵⁾.

Figure 12 shows the melted resin in the two pods in each die being transferred from the runner and filling the cavity. Applying the molding conditions for single-piece operations established during the product development as they are, and using the newly-developed epoxy resin⁽⁶⁾, the high quality, high productivity molding method has been realized.

Placing more than 10 pcs of the PCB, which has been downsized by 20% by the card edge connector design, in the molding die, the production efficiency more than five times higher than the conventional ECU has been achieved.

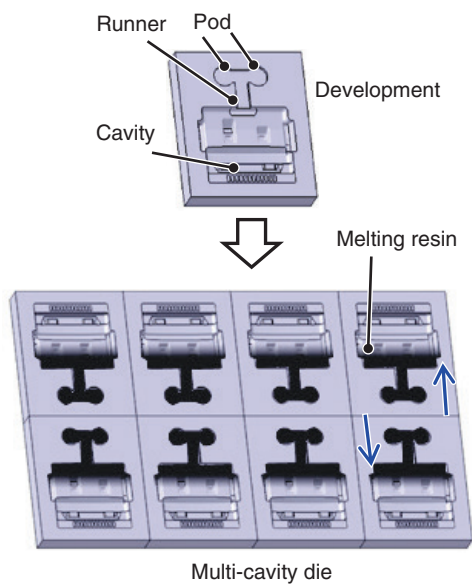


Fig. 12 Multi-cavity molding dies arrangement

4. New Technologies Applied to Card Edge Connector

Described hereafter is the enhancement of attaching/detaching durability, electric contact stability, and vibration resistance among the new technologies applied to the card edge connector.

4.1. Attaching/Detaching Durability

Figure 8 (c) shown earlier gives image pictures of an ordinary card edge connector being mated. It was mentioned that damages such as scratch and/or plating peeling occur on the female terminal surfaces due to the edges on the sheared surface of PCB. In the newly developed ECU, the sheared surface is sealed with the epoxy resin for waterproofness. However, the epoxy resin contains hard fillers such as silica,

which cause damages if adhering on the terminal surface.

We have developed the floated attaching/detaching system that keeps the sheared and sealed PCB end surface from contacting on the female terminal when the connector and the ECU are mated. What produces this floating effect is the spacer provided in the female connector housing [Fig. 2 (b)]. Figure 13 shows how it functions in details.

In the pictures, (1) shows the conditions before the ECU is mated in the connector. Though mating with the ECU into the female housing is starting at that time, the spacer remains at the initial position in the female housing. Accordingly, none of the ECU, the spacer, the female terminal or the edge connector terminals is in contact with each other.

Shown by (2) are the conditions when the ECU is being mated into the connector. As the ECU is gradually attached in, it comes in contact with the spacer, and pushes the spacer toward the far end of housing. Then, the spacer comes in contact with the female terminal at the point (a).

Shown by (3) are the conditions when the ECU is fully mated in the connector. As the ECU is further attached in and the spacer is pressed to the far end of the housing, the female terminal, which contacts at the point (b), is pressed downward in the picture. At the same time, the female terminal finally contacts the edge connector terminal at the point (c).

When detaching the ECU, the spacer moves to the opposite direction along with the mating with ECU, and the ECU comes off the connector after the pressure on the female terminal is released. As such, the spacer moves along with attaching/detaching of the ECU. Thus established is the structure that is free of damages even the ECU is repeatedly attached and detached for motorcycle maintenance.

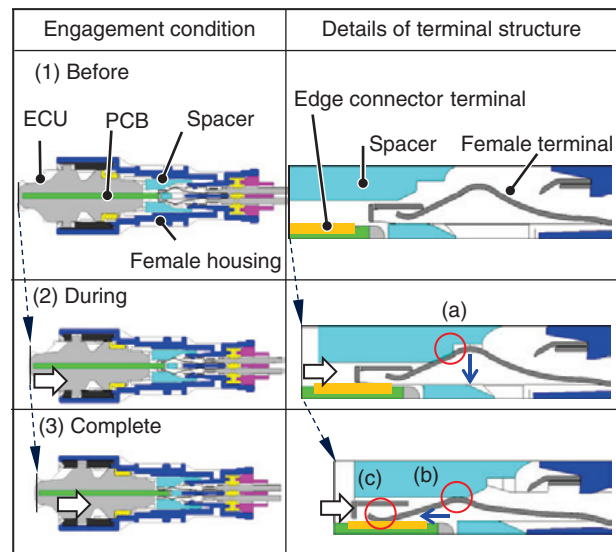


Fig. 13 Mating operation with spacer

4.2. Contact Stability

Next, the technology to stabilize the terminal contact state of the card edge connector is described.

Figure 14 shows image pictures of the terminals in contact in a conventional connector and a card edge connector. In the conventional connector, the female terminal pinches the male terminal. Both terminals are made of the same copper alloy material.

In the card edge connector, the female terminal made of copper alloy applies a load on the male terminal formed on the PCB. As the PCB is not designed for contacting of terminals, it deforms when a large load is applied. Furthermore, as the bending stiffness of PCB lowers under high temperature conditions, even more deformation occurs, causing a loss of contact stability.

To deal with this issue, the new technologies are employed in each of the female terminal shape and the PCB.

Figure 15 shows image pictures of the card edge connector being in contact. Figure 15 (a) shows the contact

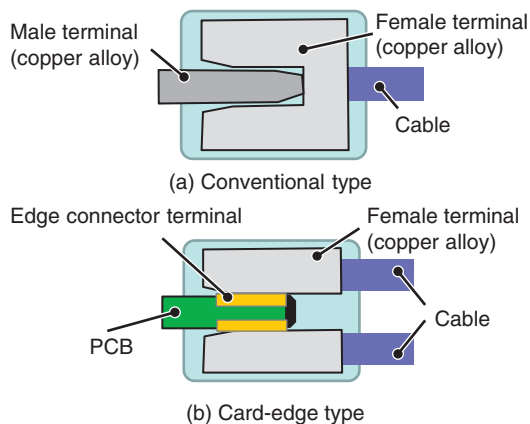


Fig. 14 Terminal contact structure

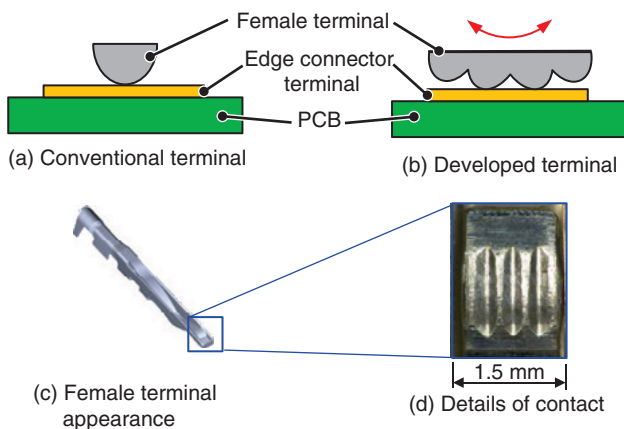


Fig. 15 Card-edge terminal contact structure

condition in conventional card edge connector. From the macroscopic viewpoint, the female terminal and the edge connector are in contact only at a point within the cross section of the terminal. Accordingly, all the applied load concentrates on the single point, causing PCB deformation when a large load is applied.

The newly developed female terminal shown by Fig. 15 (b) has a number of projections, and two of them are in contact on the edge connector terminal. Even when the motorcycle's wire harness clamping the female terminal swings, two contact points are always maintained on the edge connector. The projections are formed on the 1.5 mm-wide female terminal using the precision press [Fig. 5 (d)]. As this terminal design splits the load on the contact points, the deformation of PCB is restricted. Also, as a number of parallel current path is maintained, the contact resistance on the terminals has been lowered to less than a half of the conventional type⁽⁷⁾.

Mentioned next is the changes of PCB stiffness. Figure 16 shows the bending stiffness of PCB for general purpose and newly developed PCB at various temperatures.

In the PCB for general purpose when at 150°C, the stiffness lowers to less than a half of that at 25°C. This means for the card edge connector that a half of the load applied to the female connector deforms the PCB, and only the remaining load is applied to the terminal.

Employed in the newly developed PCB is the resin material having a high glass-transition temperature along with the inner layer structure that resists changes of stiffness. With these technologies applied, 80% of the stiffness at 25°C is maintained even at 150°C.

The application of the above mentioned two ideas realized the stable contact structure.

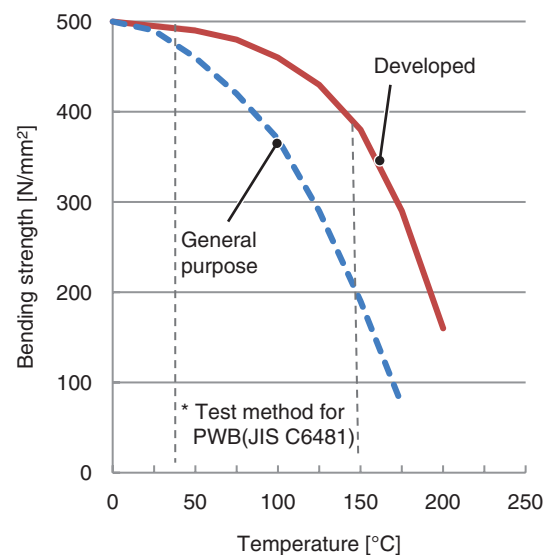


Fig. 16 Bending strength of PCB

4.3. Vibration Resistance

The last challenge in the development of card edge connector was how to increase vibration resistance.

This issue is addressed by applying the slider⁽⁸⁾, which is used in highly vibration resistant connectors. Figure 17 shows a cross-section of the waterproof card edge connector with the slider and the image picture of ECU when mated.

The center of gravity of ECU shown by the image picture is distant from the terminal contact point. Accordingly, when subjected to vibrations from outside, the end of ECU vibrates. The contact points on the terminal are affected, causing fretting wears to occur.

This phenomenon is due to the unique structure of the card edge connector. To increase vibration resistance, it is necessary to reduce relative vibrations between the ECU and the female connector housing.

We have therefore employed such a structure in that the ECU and the female housing are help securely held together by the slider at the location near the center of gravity of the ECU. Figure 18 shows an example of vibration suppression effect when the abovementioned technology is applied. In Fig. 18 (a) without the slider, a phase difference “ θ ” is seen between the acceleration at the front end of ECU and the acceleration at the rear of female housing. In Fig. 18 (b) with the slider, however, such a phase difference is unseen. That means that the ECU and the female housing become an integrated part, which enhances connecting stiffness between the two parts.

The basic technology of this slider is applied in the longitudinal and lateral directions to enhance connection stiffness between the ECU and the female housing.

Figure 19 shows an example of vibration analysis under such conditions. Figure 19 (a) without the slider indicates that the amplitude of oscillation is large at the red part, which corresponds to the front end of ECU. On the

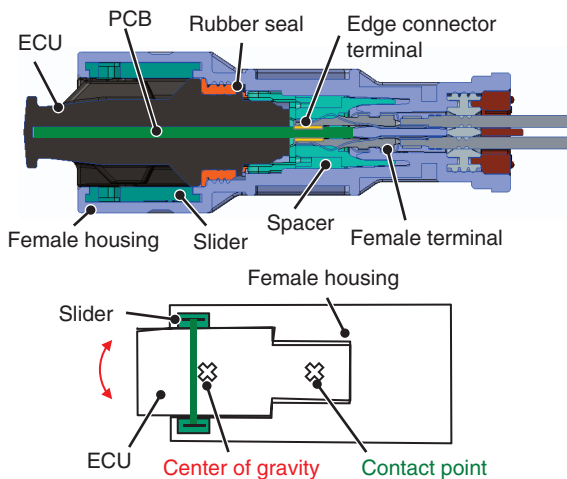


Fig. 17 Cross section of developed vibration-resistant connector with slider

other hand, in the female housing, the vibration amplitude is small as shown by the green color, which means that there is a relative displacement between the two parts. In Fig. 19 (b) with the slider, the ECU and the female housing are of the same green color, which means that there is no relative

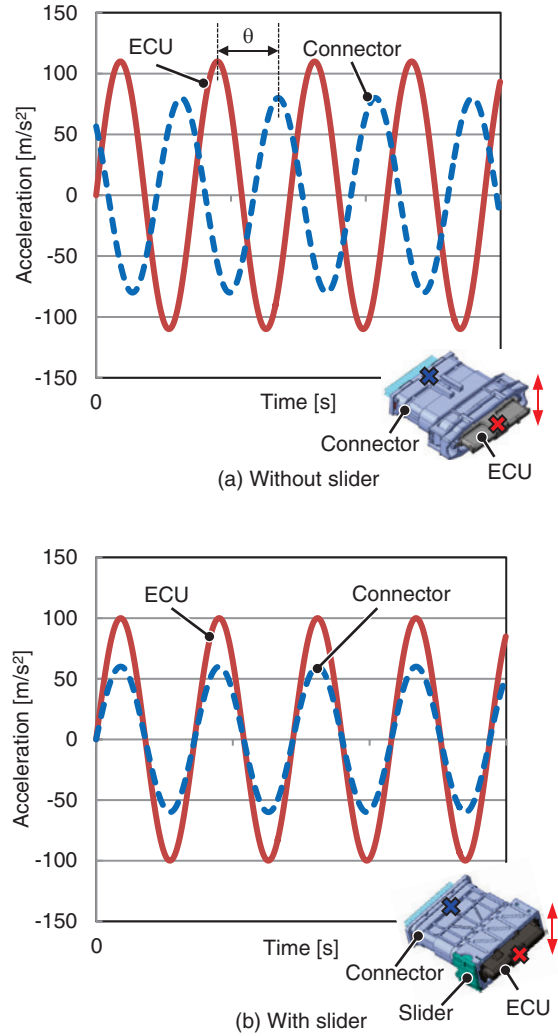


Fig. 18 Vibration suppression effect by slider

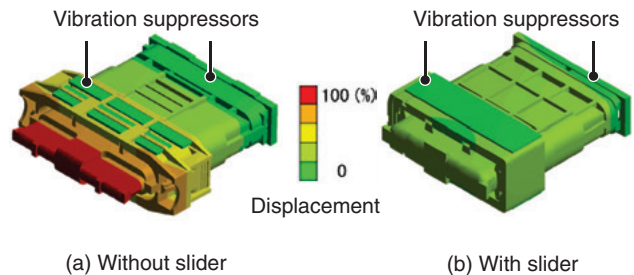


Fig. 19 Vibration analysis result by slider

displacement between the two parts in any direction.

Also, this slider system contributes to maintainability. Figure 20 shows attaching and detaching of the ECU. If there is a 20 mm space in the side of ECU, the slider can be drawn out. This design allows attaching and detaching of ECU in a space smaller than in the conventional type.

The technologies using the waterproof card edge connector with the slider has realized the vibration resistance as high as the conventional design while realizing the good maintainability.

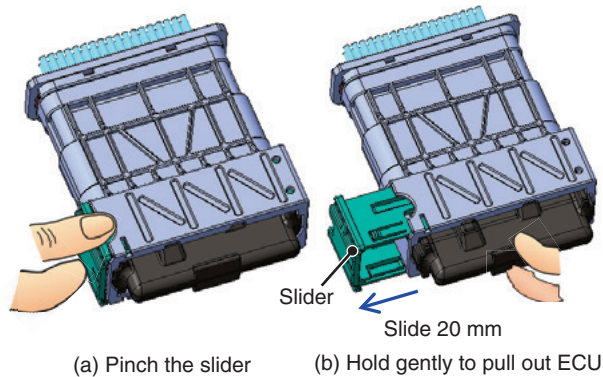


Fig. 20 Good workability by slider

5. Durability and Cost Reduction

Lastly described is the durability and the cost reduction.

5.1. Durability

The durability tests were conducted by the unit test under such conditions in that the ECU mated with the connector at the prescribed conditions along with the actual test runs of the motorcycle.

Mentioned hereafter is about the combined durability test, which is the hardest of all the unit durability tests. This test simulates the working environment of motorcycle by periodically altering the temperature, humidity, current, and vibrations. After the durability test, no fault was found in the electric properties and the waterproofness.

Actual running tests were conducted at the prescribed conditions, and the requirements were satisfied. Moreover, to clarify failure modes of the ECU and the connector, test runs were extended to the distance five times more than the test standard. There was no faulty contact in all the terminals when running. No fault was found in the ECU inspection after the durability tests.

5.2. Cost Reduction

Figure 21 shows the cost breakdown. Compared to the conventional ECU, the number of parts is reduced in the

newly developed ECU by eliminating the male connector and the case. Accordingly, soldering for male connector, resin filling and hardening processes are no longer required in this production process⁽⁹⁾, which contributes to the production efficiency more than five times higher and to the 20% reduction of production cost including the female connector from the conventional design.

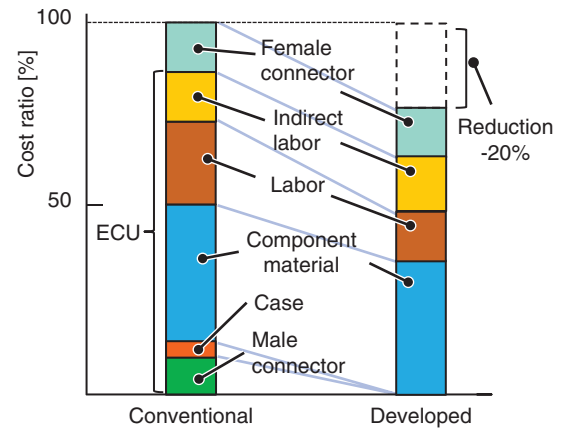


Fig. 21 Cost reduction result and contributing factor

6. Conclusion

With the transfer molding method and the card edge connector applied, the following has been achieved through the development of the new ECU for small motorcycles.

The waterproofness corresponding to IPX7 when the ECU is mated with the card edge connector is achieved by controlling the height of die parting lines on the ECU to under the prescribed level.

The card edge ECU molded by the new die having the movable insert practically realized the world's first waterproof structure as a unit part.

The employment of the card edge connector having a very short momentary interruption of connection permits substitution of the electrolytic capacitor to the ceramic capacitor, contributing to the downsizing and cost reduction of the ECU.

The target production efficiency is achieved by the use of the epoxy resin developed for the ECU along with the application of multi-cavity molding equipment.

The new technologies that helps secure steady connection and reduces vibrations is employed in the waterproof card edge connector to satisfy the vibration resistance requirements as well as maintaining a good maintainability.

With these new technologies applied, the production

efficiency of the new ECU is higher by more than five times than the conventional ECU. Also, the cost of ECU including the female connector is lowered by 20%. Applications of the new ECU to the mass production of small motorcycles having a single-cylinder engine started from the 2018-year model.

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Development of Water- and Oil-repellent Fabric Considering Durability of Automotive Seat Fabric

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ABSTRACT

In order to enhance vehicle usability, seat fabric material was developed that can easily be wiped off and resists staining even by oil from fried foods, snack foods, and other such substances, as well as from mayonnaise and other such oily foods.

The main focus in the past was to increase water repellency by applying a type of fluororesin to fibers by means of a dipping process. Now three types of fluororesin in an appropriate compound have been newly added to the dipping process, and one of those types is also applied to the back of the fabric in a back-coating process. This has made it possible for automobile interior materials to maintain water- and oil-repellency even in the high-temperature environments they are exposed to and following the abrasion caused by occupant entry and exit.

1. Introduction

In recent years, importance has been placed on comfort in the interior of automobiles viewed as personal cars, and with the expansion of the share-car business⁽¹⁾, the automobile interior has been taking on increasing importance. Car seats also have contact with vehicle occupants and can contribute greatly to enhancing comfort. Seats are being mass-produced using fabrics with deodorizing, anti-allergen, and anti-virus finishes⁽²⁾, etc.

As the needs for enhanced comfort in seat fabric materials are expanding, a study was conducted of the functions sought in car seat fabrics by users in Japan, China, Thailand, and the United States.

The study was conducted on male and female private car owners aged 20 years and over, with approximately 600 study subjects in each country. Figure 1 shows the results. Given such items as protection from soiling, reduction of stuffiness and stickiness, deodorizing, protection from scratching, and so on, it was found that the greatest needs expressed in every country were for ease in wiping off dirt and protection from spilled food and drinks.

At present, most automobile manufacturers are generally utilizing water-repellent fabrics as a performance material to deal with spilled food and drinks. In comparison with non-processed fabrics, drinks and other such aqueous liquids are less likely to stain and spills are easier to wipe up. Oils, however, are more likely to stain and tend to readily permeate the fabric. Due to the structure of the car seat, when soiling of this kind permeates to the back side of the fabric, it can permeate as far as the wadding

urethane, cover, and seat cushion pad⁽³⁾. Such stains are not readily removed, and can also become a source of odors. In light of enhanced usability, therefore, it was reasoned that adding the ability to deal with oil stains from fried foods, snack foods, and so on, as well as soiling from mayonnaise and other such oily foods, would contribute to enhanced comfort.

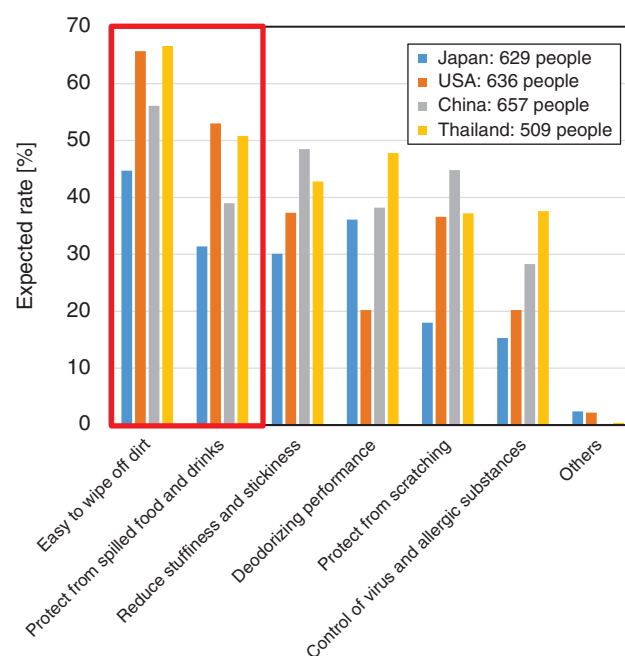


Fig. 1 Expected functions for car seats

¹ Automobile Center

It is also the case that when car seat fabrics are exposed to high-temperature environments, they are simultaneously subjected to abrasion from occupant entry and exit. Durability with respect to these factors thus also needs to be taken into account, as well as the needs for external appearance and other such features that are required of automotive seat fabrics.

Given the above background, the present research aimed to enhance comfort in the car interior through development of water- and oil-repellent seat fabrics that can satisfy the basic performance desired for seat materials by providing for durability against abrasion in a variety of scenarios of high temperatures and occupant entry and exit, while still resisting staining from spilled food and drink that may adhere to the fabric, and allowing spilled matter to be easily wiped up.

2. Conceptual Approach to Target and In-house Evaluation Criteria

As the Japanese Industrial Standards (JIS) include no test methods or technical standards for fibers being soiled by food and drink, an investigation was made of test methods and target values for confirming that a developed product would repel soiling, resist staining, and be easily wiped off. This involved more than just configuration of initial values, and extended also to the performance sought for seat fabrics in terms of durability following heat aging, heat and humidity aging, and abrasion.

2.1. Settings for Types of Soiling

The types of soiling to be covered when testing performance were established in accordance with results from a study of types of soiling from foods and drinks that can adhere to car seats. The study was conducted with 43 Honda employees as subjects. Examples of the substances tested were chocolate, potato chips and other such snack foods, Worcestershire sauce, mayonnaise and other such condiments, and tea, coffee and other drinks. The general categories of components in types of food and drink stains are shown in Fig. 2.

Based on the previously described results, the following were set as representative substances for the various types of stains: For aqueous liquid stains, Worcestershire sauce was chosen because the distinct staining caused by its

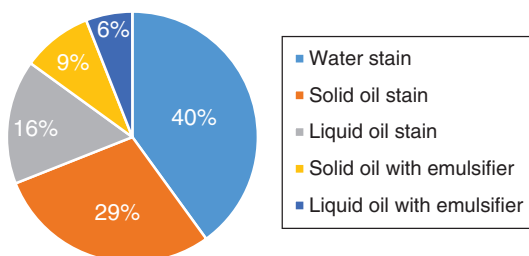


Fig. 2 Types of stains (foods and drinks)

Table 1 Typical stains adhered to seat

Classification	Target stain
Water stain (dark color)	Worcestershire sauce
Solid oil stain + Protein	Mayonnaise (sandwich, hamburger)
Liquid oil stain	Salad oil (potato chips)
Solid oil and emulsifier	Chocolate
Liquid oil and emulsifier	Coffee cream

Table 2 Requirements of water- and oil-repellent performance

Test item			Requirement
Water- and oil-repellent	Water- and oil-repellent (for foods)	Initial state	Contact angle between stain and test piece is over 90°
	Water-repellent (for drinks)	Initial state	Grade 4 min.
		· After heat aging · After heat and humid aging · After abrasion	Grade 3 min.

dark color can be easily discerned; for solid oil stains, the substance chosen was mayonnaise, which includes oil and protein; and for liquid oil stains, the substance chosen was salad oil, which is used in snacks and other foods. For staining by a solid oil with an emulsifier, chocolate was chosen, as temperature changes cause it to become a liquid; and for staining by a liquid oil with an emulsifier, the substance chosen was coffee cream (Table 1). Ordinary products from specific manufacturers were chosen for each type of stain.

2.2. Fabric Standalone Performance

2.2.1. Water- and oil-repellency

Regarding water- and oil-repellency, it was confirmed that a fabric will generally repel the soiling substance when the contact angle between the fabric and the substance causing adherence is 90° or greater⁽⁴⁾. The test was therefore configured so that the food and drink items in Table 1 would adhere to the fabric with a contact angle between stain and test piece of 90° or greater. Regarding water repellency with respect to soiling by drinks, the “Testing methods for water resistance of textiles” in JIS L 1092 (2009) that are also configured for use with conventional water-repellent fabrics were taken as a basis. The initial target value was set at Grade 4 or higher, and the value after aging at Grade 3 or higher. Table 2 shows Requirements of water- and oil-repellent performance.

2.2.2. Resistance to permeability to the back side

Resistance to permeability to the back side defines resistance to staining, and high-temperature states were taken into account to address users who only drive on

Table 3 Requirements of permeability to fabric back side

Test item		Requirement
Permeability to fabric back side	Initial state	No penetration to back side
	· After heat aging · After heat and humid aging · After abrasion	No penetration to back side

Table 4 Requirements of wipeability

Test item		Requirement
Wipeability	Initial state	After wet wipe: Grade 4 min.
	· After heat aging · After heat and humid aging · After abrasion	After wet wipe: Grade 3 min.

weekends and cause soiling substances to adhere to the fabric during high summer, only noticing it a week later. Target values were set so that the substance would not stain the fabric completely even in these conditions.

Testing employed the five types of stain substances in Table 1. The accelerated test conditions used to confirm the influence of high temperatures were set at 80°C × 24 h. This was calculated from the actual vehicle temperature measurement data obtained by the thermal history concentration method⁽⁶⁾ that employs Arrhenius plots and that is also used with rubber and organic materials. The objective was for the fabric to resist allowing the stain to permeate to the back side, even after leaving a substance on the fabric for the prescribed period, thereby staining it. Table 3 shows the Requirements of permeability to fabric back side.

2.2.3. Wipeability

In order to confirm wipeability, methods of wiping substances off the fabric were defined (Fig. 3). Dry- and wet-wipe methods were chosen since these obtained

approximately 80% responses in an in-house questionnaire survey. First, a soiling substance was dripped onto the fabric and a dry wipe was used without pressing to avoid the substance physically infiltrating the structure of the fibers. If any soiling remained after the substance was wiped off, a wet wipe was used with a tapping motion. The “Grey scale for assessing staining” in JIS L 0805 (2005)⁽⁷⁾ was then used to evaluate the differing intensity of staining once the above methods were used to wipe off the fabric following application of the test conditions described in Clause 2.2.2. Generally, a difference in stain intensity that users can easily perceive will be classified under Grade 3, so the target value for the fabric after durability aging is defined as Grade 3 or higher, while the initial value is defined as Grade 4 or higher. Table 4 shows the Requirements of permeability to fabric back side.

2.2.4. Basic performance of fabric

Together with providing water- and oil-repellency, resistance to permeability to the backside, and wipeability, the developed product was defined as having the strength characteristics, color fastness, and other such elements of basic performance required of car seat fabrics equal to or at a higher level than non-processed products. Table 5 shows the performance items and test methods.

2.3. Seat Assembly Performance

2.3.1. Manufacturability of seat assembly

When utilizing the fabric material in seat assembly, it is important to maintain manufacturability and appearance for good product appeal. Generally, fabrics become harder when coated with processing agents, so various items were defined for confirmation. These include checking whether water- and oil-repellent fabrics have developed wrinkles typical of such materials, whether the steam applied during manufacturing has caused steam marks to be left as white traces, whether the sewing process has left visible needle holes, and so on.



Fig. 3 Test method of wiping off

Table 5 Test items for basic performance of seat fabric

	Items	Test methods
Basic items	Constant elongation	JIS L 1096 Testing methods for woven and knitted fabrics ⁽⁸⁾
	Tensile elongation	JIS L 1096 Testing methods for woven and knitted fabrics ⁽⁸⁾
	Tearing strength	JIS L 1096 Testing methods for woven and knitted fabrics ⁽⁸⁾
Concern items	Electrification property	JIS L 1094 Testing methods for electrostatic propensity of woven and knitted fabrics ⁽⁹⁾
	Flammability	FMVSS Flammability of Interior Materials ⁽¹⁰⁾
	Color fastness	JIS L 0849 Test methods for color fastness to rubbing ⁽¹¹⁾
	Light resistance	JIS L 1096 Testing methods for woven and knitted fabrics ⁽⁸⁾
	Heat resistance	Color change of test piece after standing at 110°C for 200 hours is judged using gray scale
	Heat and humidity resistance	Color change of test piece after standing at 50°C /95RH for 500 hours is judged using gray scale

2.3.2. Seat assembly durability performance with respect to entry and exit

Seat assembly durability performance with respect to entry and exit was verified by checking appearance for good product appeal, permeability to the back side, and wipeability of the product. Durability testing with respect to entry and exit comprises testing of the seat assembly using a robot with a dummy of a vehicle occupant's buttocks. The test involves the robot repeating the back-and forth actions for entry and exit mode. As to appearance for good product appeal, the objective was defined as not having any visible deposits of resin, unusual abrasions, or other such issues. To verify resistance to permeability to the back side and wipeability, portions of the seat fabric were removed from the seat assembly after durability testing for entry and exit. The objective for the seat fabric was to satisfy the target value for abrasion durability after applying salad oil, which was chosen from the five stain types shown in Table 1 because of its lower surface tension.

3. Basic Specifications of Water- and Oil-Repellent Fabrics

3.1. Conventional Water-Repellent Fabric Specifications and Issues for Water- and Oil-Repellent Fabric Material

Water- and oil-repelling performance produces its effect by means of fine cilia such as those found on lotus leaves and peach skins, and from chemical action that produces its effect by a coating of chemical agents⁽⁴⁾. For the present development, it was decided to adopt chemical action because it imposes fewer constraints on the design and

can continue to provide performance even after testing for durability with respect to entry and exit.

The reasons why coating with chemical agents yields performance are given as follows. When a droplet of liquid (water, oil, etc.) placed on the surface of a solid forms contact angle θ , the surface tension γ_L of the droplet, the surface tension γ_s of the solid surface, and the interaction γ_{LS} between the solid and the droplet are described by Young's equation⁽⁴⁾ as shown in Eq. (1).

$$\gamma_s = \gamma_L \cos\theta + \gamma_{LS} \quad (1)$$

$$\cos\theta = (\gamma_s - \gamma_{LS}) / \gamma_L \quad (2)$$

Equation (1) can be converted into Eq. (2), which shows that when the surface tension of the solid is lower than that of the liquid, the lower it is the greater the contact angle will be, thereby yielding repellent performance. Consequently, silicone resin with the CH_3 group and fluororesin with the CF_3 group that have low surface tension can be cited as prime examples of agents for chemical action. However, since the CF_3 group has lower surface tension than the CH_3 group, the same fluororesin used in conventional water-repellent fabric was investigated. Figure 4 shows an example of a fluororesin array on a fiber. Thus, the main chain of adhesive polymer adheres to the fiber and the fluororesin side-chain yields water- and oil-repelling performance.

Conventional water-repellent fabric is coated by dipping it in a fluororesin of one type that has a hydrophilic group. Figure 5 shows the structure of conventional water-repellent fabric material. Fluororesin is distributed over the entirety of the fabric fibers and is fixed on it by the dipping process.

However, even though this material specification yields satisfactory water repellency, oil has lower surface

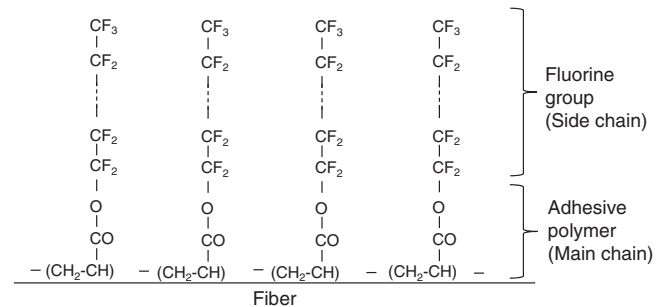


Fig. 4 Array of fluororesin on fiber

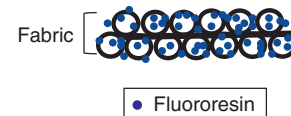


Fig. 5 Structure of conventional fabric

tension than water and so this specification does not yield the objective of satisfactory oil repellency. Furthermore, if larger amounts of fluororesin are coated than that coated on conventional mass-produced water-repellent fabric in order to yield satisfactory water- and oil-repelling performance, then when the fabric is scratched by a fingernail or other such object, it will leave visible white traces known as chalk marks and will reduce electrification and flame resistance. These are examples of how this would be counterproductive.

Measures were devised regarding fabric structure and selection and compounding of a type of fluororesin in order to yield satisfactory target values while also resolving these issues. In order to remove the water- and oil-repelling performance rooted in physical action by cilia from the fabric used for verification, the testing was conducted with non-raised tricot fabric.

3.2. Selection and Compounding of Fluororesin for Use in Dipping Process

The fluororesin (Type A) with a hydrophilic group that is used in conventional water-repellent fabric material, as described in Section 3.1., has the advantage of achieving a simultaneous balance with electrification. It also has the characteristic, however, that physical impact and thermal load can cause the orientation to become disordered so that water- and oil-repelling performance is reduced (Fig. 6).

Fluororesins of various types were therefore selected. First, for the main chain, an adhesive polymer of a high glass transition point (T_g) type was arranged and a fluororesin (Type B) was selected that, by rigidifying the

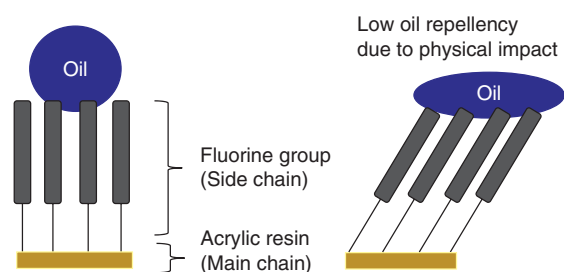


Fig. 6 Image of chemical structure of fluororesin

Table 6 Test results of one kind of fluororesin

Percentage of fluororesin (%)	Type A	100	0	0
	Type B	0	100	0
	Type C	0	0	100
Concern property items	Permeability to fabric back side	–	+	–
	Water-repellent (Test result)	+(Grade 5)	–(Grade 3)	+(Grade 4)
	Chalk mark	–	–	–

+ : Acceptable
– : Unacceptable

main chain, causes the orientation of the side-chain fluorine group to be less susceptible to becoming disordered and enhances water- and oil-repelling performance. When the polymer changes from a liquid to a solid, it goes from a rubber state in which the molecules move easily to a glass state in which the movement of the molecules is limited. T_g is the temperature at which it changes to this glass state, and a type with a higher T_g exists in a higher temperature range when in a glass state. Thus, the main chain rigidifies even when the interior temperature reaches a high level, making the orientation of the side-chain fluorine group less susceptible to becoming disordered.

Next a fluororesin (Type C) was selected that has an adhesive polymer main chain with a lower T_g than Type B and that therefore limits the hardness of the fabric after processing. Figure 7 shows a schematic illustration of the selected fluororesin and their features. Table 6 shows the results for initial resistance to permeability to the back side by salad oil when left standing after exposure to $80^\circ\text{C} \times 24$ h, initial water repellency, and chalk mark with test pieces each coated with just one of the Type A, Type B, or Type C fluororesins. As this indicates, the desired performance could not be satisfactorily realized with just one kind of fluororesin.

In order to meet all the target values, therefore, an investigation was made into compounding three kinds of fluororesin and adjusting their proportions.

Table 7 shows the results for initial resistance to permeability to the back side by salad oil when left standing after exposure to $80^\circ\text{C} \times 24$ h, initial water repellency, and chalk mark with Type A, Type B, or Type C in varying proportions.

Type of fluororesin		
Type A	Type B	Type C
Fluorine group Acrylic resin Hydrophilic group	Fluorine group Acrylic resin (high T_g)	Fluorine group Acrylic resin (low T_g)
Control electrification performance by hydrophilic group	Advanced oil repellent performance by high T_g	Control hardness of fabric by lower T_g than Type B

Fig. 7 Features of fluororesin

Table 7 Test results with varying proportion of fluororesin

Percentage of fluororesin (%)	Type A	95.2	52	25	0
	Type B	4.8	2	0	4.8
	Type C	0	46	75	95.2
Concern property items	Permeability to fabric back side	+	+	–	+
	Water-repellent (Test result)	– (Grade 3)	+	+	– (Grade 3)
	Chalk mark	–	+	+	–

+: Acceptable
–: Unacceptable

The results show that chalk mark results are unacceptable unless the Type B fluororesin is in a low proportion, but unless some Type B is included in the compound, the oil repellency cannot meet the target value. It was also found that including just two kinds would not achieve satisfactory results. By observing the balance of the three kinds of fluororesin in this way, the optimal compounding proportion was ascertained.

3.3. Optimization through Treatment Process

Even when the three kinds of fluororesin have been compounded, treatment by the dipping process alone results in variations in water- and oil-repelling performance because the pattern in the seat fabric has raised and recessed portions, and the increased amount of resins reduced flame resistance. Another factor is that each treatment process involves a drying process to fix the dye and chemical agent to the material, adding to the thermal history, which was found to become an issue for color fastness due to sublimation of the dye. These issues were resolved by optimization of the treatment process.

3.3.1. Performance stabilized by back-coating process

In order to limit variations in water- and oil-repelling performance and reduction in flame resistance, a process of back coating with fluororesin (Type A) that includes a hydrophilic group as well as a flame retardant was applied to the back side of the fabric. Ordinarily, back coating is used to apply a coating of flame retardant, but in this case, the addition of fluororesin successfully stabilized the material's oil-repellency and resistance to permeability to the back side. Also, as shown in Fig. 8, treating the material with fluororesin using a combination of dipping and back coating provided stable, satisfactory water- and oil-repelling performance regardless of fabric pattern.

3.3.2. Maintaining color fastness by addition of washing process

Since the addition of the back-coating process caused the drying process to increase, the resulting increase in the thermal history made color fastness an issue. Consequently, it became necessary to remove excess dye so that the target values for color fastness could be met even in the case of darker-colored fabric that contains larger amounts of dye, and a washing process was added after the dipping process. Figure 9 shows the developed treatment process.

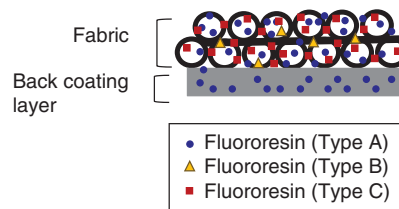


Fig. 8 Fabric structure

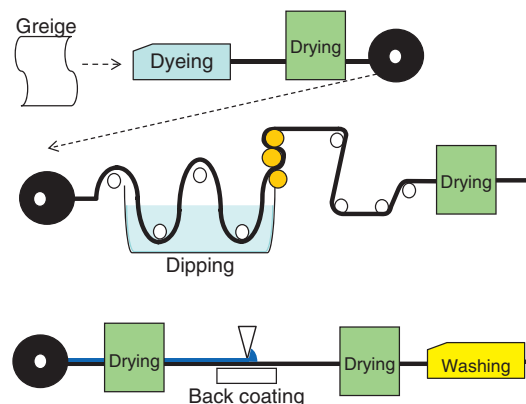


Fig. 9 Process of chemical compound treatment

4. Results of Performance Tests

4.1. Fabric Standalone Performance Results

Tables 8 through 10 show the results for the in-house evaluation criteria defined for the water- and oil-repellent fabric developed here. As indicated, all target values were confirmed to have been satisfactorily achieved. The results for the developed product also compare favorably with non-processed products in terms of the basic performance sought in car seat fabric, and the fabric standalone performance satisfactorily meets all of the in-house evaluation criteria.

Figure 10 shows the comparative results for initial

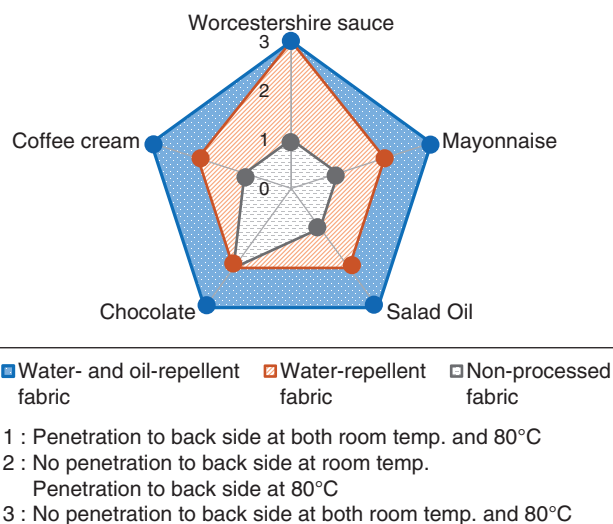


Fig. 10 Comparison of permeability

Table 8 Test results for water- and oil-repellent performance

Test item		Requirement	Test result	Judgement
Water- and oil-repellent	Water-repellent (for drinks)	Initial state	Grade 4 min.	Acceptable
		· After heat aging · After heat and humid aging · After abrasion	Grade 3 min.	
	Water- and oil-repellent (for foods)	Initial state	Contact angle between stain and test piece is over 90°	

Table 9 Test results for permeability to fabric back side

Test item		Requirement	Test result	Judgement
Permeability to fabric back side	Initial state	No penetration to back side	None	Acceptable
	· After heat aging · After heat and humid aging · After abrasion	No penetration to back side	None	

Table 10 Test results for wipeability

Test item		Requirement	Test result		Judgement
Wipeability	Initial state	After wet wipe: Grade 4 min.	Worcestershire sauce 4 Mayonnaise 4 Salad oil 4 Chocolate 4 Coffee cream 4		Acceptable
	(1)After heat aging (2)After heat and humid aging (3)After abrasion	After wet wipe: Grade 3 min.	(1)	Worcestershire sauce 4 Mayonnaise 3.5 Salad oil 4 Chocolate 4 Coffee cream 3	
			(2)	Worcestershire sauce 4 Mayonnaise 3.5 Salad oil 4 Chocolate 4 Coffee cream 4	
			(3)	Worcestershire sauce 4 Mayonnaise 4 Salad oil 3.5 Chocolate 4 Coffee cream 4	

permeability to the back side of the fabric by the five types of stain substances applied to water- and oil-repellent fabric, mass-produced water-repellent fabric, and non-processed fabric materials after standing for 24 hours at room temperature and at 80°C. When a colored background covers a larger area, this means the corresponding fabric is displaying increased water- and oil-repelling performance.

The non-processed fabric material was permeated by every type of stain substance except chocolate at room temperature and at 80°C. The mass-produced water-

repellent fabric material was not permeated at room temperature, but it was permeated at 80°C by every type of stain substance except Worcestershire sauce. In contrast with these, the water- and oil-repellent fabric material showed no permeation by any of the stain substances either at room temperature or at 80°C.

Further results confirming permeability by salad oil at an initial 80°C are shown as a representative case in Fig. 11. This confirms that the developed product possesses oil-repellency.

In addition to the test with salad oil, performance was confirmed by placing fried chicken, which tends to exude oil, on water- and oil-repellent fabric and non-processed fabric materials. Figure 12 shows the results. The non-processed fabric developed stains soon after the chicken was placed on it, but oil stains were not seen on the water- and oil-repellent fabric even after leaving the chicken on it for seven days.

4.2. Seat Assembly Performance Results

The developed product was also confirmed to have satisfactorily achieved all the objectives for manufacturability of the seat assembly. The results for seat assembly performance after aging for durability with respect to entry and exit described in Clause 2.3.2. are shown in Fig. 13. The developed product was successfully confirmed to have satisfied the item regarding seat assembly performance after aging for durability with respect to entry and exit.

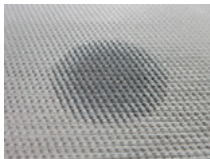
	Water- and oil-repellent (developed item)	Water-repellent (mass production)	Non-processed
Salad oil			
Results	Oil-repellent	Penetrate	Penetrate

Fig. 11 Comparison of developed material

	Water- and oil-repellent (developed item)	Non-processed
	After one week	After 5 seconds
Fried chicken		
Results	Oil-repellent	Penetrate

Fig. 12 Result of placing fried chicken

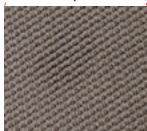
Test items	Requirements	Results
Ingress and egress durability (10000 cycles)	· No unusualness such as wrinkles · No tear of fabric	Acceptable 
Permeability and wipeability after ingress and egress durability test	· No penetration to back side · After wet wipe: Grade 3 min.	Acceptable (Grade 3.5) 

Fig. 13 Results of ingress and egress durability test

5. Conclusion

In the present research, water- and oil-repellent fabric was developed that is readily wipeable and resists staining from food and drink containing oil that adhere to car seat fabrics even in the high temperatures to which such material is exposed, and even after providing for durability against abrasion.

- (1) Three types of fluororesin in appropriate compounding proportions were applied in a dipping process and one type of fluororesin was applied in a back-coating process. With these specifications established, the treated materials displayed water- and oil-repellency in high temperatures and following abrasion. This approach also satisfied the need for the seat assembly to realize an appearance for good product appeal.
- (2) By adding a washing process to follow fluororesin dipping, the need for color fastness was satisfied and stable production processes were established even for material with varying gradations of color.

The water- and oil-repellent fabric developed through the present research was applied in the 2020 model year STEPWGN. The technology for providing seat fabric with added functionality is expected to have expanded applications for these seats not only in automobiles but also in buses, trains, and so on, as well as in upholstery for sofas and other such applications where the fabrics cannot be laundered.

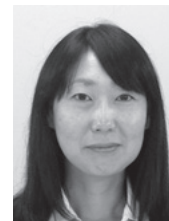
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Honda RaaS Platform

Honda Robotics as a Service Platform Integrates Cloud and Robot Technology

Haruomi HIGASHI¹

ABSTRACT

Honda Robotics as a Service Platform is a platform for the purpose of developing and operating robotics services.

In terms of development and operation for the purpose of establishing such services, past verification tests of delivery service using ASIMO identified issues for further work that required investigation relating to the network, the creation of testing environments, the development and operational environments, and the establishment and expansion of service.

Regarding each of the above issues, the Honda RaaS Platform can enhance the development and operation of robotics services by providing for a secure communication environment and expansion of the operating area by means of SIM, a scalable infrastructure environment using the Cloud, a development and debugging environment that is network accessible, an operational environment that enables remote monitoring, and an environment for establishment and expansion of service by API provision.

In addition to showing the architecture and interface of the Honda RaaS Platform, the concept of “collaboration of diverse talents all over the world” was also proven by case examples of a series of delivery services that create collaboration and coordination by multiple different robotics devices.

1. Introduction

Looking ahead to the year 2050 when Honda passes the centennial of its founding, the company formulated the 2030 Vision in 2017⁽¹⁾. This makes a statement, which is, “Serve people worldwide with the ‘joy of expanding their life’s potential’: Lead the advancement of mobility and enable people everywhere in the world to improve their daily lives.”

The Honda Robotics as a Service (RaaS) Platform was proposed in 2017 as a theme that would provide one means of realizing that vision in material form by taking steps to strengthen the company’s capability for creating solutions; not only in hardware, where Honda had for a long time boasted particular strengths in a wide range of Mono-zukuri (creating things, i.e. high-quality manufacturing), but also including Koto-zukuri (creating experiences) by means of software. The role this would play at Honda would be to aggregate the results of advanced research and development on various algorithms and applications within the company in reusable form, combined and organized to be of use to people worldwide. In doing so, it would heighten the value and importance of software throughout the company.

2. Robotics Vision

The history of robot development at Honda started in 1986 with research and development on bipedal walking (Fig. 1). Honda Robotics is the collective name for robotics technology produced from research on humanoid robots, exemplified by ASIMO, together with products for practical application. In parallel with that thrust, the development of ASIMO also involved the development of integrated control systems for the automation of reception desk and delivery service functions. The aim was to realize “a robot that can coexist with and assist people in society^{(2), (3)}.”



Fig. 1 Honda Robotics history

¹ Life Creation Center

In 2018, Honda announced a new vision of robotics that aimed to realize a “human-centered intelligent robotics society.” This was announced together with the concept of “3E,” which stands for “Empower, Experience, Empathy” (Fig. 2)⁽⁴⁾.

“Empower” in the 3E concept means that people and robotic devices work cooperatively in their respective areas of particular strength to provide people with an extra margin of capability in terms of their time, psychological state, and bodily state. People can then turn that extra capability in new directions to expand their own possibilities. “Experience” means that people experience entirely new things through robotics to enable them to grow. Robotic devices will also learn from people and grow in themselves to become better able to serve people. “Empathy” is a conceptual approach according to which robotic devices will care about people, empathize with them, and provide support for what people do.

It is clear, therefore, that “artificial intelligence that cooperates with people” will be a crucial factor in realizing the 3E concept.

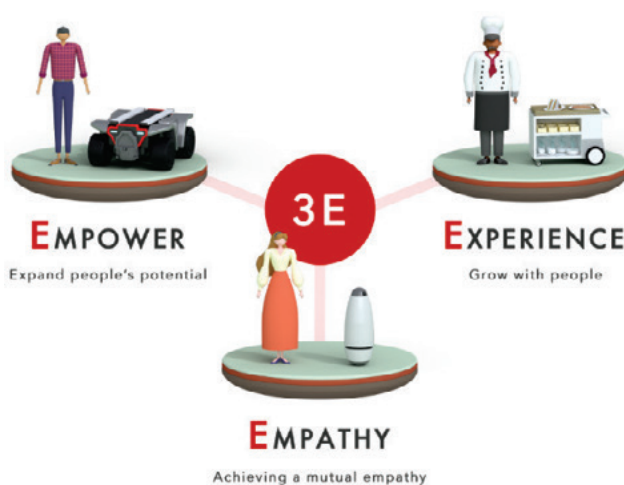


Fig. 2 3E concept

3. Robotics as a Service: RaaS

RaaS is generally considered to mean providing robotic functionality by means of the cloud. This approach seeks to have the burden of high-load processing taken on in the cloud environment so that the processing burden on the robot side can be lessened (off-loaded). Honda further reasons that making use of RaaS will bring the three main advantages shown below:

- (1) Increased efficiency in development and operation of common management for robots;
- (2) Flexible cost management according to robot operating circumstances; and
- (3) Continuous updating for new functions.

In (1), the basic functions for implementing robot management and operation are made common functions that are reusable. This enhances the efficiency of robot service development and operation.

In (2), RaaS makes it possible to charge according to the service used and so on, for example by calculating the cost just for the portion of a service that utilized a robot.

In (3), the software in the robot and in the cloud can be updated continuously so it is kept up to date. This makes it possible to respond flexibly with robotic services that address customer needs and requests.

4. Concept of Honda RaaS Platform

Having a multiplicity of different, human-centered robots cooperate and coordinate is a crucial factor in realizing the Robotics Vision. The capability to seamlessly link together systems and robots that are not just from Honda but also from various development partners is key. Honda announced its RaaS Platform Concept at CES 2019 as the base system for realization of the “human-centered intelligent robotics society” that is the Robotics Vision as well as of the 3E concept and cooperative intelligence (CI)⁽⁵⁾.

The Honda RaaS Platform is intended to ease the development and operation of robotic services. It does this by providing data accumulation and sharing, communication control, state transition management, cooperation among robots, and other such common functions by means of an interface, which is the application programming interface (API), or as a software development kit (SDK) (Fig. 3).

The Honda RaaS Platform also involves the concept of “collaboration of diverse talents all over the world.” This concept aims to realize services that a single robot cannot provide by linking together robots and systems that have various different roles and functions and causing them to work together cooperatively. In other words, the goal that should be aimed for is to work together with various robot manufacturers, service integrators, and so on to cultivate platforms while also building arrangements to enable mass production of robotic services by large numbers of people⁽⁵⁾⁻⁽⁸⁾.

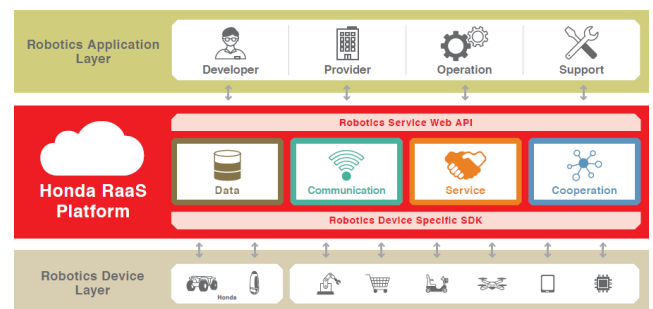


Fig. 3 Honda RaaS Platform conceptual diagram

Issues for enhancement of the network will be addressed by implementing cellular communications using SIMs provided for the robots by the Honda RaaS Platform, following the approach in item (1) above, so that they can also communicate in other than the WiFi domain. This will enable the robots to connect with the network in various locations both indoors and outdoors, allowing the operating area to expand. The SIM information for each robot will also be used to implement device authentication, and the ability to communicate over cellular circuits, without passing through the Internet, means that secure communication between robots and the cloud can be established. Secure communication on the Honda RaaS Platform is capable of covering both WiFi communication and cellular communication by SIM. In the case of WiFi, security is enhanced when communicating over the Internet by using security tokens issued by the Honda RaaS Platform that are needed for authentication.

Issues for enhancement related to the creation of testing environments were addressed by the approach in item (2) to provide an infrastructure environment that uses a cloud environment to enable the increase of dynamic computational resources and distribution of loads (i.e. is scalable) according to processing capability. If a web browser is available, then it will also be possible to access the web GUI of the Honda RaaS Platform from any terminal and easily carry out registration and management of the robots at each center without having to log on individually to each server.

Issues for enhancement of the development environment were addressed by the approach in item (3), which makes it possible to conduct quick and continuous development and modification by making newly developed software available over the network in a form usable by the robots. The developers will also be able to log on to a robot remotely by means of its SIM from any terminal. This will allow them to change its configuration and access the robot's log for debugging.

Issues for enhancement of the operational environment were addressed by the approach in item (4), which allows operators to remotely check and monitor the robot's

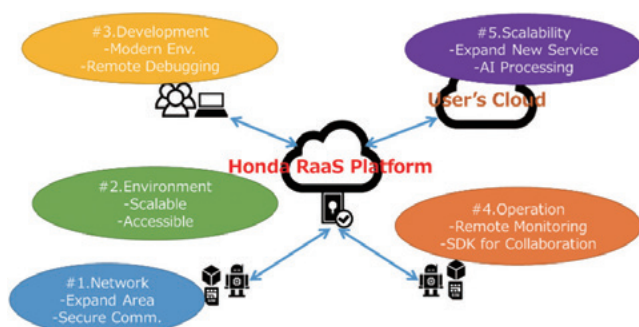


Fig. 6 Approach of Honda RaaS Platform

operating circumstances from a remote location, thereby enabling efficient batch monitoring. The operational environment can also be linked with various external systems by means of Web API and SDK.

Issues for enhancement with regard to the costs of establishing services were addressed by the approach in item (5), whereby the Web API provided by the Honda RaaS Platform is used to link together the cloud environment of the user (hereafter, User's Cloud) and the system, allowing expansion of robotic service functionality. In this way, the core functions provided by the Honda RaaS Platform can be augmented by developing new functions, expanding existing services, and so on. This also makes it possible for high-load processing, such as machine learning, AI processing, and other processing that cuts across multiple systems to be off-loaded to the cloud environment (distributing the load). Doing so expands the possibilities for realizing various use cases, such as, for example, when searching for a specific person in order to go outside to greet that person, which involves linking to external systems to acquire information on the location of the specific person.

6.1. Roles of the Honda RaaS Platform

One of the main roles of the Honda RaaS Platform is to grasp the state of connected robots and to issue instructions by appropriately distributing tasks among them. For example, in the case of the tea delivery service, the platform takes on the role of task management and instruction control for each robot during the process of executing the overall scenario. As each robot receives task instructions from the Honda RaaS Platform's task management and instruction control, the robots perform the tasks involved, such as loading the tea, transporting the tea, and so on. All of the tasks are managed by the Honda RaaS Platform, and the status of task execution can be checked by developers and operators through the Honda RaaS Platform's Web GUI screen (Fig. 7).

The Web GUI screen of the Honda RaaS Platform consists of a map showing the current locations of the

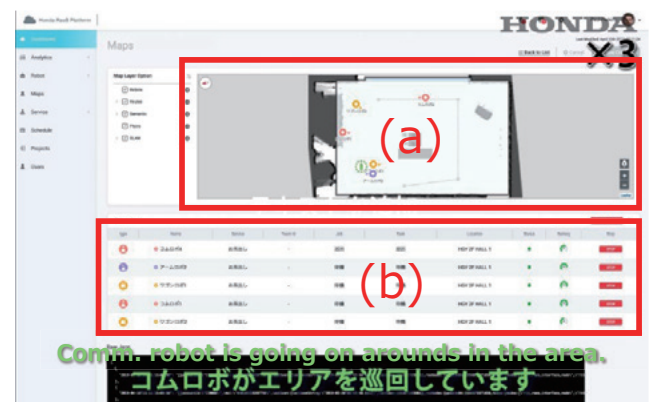


Fig. 7 Web GUI configuration

robots [Fig. 7(a)] and a robot list showing the current status of the robots [Fig. 7(b)].

The robot list provides for control of the status of robot tasks and so on. When there is an update to a task, the line for the robot concerned flashes blue and blinks at the same time that the task update takes place. After the communication robot receives an order for tea, for example, the figure here shows how the wagon robot's task is updated by the Honda RaaS Platform from stand-by to delivery (Fig. 8).

6.2. Image of Overall Function

The image here summarizes the overall function of the Honda RaaS Platform used for the delivery service (Fig. 9).

- (1) Secure communication with authentication by SIM and TLS protection
- (2) Transfer robot data to the User's Cloud environment
- (3) Enable visualization of robot task status and location information
- (4) Create service scenario applications using API

6.3. Architecture and Interface

The diagram of the architecture shown here should help give an overall understanding of the Honda RaaS Platform (Fig. 10). The Honda RaaS Platform is made

up of three layers, which are the infrastructure service layer, the application service layer, and the interface layer. The functions implemented on the infrastructure service layer mainly involve networks and authentication. The application service layer has implementations of various applications related to functions needed by the Web API and Web GUI.

The explanation here will be related primarily to the interface layer. In the interface layer, robots are provided SIM and cirobot-sdk as interfaces that enable the robots to use the Honda RaaS Platform. Robot developers can connect the robots they are developing with the Honda RaaS Platform by inserting a SIM and installing cirobot-sdk, which is an SDK implemented in the programming language python. cirobot-sdk mainly provides functionality relating to communication, and it is software that conceals the authentication and communication protocols (HTTP, MQTT, and so on) between Honda RaaS Platform and the robot. It also provides RosNode, which is geared to use with the robot communication middleware ROS⁽⁹⁾. Equipped in this way, robot developers who use ROS can engage in ROS Topic communication and programming for the purpose of linking and coordination with other robots that are connected to the cloud without having to be any more aware of the cloud than necessary.

The User's Cloud is provided with Web API and ciraas-sdk (a python client application). Service integrators can use Web API and ciraas-sdk to build robotic services. The data that the Honda RaaS Platform receives from robots is transferred to stream services on the User's Cloud. On the User's Cloud, users can freely utilize the Honda RaaS Platform Web API to build applications. The Web API is designed as the REST API, which is an HTTP interface with web systems. ciraas-sdk provides functionality for dialogic programming on the User's Cloud.

Client systems for operation on the PCs, tablets, or other such operator equipment are provided with Web GUI as an interface. Operators who want to use an operational environment can access Web GUI from a device of their own choosing, allowing them to monitor operation while tracking robot registration and location or other such information.



Fig. 8 Honda RaaS Platform sends task

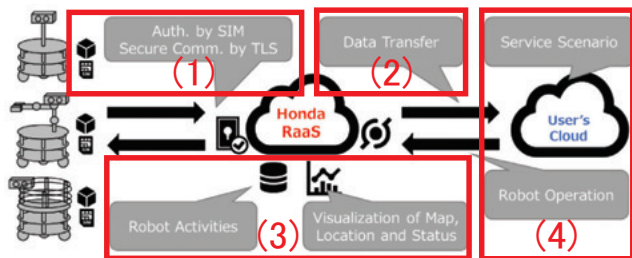


Fig. 9 Overall function

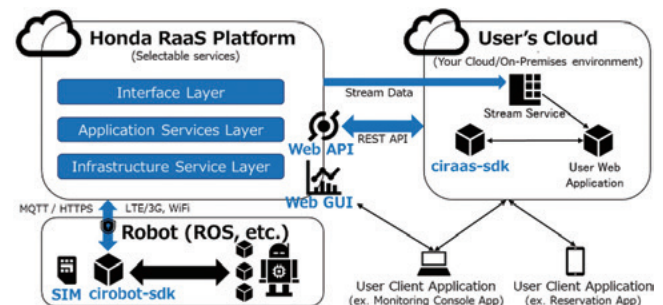


Fig. 10 System architecture diagram

6.4. Methods for Creating Robotics Services

Engineers wishing to create robotic services who are users of the Honda RaaS Platform need to prepare a User's Cloud and mount applications on it. As an example, a case of robotic services created using the cloud environment of Amazon Web Services (AWS)⁽¹⁰⁾ as the User's Cloud is shown below (Fig. 11).

The AWS data transfer service called Amazon Kinesis Data Streams⁽¹¹⁾ is used in order for the User's Cloud side to receive the data stream uploaded from the robot. For a scenario like the tea delivery service here, programming is done using a service called AWS Lambda⁽¹²⁾ that enables simple creation of applications to run in AWS.

Using these resources, AWS engineers can readily implement scenarios for robotic services. Beyond tea delivery, reception services, guide and information services, and other such robotic services can be built.

6.5. Scalable Architecture

The Honda RaaS Platform is built in the AWS environment (Fig. 12). The components of Honda RaaS Platform that perform particularly crucial core functions are Robot Manager, Authentication Manager, and Object Manager.

The Robot Manager performs management of robot registration information. The Authentication Manager manages authentication of robots, and the Object Manager performs management of data. Through these components, robot managers are able to access the Honda RaaS Platform's Web Console (the GUI for managers) and carry out management tasks such as adding and deleting robots. In addition, the robot operators can carry out operation of

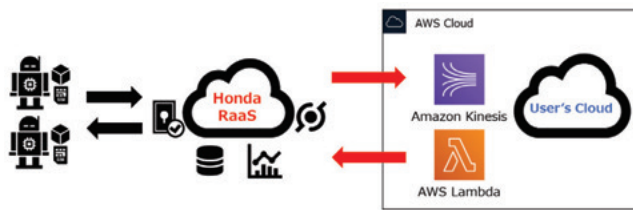


Fig. 11 How to build robotics service on AWS

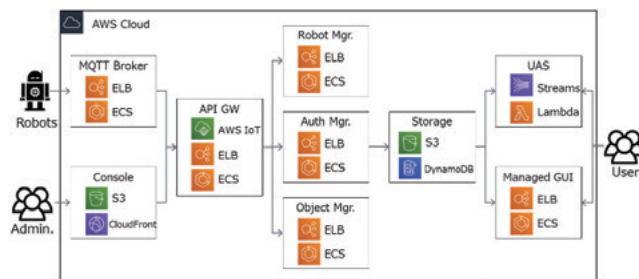


Fig. 12 Cloud architecture diagram

robotic services by accessing the Managed GUI (Web GUI).

The Honda RaaS Platform is envisioned as providing access for various robots in various locations simultaneously and in parallel. For components that are likely to experience concentrated access, provision is made for autoscaling by means of Elastic Load Balancing (ELB)⁽¹³⁾, which automatically distribute the traffic load, and by means of the Docker environment, which is a container management tool configured on the virtualization service known as the Amazon Elastic Container Service (ECS)⁽¹⁴⁾.

6.6. API and Use Cases

As examples of API provided by Honda RaaS Platform, the State API and Object Storage API are shown below together with use cases of the utilization of these respective APIs.

6.6.1. State API

Using the State API allows one to configure and acquire the robot's state. Use cases include acquiring robot battery information and setting tasks for the robot.

State API can be used with robots, as shown below in Fig. 13, to transmit the robot's battery information by means of the Honda RaaS Platform to the User's Cloud. Here, the value of "20" (meaning 20%) is being transmitted under the "battery" key. The data is transferred using cirobot-sdk and transmitted by MQTT, which is a lightweight communication protocol [Fig. 13(1)]. The value transmitted by the robot {"battery":20} is stored in the database on Honda RaaS Platform [Fig. 13(2)]. Next, the information is transferred by means of the Honda RaaS Platform to the Amazon Kinesis Data Streams in the User's Cloud [Fig. 13 (3)].

The flow for setting a robot task from the User's Cloud is shown in Fig. 14. Here, the remaining battery charge is considered to have diminished to 20% according to the battery information in Fig. 13, so that the robot is being issued the task to move to a charging station. The data transfer is carried out by the HTTPS protocol [Fig. 14(1)]. The value {"battery":20,"task": "GoToStation"} is transmitted from AWS Lambda, which has been programmed in the User's Cloud, and this value is stored in the database on the Honda RaaS Platform [Fig. 14(2)]. The value for the task instruction is then transferred to the robot

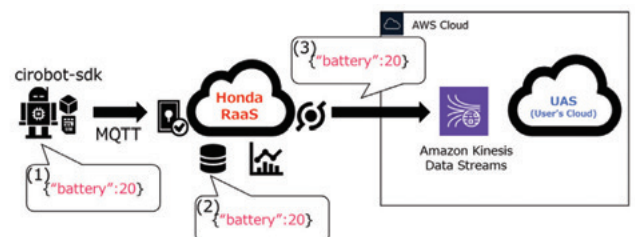


Fig. 13 Battery notification from robot with State API

by means of the Honda RaaS Platform using the MQTT protocol [Fig. 14(3)].

By using the State API in Figs. 13 and 14, the robot's state can be set and acquired. The state of the robot is constantly being managed on the Honda RaaS Platform. This is realized by implementing a mechanism called robot shadow, which synchronizes the robot state with the cloud. In this way, the robot and cloud are kept appropriately synchronized with regard to the robot state and management is possible (Fig. 15).

6.6.2. Object Storage API

The use of Object Storage API enables high-volume bidirectional data transfers between the robot and the Honda RaaS Platform. The use case shown here is the distribution of map data from the User's Cloud to the robot (Fig. 16).

In order to have mobility in an actual space, the robot requires robot-usable map data. However, as map data is ordinarily large in size, it is handled using batch management. Here, the map data is considered to have been uploaded to the User's Cloud environment in advance so

that it is available to be distributed to the robot as common data [Fig. 16(1)].

Map data is transferred to the Honda RaaS Platform from AWS Lambda in the User's Cloud environment by HTTPS protocol using the Object Storage API [Fig. 16(2)]. The Honda RaaS Platform stores the transferred map files in a database [Fig. 16(3)].

At this point the Honda RaaS Platform issues a download URL for the map data to the specified robot by MQTT protocol [Fig. 16(4)].

The robot can download the map data by means of the HTTPS protocol by whatever timing is safe for the robot. For example, it may do this when it has returned to a charging station [Fig. 16(5)].

The robot is constantly engaged in various kinds of processing, such as moving while avoiding obstacles. If the Honda RaaS Platform were to simply break in and distribute a large amount of map data, therefore, it could affect an already ongoing process. Using the Object Storage API in the way illustrated here, however, enables distribution of large amounts of data to the robot in safety.

7. Demonstration Cases

The following shows cases of demonstrations using the Honda RaaS Platform.

7.1. Disassembling and Rebuilding Services

The purpose here is to demonstrate the concept of "collaboration of diverse talents all over the world" by means of the Honda RaaS Platform linking and coordinating a multiplicity of different robotic devices. The example implemented here is a tea delivery service that serves as a case of services built to be provided in a seamless sequence.

The first step was to take the tea delivery service implemented in the past by ASIMO and to disassemble it into three standalone services (Fig. 17), which are:

- (1) Service that receives the order (the communication robot is in charge of this);
- (2) Service that loads the tea (the arm robot is in charge of this); and
- (3) Service that delivers the tea (the wagon robot is in charge of this).

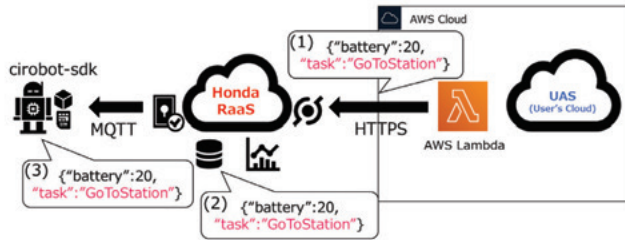


Fig. 14 Set task with State API from User's Cloud

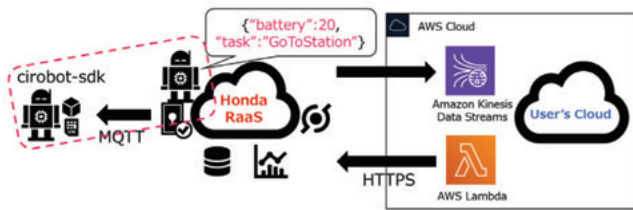


Fig. 15 State synchronization with robot shadows

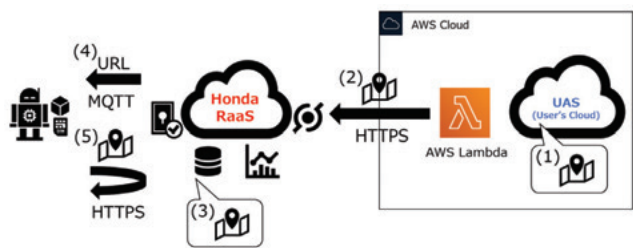


Fig. 16 Map distribution using Object Storage API

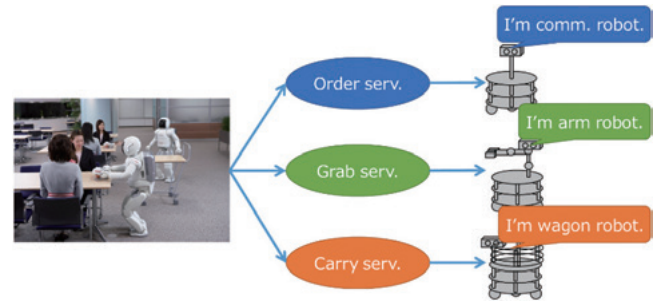


Fig. 17 Assigning role for each service to robot

In past verification tests, everything was done by a single ASIMO unit. With the services disassembled into three, however, the tea delivery service was rebuilt as a sequence of services that link and coordinate three robot units that have different roles. The next step was to install a SIM and SDK in each of these three robots and connect them with the Honda RaaS Platform. In addition, developers and operators were enabled to access the Honda RaaS Platform by means of the web from any terminal.

An environment was, therefore, built that enabled both robots and people to access the Honda RaaS Platform. In this way, a fusion of the cloud and robotic devices was achieved that has the capability to realize services in an integrated manner by enabling management of all the robots on the Honda RaaS Platform and by enacting implementation and control on the cloud of scenarios for realizing robotic services (Fig. 18).

7.2. Distribution of Operations for Each Service

Verification tests were conducted of the tea delivery service that coordinates a multiplicity of different robots using the Honda RaaS Platform.

The figures below illustrate the implementation of services divided into three, namely the service that receives orders (Figs. 19-20), the service that loads the tea (Figs. 21-22), and the service that delivers the tea (Figs. 23-25).

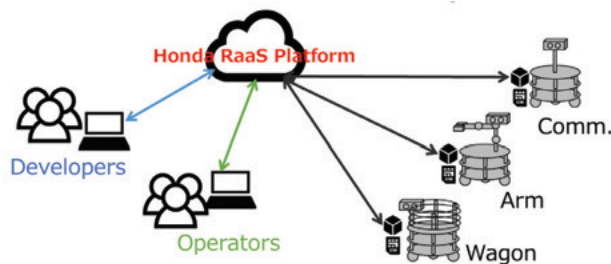


Fig. 18 Fusion of cloud and robotics device



Fig. 20 Acceptance of service request



Fig. 21 Start the task of grabbing tea



Fig. 22 Grab tea up and give to wagon robot



Fig. 19 Request tea delivery service



Fig. 23 Deliver tea to staff seat



Fig. 24 Tea delivery notification by communication robot



Fig. 25 Staff member receives tea

8. Issues for Future Investigation

The realization of a networked robot system by which multiple robots linked together in the same environment provide services requires adjustment of the tasks of each robot, their routes of movement, and their coordinated scenario⁽¹⁵⁾.

It is also the case that robotic services realized by means of the Honda RaaS Platform will utilize SIMs and a cloud environment. Consequently, modification of the design of system architecture and adjustment of resource allocation is expected to be necessary in order to realize services across a broad range of varying environments both indoors and outdoors.

For example, when searching for a person outdoors, the system will have to acquire imagery from many robots and IoT cameras, recognize and identify the person on the cloud, and calculate the optimal route to that person's location from various environment data, map data, and other such information. This involves high-load processing. However, the robot with the role of finding the person only needs to perform the low-load process of receiving that location information and moving there according to the given route. It is conceivable that processing loads will be adjusted in such ways.

The computational resources available for use in the cloud environment are abundant by comparison with the limited hardware resources internal to the robot. Since communication occurs between the robot and the cloud, however, real-time immediacy is lost. On the other hand, even though engaging in processing with the robot's internal hardware resources provides a high degree of real-time immediacy and responsiveness, there is a trade-off due to the constraints on the computational resources.

It is necessary, therefore, to design the system architecture with attention to how the computational resources are to be assigned in a balanced manner according to the use cases.

As a general guideline, when complex computation is required, as, for instance, in the case of computation of scenario control extending across multiple robots, or in that of computation of the destinations to which robots are moving in a large-scale perspective, then the abundant computational resources on the cloud will be utilized. When more immediate, real-time processing is necessary, as, for instance, in the case of detecting and avoiding obstacles, or in that of interactions with people, it will be considered desirable to perform processing on the robot side (Fig. 26).

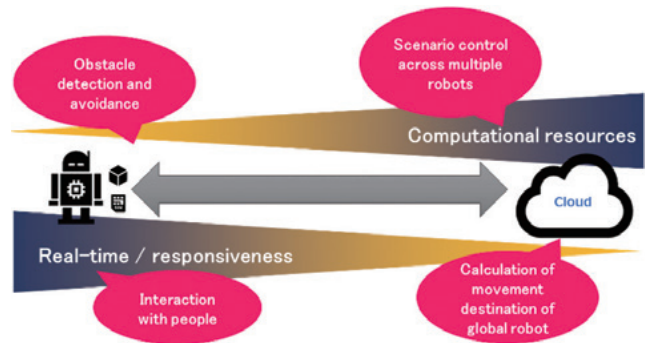


Fig. 26 Role sharing between robot and cloud

9. Summary

Honda RaaS Platform is a platform for the purpose of developing and operating robotic services.

In addition to describing the architecture and interfaces of the Honda RaaS Platform, this paper has presented a demonstration case of the concept of “collaboration of diverse talents all over the world” realized by linking and coordinating a multiplicity of different robotic devices to perform a sequence of delivery services.

This paper demonstrates that adoption of the Honda RaaS Platform can enhance the development and operation of robotic services (Table 1) by means of SIM to enable expansion of the operating area and provide a secure

Table 1 Comparison of enhancements

No.	Issues	Previous (ASIMO)	Present (Honda RaaS Platform)	Effect
1	Network security	Per-network authentication	Device authentication by SIM	Secure communication to cloud
2	Experimental environment	Complex individual construction	Build on cloud environment	Provide scalable environment
3	Development environment	Physical update	Update via remote	Enable agile development
4	Operation environment	Human operation at each site	Remote central operation	More efficient remote monitoring
5	Service scalability	Individual implementation	Utilizing common API	More efficient development

communication environment, a scalable infrastructure environment that uses the cloud, a development and debugging environment that is network accessible, an operational environment capable of remote monitoring, and, by means of API provision, an environment for the establishment and expansion of service.

Going forward, it will be necessary to further enhance the functions and tools required for the development and operation of robotic services by verification tests for a variety of different use cases. In order to enable handling use cases in a variety of indoor and outdoor areas, it will also be necessary to continue modifying the design of the system architecture to make it capable of using 5G networks and flexibly distributing resources between the robot and the cloud.

10. Conclusion

In a first for Honda, the company has globally disseminated content that constitutes a “software platform.”

In order to realize the 2030 Vision and the Robotics Vision declared by Honda, it will be important to build an ecosystem not just by the efforts of this company alone, but together with a variety of partners. For that purpose, the Honda RaaS Platform needs to be made known to a variety of engineers and professionals not just in the field of robotics, but also in the cloud and IoT. With the benefit of their fellow feeling and cooperation, growth toward the goal will be possible together.

It is to be hoped that this paper will help to bring about concrete progress with the Honda RaaS Platform as a “collaboration of diverse talents all over the world.”

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Haruomi HIGASHI

Study of Seat for Reduction of Stress of Sitting with Consideration of Influence of Physical Characteristics

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ABSTRACT

Targeting individuals with physical characteristics that make them prone to experience a stress associated with sitting, the research discussed in this paper studied postures and methods of support for the lumbar and pelvic areas that would reduce the stress experienced by vehicle occupants during long periods of driving. Test subjects were asked to sit in seats offering different levels of support. In addition to a subjective evaluation of the stress associated with sitting, physiological indicators were measured. A Visual Analog Scale was employed for the subjective evaluation. For the measurement of muscular stress, in addition to conventional electromyograms, muscles in the deep layer were studied using an ultrasonic diagnostic device. A spinal mouse was employed to measure the shapes of test subjects' spines. The results indicated that the provision of adequate support from the 3rd lumbar vertebra to the 3rd sacral vertebra reduces the stress associated with sitting even in individuals with physical characteristics that make them prone to experience a stress in the lower lumbar or shoulder area. In addition, it was found that reduction of the stress associated with sitting made it possible to control both retroversion of the pelvis and kyphosis of the lumbar area. It was also determined that individuals who experience a greater stress in the shoulder area are experiencing a stiffening of the muscles in the deep layer of the shoulders.

1. Introduction

Prolonged periods of driving place a mental and physical stress on the occupants of a vehicle. The mental stress is due to the tension and anxiety produced by the road environment and by driving itself. The physical stress results from posture maintenance and pressure on the body. The muscles are used to maintain the body's posture, the nerves are compressed by sitting, and the flow of blood decreases. It is considered that these factors cause symptoms such as tension, numbness, and pain in each part of the body.

With regard to thinking concerning postural adjustments that can reduce the stress of sitting, proposals have included reducing the activity of the back muscles by inducing a state close to the neutral posture that occurs in weightlessness⁽¹⁾, and reducing the pressure on the intervertebral discs by inducing an S-shaped curve in the spine⁽²⁾.

With regard to the method of maintaining the posture, proposals have included using the combined support of the lumbar area and the pelvis to reduce the sense of discomfort

in relation to the strength of support⁽³⁾, and using support from the 3rd lumbar vertebra to the 3rd sacral vertebra to control both pelvic retroversion and lumbar kyphosis⁽⁴⁾.

In addition, in order to address the reduction in blood flow, approaches have included changing the amount of support close to the 3rd and 4th lumbar vertebrae over time⁽⁵⁾ and changing the way that the femurs are supported⁽⁶⁾.

At the same time, research has also been conducted on individual differences. For example, research has also shown that because there are individual differences in the length and the strength of bones and muscles, there are differences in the comfortable angle of the neck and the relative angle between the pelvis and the femurs when sitting⁽⁷⁾, and that individual differences in the curvature of the spinal column result in differences in the stress on the lower lumbar vertebrae and the shoulders when sitting⁽⁸⁾.

It can be expected that setting the sitting posture to suit the individual's physical characteristics will reduce the stress associated with sitting, but the posture and the method of support for the lumbar area and the pelvis, which are important for maintaining posture, are not well understood.

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Seeking to reduce the stress of sitting for a greater number of people, the research discussed in this paper referred to the results of previous research⁽⁸⁾ and selected individuals whose physical characteristics would make them prone to stress when sitting, and studied the posture of and methods of support for their lumbar and pelvic areas.

2. Selection of Individuals Prone to Stress when Sitting

2.1. Method of Measurement of Shape of Spinal Column

The test subjects were 15 adult males gathered by in-house recruitment. The shape of the spinal columns of potential test subjects was measured in chairs with no backs. Subjects displaying physical characteristics that would make them prone to stress when sitting were selected. An easily operable spinal mouse manufactured by Index Ltd. was employed in the measurements. The test subjects were instructed to relax their back and abdomen, and to keep their heads facing forwards and their gaze level.

A spinal mouse makes it possible to measure the relative angle of each vertebra in the spinal column by moving the tracking wheel of the device from the head to the pelvis, measuring spinous processes from the 7th cervical vertebra to the 3rd sacral vertebra.

Figure 1 shows the definition of spine shape employed. ThSp indicates the degree of curvature of all of the thoracic vertebrae; this was the sum of the angles formed by contiguous vertebrae from the 7th cervical vertebra to the 12th thoracic vertebra. LSp indicates the degree of curvature of all of the lumbar vertebrae. This value was determined as the sum of the angles between contiguous vertebrae from the 12th thoracic vertebra to the 1st sacral vertebra. LLSp indicates the degree of curvature of the lower lumbar vertebrae, and was defined as the sum of the angles between contiguous vertebrae from the 3rd lumbar vertebra to the 1st sacral vertebra. L5-S1 indicates the degree of local flexion of the lower lumbar vertebrae, and was defined as the angle

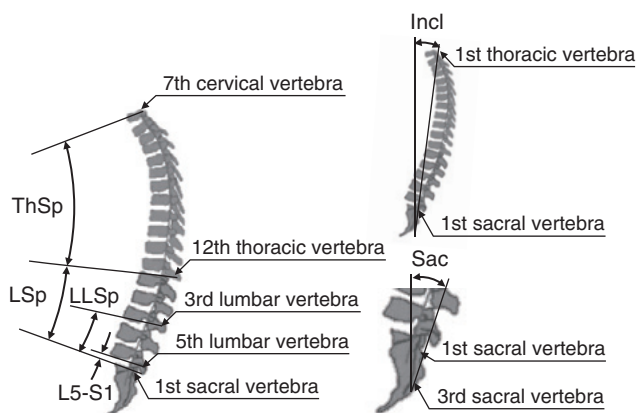


Fig. 1 Definition of spine shape

between the 5th lumbar and the 1st sacral vertebrae. The direction of kyphosis is shown as positive, and the direction of lordosis is shown as negative.

Incl indicates the degree of inclination of the upper body, and was defined as the angle between the line connecting the 1st thoracic and the 1st sacral vertebrae and a vertical line. Sac indicates the inclination of the pelvis, and was defined as the angle between the line connecting the 1st and 3rd sacral vertebrae and a vertical line. In relation to the vertical lines, backward inclination is defined as positive, and forward inclination is defined as negative.

This experiment was conducted with the approval of Honda's Bioethics Review Board. The purpose and details of the experiment and the rights of the test subjects were fully explained both orally and in writing by the personnel conducting the experiment prior to the experiment, and the consent of the test subjects was obtained in writing.

2.2. Method of Selection of Test Subjects

Previous research⁽⁸⁾ showed that individuals with a greater degree of curvature of the lower lumbar area tended to be prone to feeling a stress on that area when sitting in a chair without a backrest. On the other hand, it has been reported that individuals with a rounded lower lumbar area and, in addition, a considerably rounded thoracic vertebrae tend to experience stress in their shoulders.

The research that forms the basis of this report, therefore, as Fig. 2 shows, defined individuals whose LLSp was the average value or higher when sitting on a chair with no backrest as individuals with physical characteristics that predispose them to experience stress in their lower lumbar area (termed the "lower lumbar group" below), and individuals whose LLSp was positive, and whose ThSp was average or higher as individuals with physical characteristics that predispose them to experience stress in their shoulders (termed the "shoulder group" below).

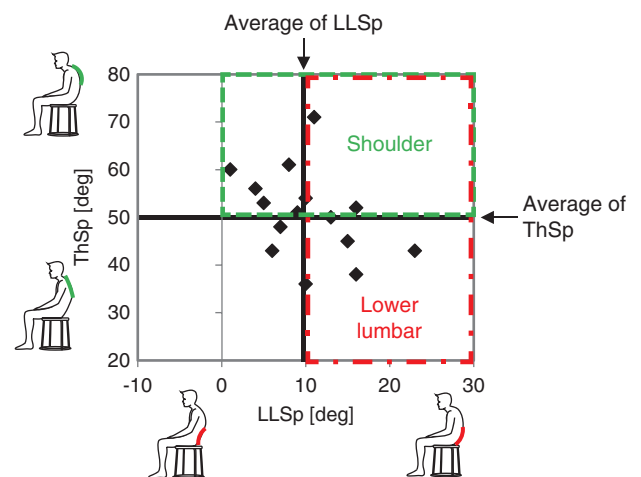


Fig. 2 Selection of test subjects prone to experiencing stress from sitting

3. Study of Method of Support for Reduction of Stress by Means of Subjective Evaluation

3.1. Method of Measurement of Stress

In order to study methods of support able to reduce the stress of sitting on the lumbar area and the pelvis, the lower lumbar group and the shoulder group were asked to subjectively evaluate the stress of sitting in an experimental seat. The experimental seat is shown in Fig. 3. The seat had a simple structure in which urethane of a level of hardness that would not affect the sitting posture was mounted on an even frame. The center of the backrest was provided with a slit so as to help prevent interference with the measurement instrument.

As shown in Fig. 4, test subjects were seated respectively for 30 minutes in a state without rigid urethane inserted between the urethane and the frame from the 3rd lumbar to the 3rd sacral vertebrae (termed “without support” below) and with a 30 mm-thick sheet of rigid urethane positioned on the frame between their 3rd lumbar and 3rd sacral vertebrae (termed “with support” below).

In order to do away with the effect of the order of the seating types, order was randomized, and the subjects were initially seated without any stress.

In order to make the front and rear positions of the test subjects’ buttocks the same in relation to the seat for both test conditions, the position of the buttocks was standardized when the test subjects were deeply settled

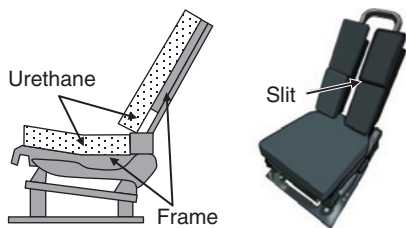


Fig. 3 Experimental seat

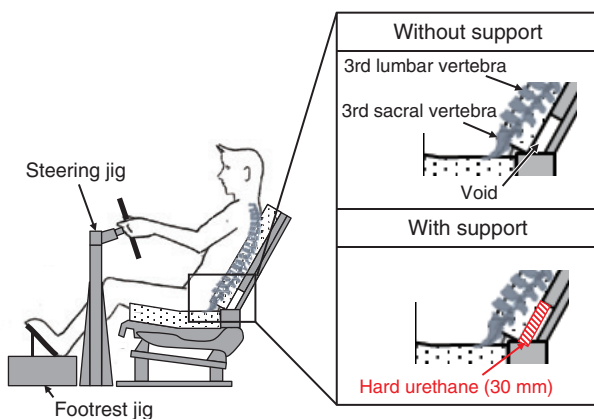


Fig. 4 Condition of experimental seat

in the seat with support, and the test subjects sat in the same position without support. In addition, the front and rear positions of the steering jig and the footrest jig were adjusted to make the angles of the elbows and the thighs the same for each test subject.

The test subjects were instructed to relax their backs and abdomens, hold the steering wheel with a light grip, turn their heads towards the front, and maintain a horizontal line of sight.

A Visual Analog Scale (VAS), which can be evaluated intuitively and is easily analyzed by means of analog quantity, was employed for the measurements. Using the VAS method, a 100 mm line is drawn, and the test subject draws a line on a scale expressing the current status when the left end is not felt at all and the right end is at the greatest possible strength that can be imagined.

3.2. Method of Analyzing Stress

The distance between the left end of the VAS and the line drawn by the test subjects after sitting for 30 minutes was defined as the magnitude of stress.

In order to study the effect of the seat on the stress on the test subjects’ lower lumbar areas and shoulders, a one-way analysis of variance (repeated measurements) was conducted using support conditions as a parameter. The statistics package SPSS Statistics 24 (manufactured by IBM) was employed in the analysis. A significance level of 5% was employed.

3.3. Analysis Results for Stress in Lower Lumbar Area

Figure 5 shows the results for subjective evaluation by the lower lumbar group when seated under unsupported and supported conditions.

The stress on the lower lumbar area from being seated was significantly lower in the supported condition than in the unsupported condition.

3.4. Analysis Results for Stress in Shoulder Area

Figure 6 shows the results for subjective evaluation by the shoulder group when seated under unsupported and supported conditions.

The stress on the shoulder area from being seated was significantly lower in the supported condition than in the unsupported condition.

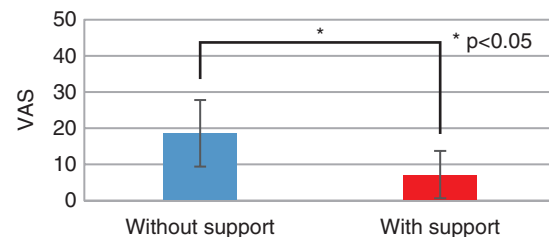


Fig. 5 Subjective evaluations for lower lumbar area

3.5. Summary of Methods of Support for Reducing Stress

It was found that the provision of adequate support from the 3rd lumbar to the 3rd sacral vertebrae reduced the stress associated with being seated, even in individuals with physical characteristics that made them prone to experiencing stress in their lower lumbar or shoulder areas.

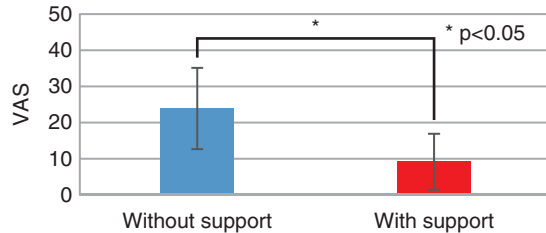


Fig. 6 Subjective evaluations for shoulder area

4. Investigation of Causes of Stress Associated with Sitting through Physiological Measurements

The stress associated with sitting described in Chapter 3 includes stress caused by maintaining the posture and stress caused by pressure on the body. The lower lumbar section of the back in which the stress was felt was positioned in the slit in the experimental seat, which meant that the seat tended not to compress the body.

In addition, the shoulders are positioned at the upper end of the experimental seat, and tend not to be compressed compared to the lumbar or pelvic areas. They therefore tend not to be compressed by the seat, and it was considered that the stress experienced in the tests was muscular fatigue due to maintaining the posture. Muscular stress was, therefore, evaluated using physiological indicators. The seating conditions were the same as described in Chapter 3.

4.1. Method of Measurement of Physiological Indicators

Electromyograms (EMG) are generally employed in order to evaluate muscular stress, and a NeXus electromyograph manufactured by KISSEI COMTEC was therefore employed for the evaluation in this research.

It is generally indicated that the accumulation of muscular stress results in stiffening of the muscular tissue. Given this, the stiffness of the test subjects' muscles was also evaluated in the research under discussion. Ultrasonic diagnostic equipment (a JS2 manufactured by Medicare) with an elastography function⁽⁹⁾ making it possible to image the stiffness of the muscular tissue (muscular strain) was employed in the measurements.

In conducting measurements of muscular strain, it is necessary to press the probe of the ultrasonic diagnostic

equipment into the test subject's back. This means that measurements cannot be conducted while the test subject is sitting on the experimental seat. The test subjects were, therefore, asked to move to a nearby chair without a backrest before and after sitting in the experimental seat, and measurements were conducted there. To help ensure that they did not relax their muscles when they transferred to the separate seat, the test subjects were instructed not to move unnecessarily, and that they should flop into the chair and not raise their heads more than necessary.

Based on the structure of the muscles, it was considered that the stress associated with seating would occur symmetrically on both sides of the spine. The EMG and muscle strain were, therefore, measured at positions that were symmetrical in relation to the spine. The measurement positions in the height direction were intermediate between the 5th lumbar and 1st sacral vertebrae, where the stress on the lower lumbar area was experienced, and at the 1st thoracic vertebra, where the stress on the shoulder area is experienced (Fig. 7).

In order to observe changes in muscle strain, it is necessary to have a strain value that serves as a benchmark. Gel pads, whose strain values would not change during the measurements (Hydro Aid, manufactured by Nippon BXI, Inc.), were, therefore, placed on the surface of the test subjects' skin at the measurement positions, and the strain in the muscle tissue and that in the gel pads (the benchmark value) were measured simultaneously.

4.2. Method of Analysis of Measurement Results

In order to evaluate the stress on the muscles, the frequency of the electromyogram was analyzed, and the mean power frequency (MPF) was determined. Generally, the value of the MPF declines as muscular stress accumulates. In the research under discussion, the difference between MPF five minutes before the test subjects stopped sitting and five minutes directly after the subjects commenced sitting was compared for the different support conditions.

In addition, the muscle tissue strain value was divided by the gel pad strain value to give a muscle strain ratio, and the difference in the muscle strain ratios before and after sitting were compared for the different support conditions.

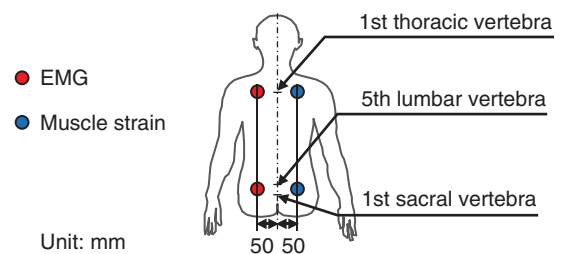


Fig. 7 Measurement points

As Fig. 8 shows, the muscles of the shoulder are layered. The shallow layer extends from 10-20 mm from the surface of the skin, and the deep layer from 20-30 mm. Muscle strain ratios were determined for each depth.

A one-way analysis of variance (repeated measurements) with the support conditions as parameters was performed in order to investigate the effect of the seat on MPF and muscle strain ratio. The significance level was set at 5%.

4.3. Results of Analysis of Physiological Indicators Measured in Lower Lumbar Area

The electromyograms and muscle strain measured in the lower lumbar area for the lower lumbar group were compared for the different support conditions. As Fig. 9 shows, there was not a significant difference between the support conditions in MPF for the lower lumbar area.

Figure 10 shows the muscle strain ratio for the lower lumbar area. Under both sets of support conditions, the average value of the muscle strain ratio was negative, indicating that the muscle tissue tended to harden with sitting. However, no significant difference was observed between (a) the shallow layer and (b) the deep layer for the different support conditions.

4.4. Results of Analysis of Physiological Indicators Measured in Shoulder Area

The electromyograms and muscle strain measured in the shoulder area for the shoulder group were compared for the different support conditions. As Fig. 11 shows, there was no significant difference between the support conditions in MPF for the shoulder area.

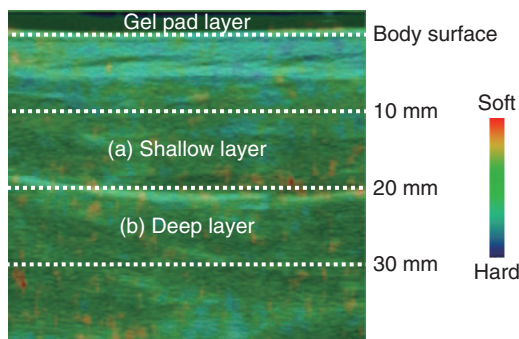


Fig. 8 Area for analysis of muscle strain

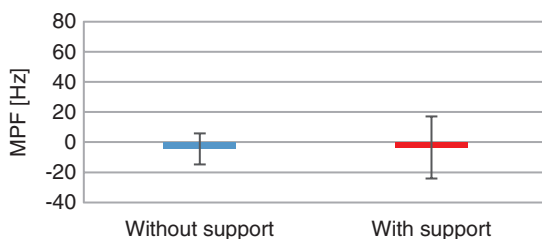
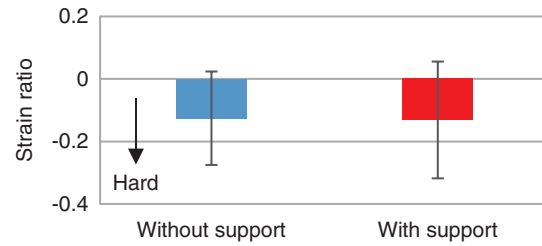
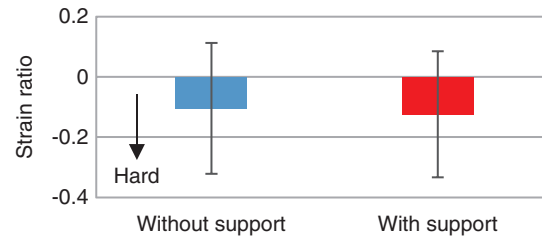


Fig. 9 EMG of lower lumbar area

In addition, as Fig. 12(a) shows, there was no significant difference in the muscle strain ratio between the different support conditions for the shallow layer of



(a) Shallow area



(b) Deep area

Fig. 10 Muscle strain ratio of lower lumbar area

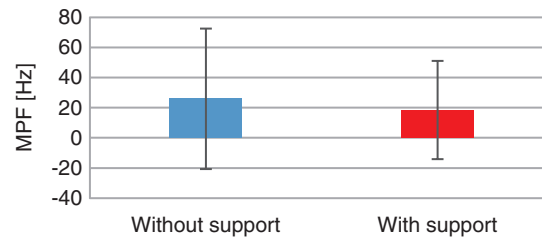
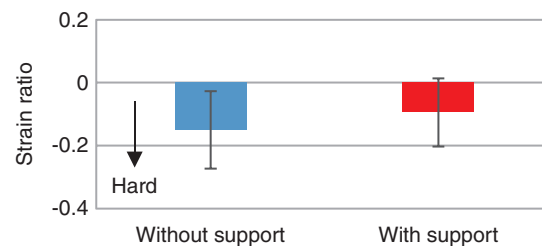
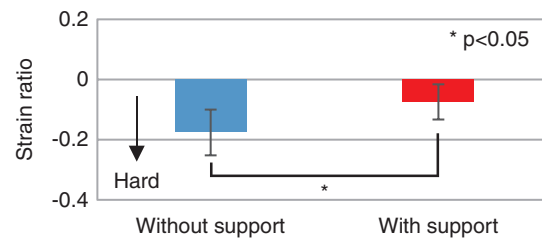


Fig. 11 EMG of shoulder area



(a) Shallow area



(b) Deep area

Fig. 12 Muscle strain ratio of shoulder area

the shoulder. However, as Fig. 12(b) shows, in the case of the deep layer, significance is lower for the muscle strain ratio without support. This indicates that the unsupported condition stiffened the muscles in the deep shoulder area.

4.5. Considerations Regarding the Causes of Stress Associated with Sitting

The subjective evaluations indicated that the stress on the lower lumbar area was significantly greater under the unsupported condition, but no significant difference was shown between the conditions in terms of the indicator expressing muscular stress. It is, therefore, possible that muscular fatigue is not the cause of stress in the lower lumbar area, and will be necessary to adopt an approach other than muscular fatigue in order to investigate the cause of this stress.

At the same time, the stress on the shoulder area was significantly greater under the unsupported condition in the subjective evaluations, and the muscles in the deep layer of the shoulder were significantly stiffer. It was, therefore, considered that the stiffness of the deep layer affects the stress on the shoulder.

5. Study of Posture towards Reduction of Stress Associated with Sitting

5.1. Method of Measurement of Posture

In order to study postures that reduce the stress associated with sitting, the shapes of the spines of the test subjects were measured using a spinal mouse when seated in the experimental seat in the unsupported condition, which was shown to produce the greatest stress, and in the supported condition, which was shown to produce the least stress in Chapter 3. The seating conditions were the same as described in Chapter 3, and the measurement positions were the same as described in Chapter 2.

5.2. Method of Analysis of Measurement Results

A one-way analysis of variance (repeated measurements) with support conditions as parameters was conducted in order to study the effect of the seat on the shape of the spine when seated. The level of significance was set at 5%.

5.3. Results of Analysis of Spine Shape

The shape of the spine when seated in the experimental seat was compared for the lower lumbar group and the shoulder group under the different support conditions.

As Fig. 13 shows, the results demonstrated that Sac, which indicates the inclination of the pelvis, LSp, which indicates lumbar curvature, and L5-S1, which indicates the flexion of the lower lumbar area, were all significantly lower for the supported condition.

In addition, as Fig. 14 shows, for the shoulder group, Sac and LSp were significantly lower for the supported condition.

This indicates that under the supported condition, both

pelvic retroversion and lumbar kyphosis can be controlled for the lower lumbar group and the shoulder group.

5.4. Considerations in Relation to Posture in Order to Reduce Stress Associated with Sitting

In the subjective evaluation, the stress on the lower lumbar area was significantly lower, and the angle of retroversion of the pelvis and the flexion of the lower lumbar area resulting from lumbar kyphosis were significantly lower for the supported condition. It is considered, therefore, that it will be possible to reduce the stress on the lower lumbar area by controlling the retroversion of the pelvis and lumbar kyphosis.

In addition, in the subjective evaluation, the stress on the shoulders was significantly lower, and the angles of retroversion of the pelvis and kyphosis of the lumbar area were significantly lower for the supported condition.

Generally, when the pelvis is tilted backwards and the

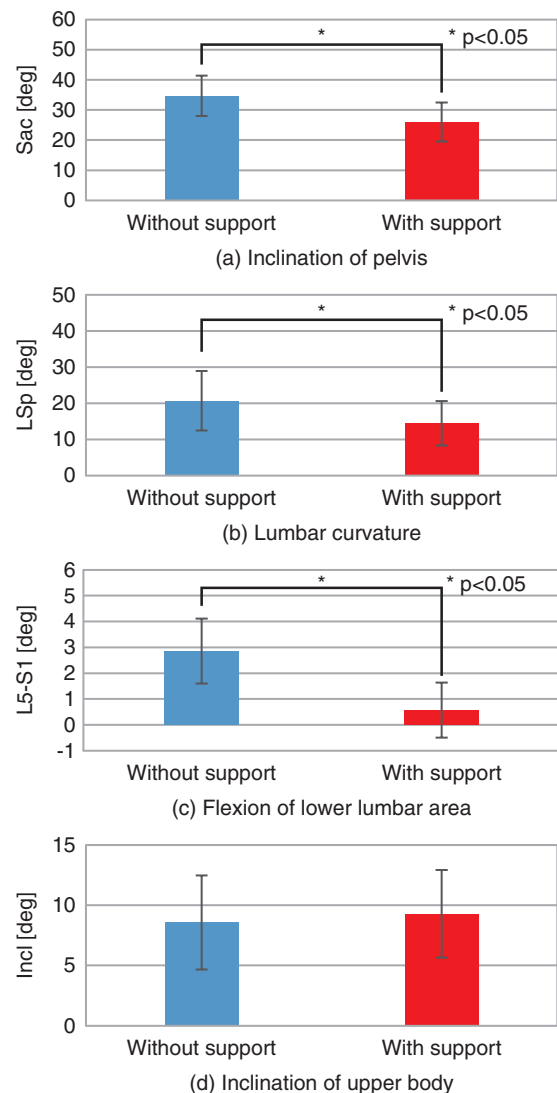


Fig. 13 Spine shape for lower lumbar group

lumbar area is in a state of kyphosis, the upper body is considered to be tilted forwards. In the present research, however, despite the fact that there was a difference in the angle of retroversion of the pelvis and the angle of kyphosis of the lumbar area due to the difference in support conditions, no difference was observed in the angle of the upper body.

Therefore, it is possible that the test subjects were utilizing muscular strength to help prevent their upper bodies from tilting forward in the unsupported condition, and it is considered that it was this that caused the muscles of the deep layer of the shoulder to harden.

This indicates that it will be possible to reduce the stress on the shoulders by controlling the retroversion of the pelvis and kyphosis of the lumbar area.

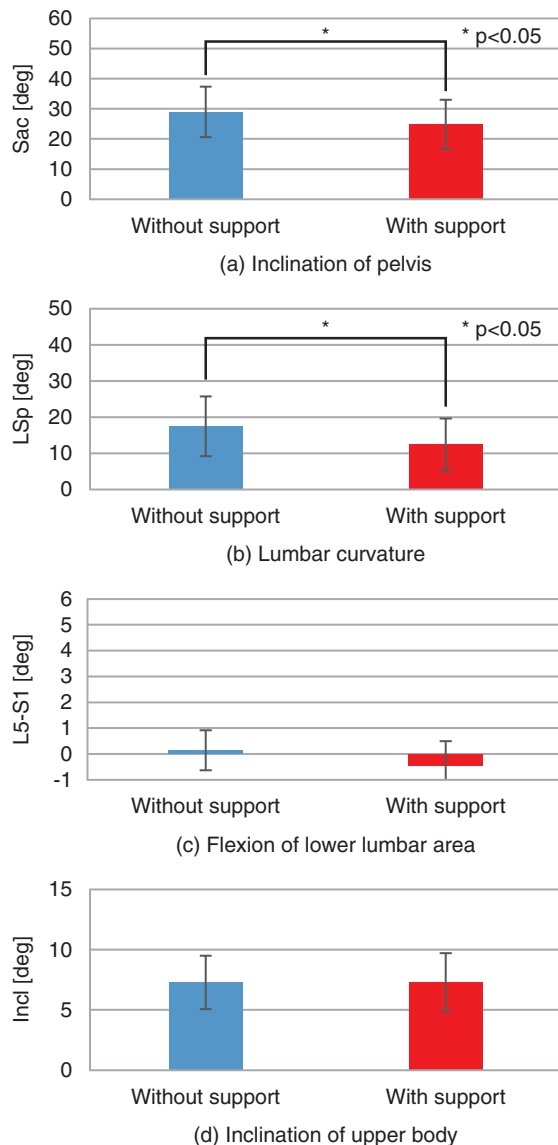


Fig. 14 Spine shape for shoulder group

6. Conclusion

Studying individuals possessing physical characteristics that make them prone to experience a stress when sitting, the research discussed in this paper studied postures and methods of support for the lumbar area and the pelvis that would reduce this stress. The results of the research are as follows.

- (1) Examination of a support method that would reduce the stress associated with sitting indicated that adequate support from the 3rd lumbar vertebra to the 3rd sacral vertebra reduces the stress associated with sitting even in individuals with physical characteristics that make them prone to experience a stress in their lower lumbar or shoulder areas.
- (2) Analysis of the causes of the stress associated with sitting based on measurement of muscle strain indicated that among individuals with physical characteristics that make them prone to experience the stress of sitting in their shoulders, the greater the stress, the greater the stiffening of the muscles in the deep layer of the shoulder. The use of ultrasound diagnostic equipment made it possible to evaluate the stress on the deep layer of the muscles of the shoulders, which had previously not been possible.
- (3) Among individuals with physical characteristics making them prone to experience stress in the lower lumbar or shoulder areas, a lower stress enabled control of both retroversion of the pelvis and kyphosis of the lumbar area.

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Load Distribution by Rear Bumper Beam in FMVSS 301R Test Protocol

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ABSTRACT

In the present research, technology was established for compliance with Federal Motor Vehicle Safety Standard (FMVSS) 301R, which is a US regulation addressing rear-end collisions. The FMVSS 301R test procedure is an offset impact test using a deformable impact barrier. In offset impact tests, there is a large difference in load input between left and right frames, and there is less deformation in the non-collision-side frame, meaning the side that does not impact with the barrier. Attention was therefore focused on the rear bumper beam, and steps were taken to increase the energy absorption of the non-collision-side frame by having the load from the barrier transferred equally to both frames. The rear bumper beam was structured so that the load input from impact with the barrier would become symmetrical. The stretch bending manufacturing method was used for practical implementation of this concept, and the beam was shaped so that it could be located within the design space of mass-production vehicle. Verification was conducted using a prototype that supposed mass production, demonstrating that the difference in input between the left and right frames, which formerly was large, could be reduced and a more nearly symmetrical load distribution achieved.

1. Introduction

Amid growing demands for automobile safety performance, active safety technology to keep accidents from happening is undergoing prominent advances. Meanwhile, the demand for passive safety technology that mitigates the damage of accidents that do occur also remains high, and official organizations are continuously updating passive safety procedures. Conformance with passive safety regulations in the North American region poses particular challenges, and it is in that context that the present research takes on the subject of FMVSS 301R, which addresses rear-end collisions.

The impact conditions in FMVSS 301R are defined as 70% offset impact by means of a deformable impact barrier (hereafter referred to as barrier). However, the impact conditions in regions other than North America are full-lap impact using a flat barrier. Furthermore, the speed of the impact by barrier to vehicle is 80 km/h, which is 30 km/h faster than the full-lap impact conditions. Consequently, the FMVSS 301R impact conditions call for the vehicle body and barrier to absorb as much as approximately three times more energy. Given the present state of vehicle body

construction, the greater part of this energy will be absorbed by the frame on the side that collides directly with the barrier (hereafter, collision-side frame).

Vehicle weights are anticipated to increase in the future as they are mounted with high-capacity batteries due to electrification and so on. As a result, even more impact energy will need to be absorbed by vehicle bodies. The general means used include raising the reaction force on the vehicle body and increasing the crushable zones. Various measures could be considered for the former, including the application of high-tensile steel with higher strength⁽²⁾⁻⁽⁴⁾, the addition of reinforcing members, and an increase in the thickness of framework segments, but these measures would contribute to increased weight in the vehicle body. As to the latter means, increasing the crushable zones would impact both occupant space and cargo capacity.

The approach here, therefore, has been to take measures on the construction of the vehicle body that would enhance energy absorption by the non-collision-side frame, which is an approach where active measures had not been successfully employed up to this point. The structure of the rear body generally comprises a rear bumper beam that is connected to the left and right rear frames. The rear bumper

¹ Automobile Center

² BENTELER Automotive K.K.

³ SOLIZE Engineering Corporation

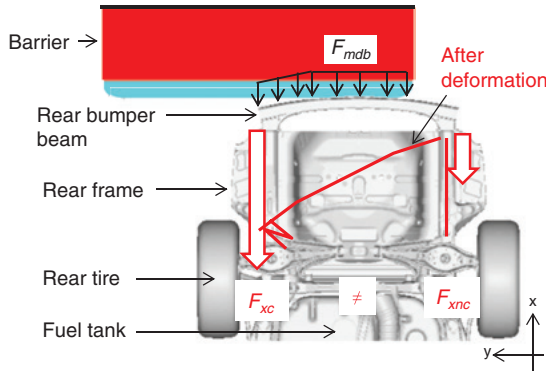
beam is an important structural member that is the first to receive input from the barrier, and research on it has mainly related to design and enhancement of low-speed crash performance⁽⁵⁾⁻⁽⁷⁾. There is also some research⁽⁸⁾ that applies to high-speed collision regulations like FMVSS 301R, but not much.

The purpose of the present research has been the construction of a rear bumper beam that would reduce the difference in load input to the two sides of the frame and increase energy absorption by the non-collision-side frame in the FMVSS 301R procedure.

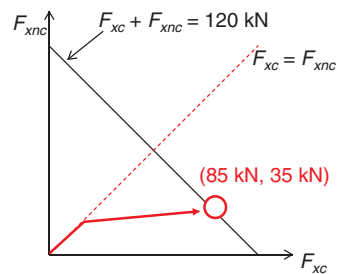
2. Load Distribution by the Rear Bumper Beam

2.1. Load Path in the Conventional Structure

A rear bumper beam of conventional structure that conforms to the test conditions for low-speed crashes is designed to generate a load of from 100 to 120 kN. Figure 1(a) shows schematically how a total load of 120 kN is applied from the barrier to the left and right rear frames under FMVSS 301R test conditions. Here F_{mdb} is the distributed load applied from the barrier to the rear bumper beam, F_{xc} is the load transferred from the rear bumper beam to the collision-side frame, and F_{xnc} is the load transferred to the non-collision-side frame. The barrier is deformed along the geometry of the rear bumper beam so that the input distribution shows the extent of contact by the barrier



(a) Schematic diagram of load paths



(b) Relationship between F_{xc} and F_{xnc}

Fig. 1 Load distribution of conventional structure under FMVSS 301R condition

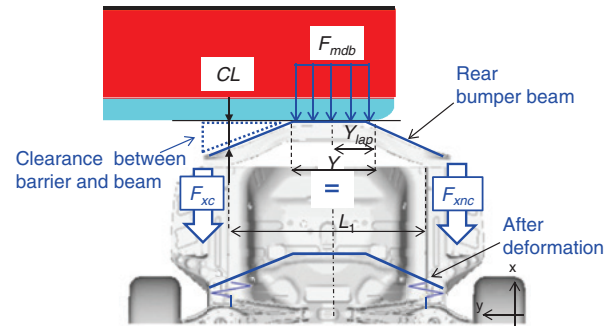
skewed toward the impact side. Figure 1(b) shows the relationship between F_{xc} and F_{xnc} . The red dotted line represents $F_{xc} = F_{xnc}$, or in other words, the state in which left and right frames receive equal load input. The red circle marks the load balance at the point when a rear bumper beam of conventional structure generates a load of 120 kN. In a conventional structure, the difference in load input to the left and right frames is large, by a factor of two or more, and as shown in Fig. 1(a), the non-collision-side frame, where the transferred load is smaller, is deformed less than the collision-side frame. This tendency is particularly strong in the case of a rear bumper beam with the geometry that skews the load distribution to the impact side.

2.2. Conceptual Approach to the New Rear Bumper Beam

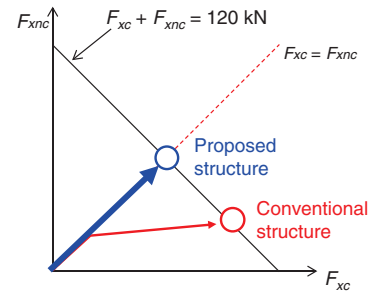
In order to reduce the difference in load input from the rear bumper beam to the left and right frames, the area of load input from the barrier needs to be made symmetrical. Since the deformation characteristics of the barrier differ according to the load range, the approach here considers two load ranges: the load range up to 120 kN that corresponds to low speed crash conditions (hereafter, lower load phase); and the load range larger than 120 kN (hereafter, higher load phase).

2.3. Conceptual Approach of Lower Load Phase

Figure 2(a) shows the relationship between F_{xc} and F_{xnc} in lower load phase. The addition of a flat section at the



(a) Schematic diagram of load paths



(b) Relationship between F_{xc} and F_{xnc}

Fig. 2 Load distribution in lower load phase

middle of the rear bumper beam causes the load input from the barrier to be limited to the extent of the flat section. The provision of the clearance shown by the blue dotted line in Fig. 2(a) further causes a time lapse until the point when the barrier and portions of the rear bumper beam other than the flat section come into contact. This causes input from the barrier F_{mdb} to act symmetrically with respect to the rear bumper beam. As shown by the blue line in Fig. 2(b), F_{xc} and F_{xnc} are distributed equally.

From the above perspective, a mound shape as shown by the blue line in Fig. 2 (a) was determined for the shape of a rear bumper beam capable of providing a flat section and clearance.

2.4. Conceptual Approach of Higher Load Phase

The method for generating a load in the range above 120 kN that is equivalently distributed is to collapse the barrier and have the rear bumper beam collide with the flat barrier plate. The state of input when this happens is shown schematically in Fig. 3(a). $F_{FLAT-plate}$ is the distributed load that is applied from the flat barrier plate of the barrier to the rear bumper beam. Then the extent of input from the flat barrier plate becomes only the flat section of the rear bumper beam, and as shown by the blue line in Fig. 3(c), symmetrical input is obtained even in the load range above 120 kN.

In the transitional phase that moves from the lower load phase to the higher load phase, the input temporarily loses its symmetry, as shown in Fig. 3(b). The strength per unit area of the barrier (hereafter, the collapse strength) is defined by standards, so that F_{xnc} displays the transitional

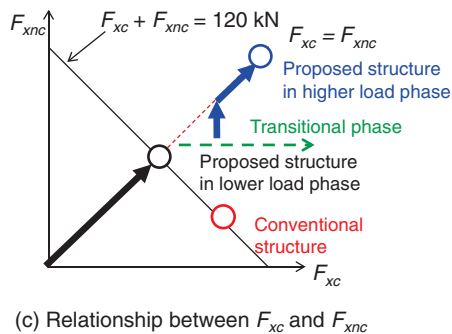
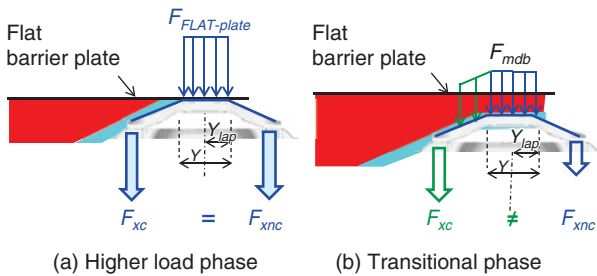


Fig. 3 Load distribution in higher load phase

characteristic whereby it does not increase, as shown by the green dotted line in Fig. 3(c).

As shown in Fig. 4(a), the barrier is made up of the bumper honeycomb (hereafter, B-honeycomb), which has high collapse strength, and the face honeycomb (hereafter, F-honeycomb), which has low collapse strength. By making the vertical overlap Δz of the barrier and the rear bumper beam smaller as in Fig. 4(a), the F-honeycomb with its lower collapse strength is caused to deform more readily. As shown in Fig. 4(b), the barrier can be collapsed when the load is low, so the range of the transitional phase can be limited as much as possible.

On the other hand, when the vertical overlap is larger, as shown in Fig. 4(c), then after the F-honeycomb deforms, the B-honeycomb becomes collapsed as in Fig. 4(d). The extent of the transitional phase is broadened as a result.

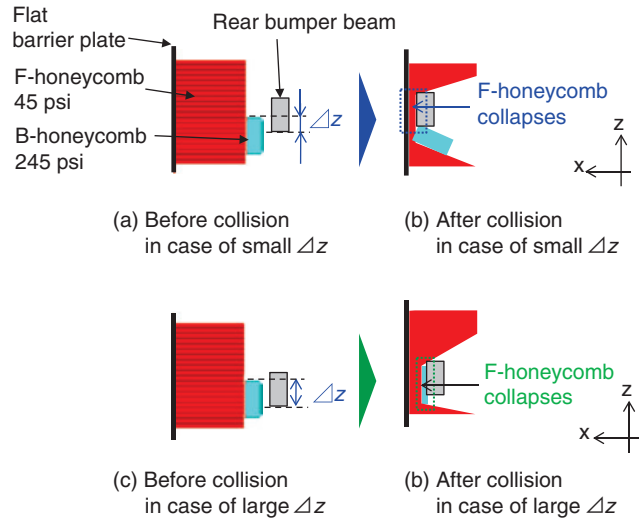


Fig. 4 Differences in collapse modes by Δz

3. Basic Rear Bumper Beam Shape Calculations

The basic structure for the rear bumper beam that will result in symmetrical load input to the rear frame was verified by theoretical calculations and by simulation. This confirmed the validity of the conceptual approach described in preceding sections.

3.1. Length of Rear Bumper Beam Flat Section

Verification was performed first for the length of the flat section provided at the middle of the rear bumper beam. As was shown in Fig. 2(a), Y is the length of the rear bumper beam flat section where the load is received and Y_{lap} is the length from the center of the rear bumper beam to the end of the barrier. L_1 is the distance between the left and right rear frames. Equations (1) and (3)

represent the load equilibrium when the rear bumper beam is taken as a beam, while Eqs. (2) and (4) represent the moment equilibrium. The relationships of Y with F_{xc} and F_{xnc} were obtained by theoretical calculation using these equations. Taking a mass-production sedan as the basis, Y_{lap} was defined as 250 mm.

$$\begin{aligned} \text{When } Y < 2Y_{lap}, \\ F_{xc} + F_{xnc} = F_{mdb}Y \end{aligned} \quad (1)$$

$$\int_{\frac{L_1 - Y}{2}}^{\frac{L_1 + Y}{2}} F_{mdb}y dy - F_{xnc}L_1 = 0 \quad (2)$$

$$\begin{aligned} \text{When } Y \geq 2Y_{lap}, \\ F_{xc} + F_{xnc} = F_{mdb} \left(Y_{lap} + \frac{Y}{2} \right) \end{aligned} \quad (3)$$

$$\int_{\frac{L_1 - Y}{2}}^{\frac{L_1 + Y}{2} + Y_{lap}} F_{mdb}y dy - F_{xnc}L_1 = 0 \quad (4)$$

Figure 5 shows the results of the theoretical calculations. The horizontal axis is the length Y of the flat section. The vertical axis is the ratio F_{xnc} / F_{xc} of the input load on the left and right rear frames. When $Y < 2Y_{lap}$, the extent of the load input from the barrier becomes bilaterally symmetrical at the center of the vehicle so that $F_{xnc} / F_{xc} = 1.0$. When $Y \geq 2Y_{lap}$, the extent of the load input from the barrier becomes asymmetrical so that $F_{xnc} / F_{xc} \leq 1.0$. Consequently, in order to have equal load input to the rear frame, Y needs to be equal to or less than two times Y_{lap} . Verification was conducted from this point with $Y = 500$ mm.

When Y is determined, the load input to the left and right rear frames can be calculated using Eq. (5).

$$F_{xc} + F_{xnc} = P_{mdb} \times A = P_{mdb} \times Y \times Z_{mdb} \quad (5)$$

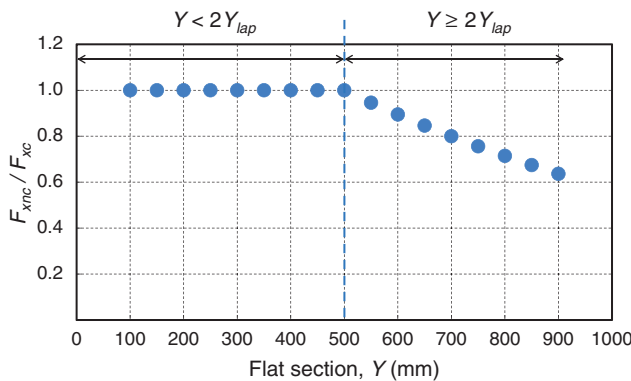


Fig. 5 Relationship of bumper beam length Y and F_{xnc} / F_{xc}

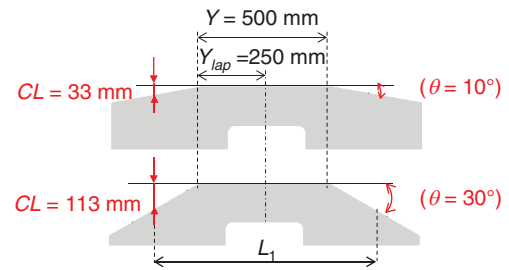
Here, P_{mdb} is the barrier collapse strength of 45 psi, A is the theoretical maximum area of the barrier where deformation is caused by the rear bumper beam, and Z_{mdb} is the prescribed dimension of 559 mm for the barrier height in the z direction. Given these values, $F_{xc} + F_{xnc} = 120$ kN. In other words, equal loads of 60 kN each are distributed to the left and right rear frames.

3.2. Clearance Between the Barrier and Rear Bumper Beam End

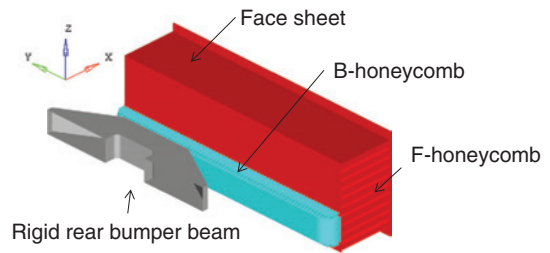
Next, a simulation was conducted to examine how much clearance is needed between the barrier and the end of the rear bumper beam. For the rear bumper beam model, Y_{lap} was defined as 250 mm, and the model was made a rigid element model of the kind shown in Fig. 6. The barrier was modeled using shell elements.

The measurement locations for clearance CL are indicated by red arrows, showing that they are located along lines extending from the frames. Based on the bending angle of 10° for mass-production vehicles, CL was evaluated with the bending angle θ from 10° to 60° as a parameter shown in Table 1. The rear bumper beam was fixed in place and the barrier was caused to crash into it at 80 km/h. LS-DYNA was used as the solver for the simulation.

Figure 7 shows barrier deformations for each of the simulation condition. It was found that when CL was subjected to increases from 33 mm to 168 mm, the area enclosed by blue lines in the figure increased in size. When CL was increased past 168 mm, the range of contact with the barrier was limited to the flat section of the rear bumper



(a) Rigid model of rear bumper beam



(b) Setup for simulation

Fig. 6 Simulation model for investigation of barrier clearance

Table 1 Parameters used for clearance investigation

	CAE01	CAE02	CAE03	CAE04	CAE05	CAE06
θ	10°	20°	30°	40°	50°	60°
CL	33 mm	72 mm	113 mm	168 mm	240 mm	346 mm

beam. It was also found that the deformed shape of the barrier had inflection points of the kind shown by blue circles in the figure.

When the distance Δx of this inflection point from the flat section of the rear bumper beam was calculated, it was found to be 105 mm. Unless the inflection point is in contact with the rear bumper beam surface, the contact with the barrier will be limited to the flat section, so that a figure of 105 mm or greater can be considered an approximate guide to the value of CL sought for the rear bumper beam.

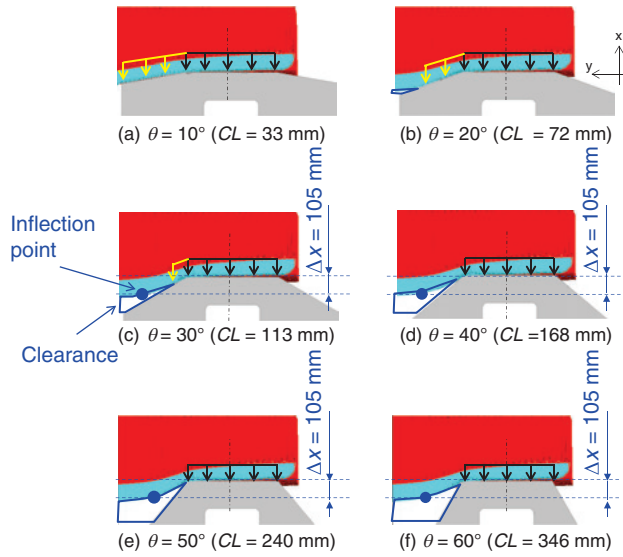


Fig. 7 Barrier deformation with different initial clearances

Figure 8 shows the load balance between left and right obtained by simulation. The results are divided into two groups based on the barrier deformation drawings in Fig. 7. Figure 8(a) shows Group 1, where $CL < 168$ mm, and Fig. 8(b) shows Group 2, where $CL \geq 168$ mm. The round marks in the figure show the points where the total load becomes 120 kN. It is apparent that in Group 1, these round marks approach more closely to the black dotted line marking an equally distributed load condition as the clearance increases. It was also found with Group 2 that no major changes in the load characteristic were observed, and that the general target figure of 60 kN for symmetrical load distribution had been achieved.

Figure 9 shows the relationship of clearance CL and the ratio F_{xnc} / F_{xc} of the input load on the left and right rear frames. The curve in the figure is a function approximation of results for the three Group 1 models. When CL was assigned the same 105 mm value as the Δx described earlier, then F_{xnc} / F_{xc} calculated by approximation yielded the value 0.85. It was found, therefore, that providing a clearance of 105 mm or more as an approximate guide would yield a

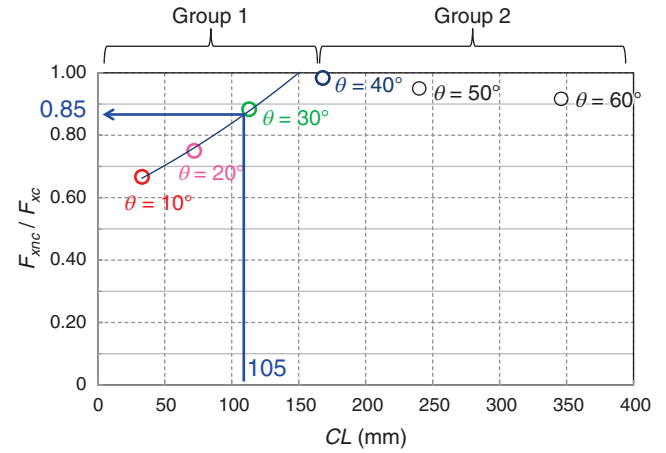
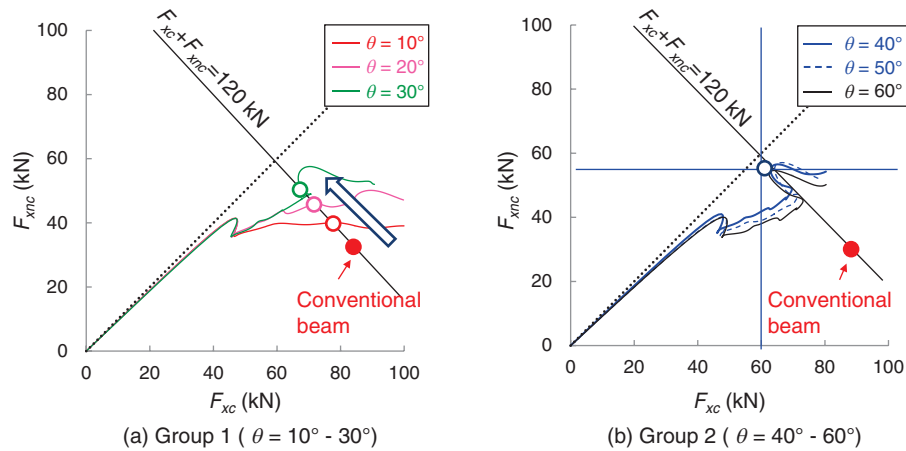
Fig. 9 Relationship of clearance and F_{xnc} / F_{xc} 

Fig. 8 Load balance of frames for different bending angles

high input load ratio. Verification was conducted from this point with $CL \geq 105$ mm.

3.3. Vertical Overlap of Barrier and Rear Bumper Beam

An investigation was made of the vertical overlap that is needed in order to collapse the F-honeycomb and obtain a greater load distribution effect. The same conditions as in the previous section were used with the model for simulation. For the geometry of the rear bumper beam, CAE03 ($CL = 113$ mm, $\theta = 30^\circ$) from Table 1 was used. The simulation was carried out with vertical overlap Δz of 150 mm, 80 mm, 70 mm, and 60 mm as shown in Fig. 10.

Figure 11 shows cross-section of barrier deformation in section XZ at the middle of the rear bumper beam. With $\Delta z = 150$ mm, both F-honeycomb and B-honeycomb are collapsed. With $\Delta z = 80$ mm and 70 mm, there was deformation in the upper part of B-honeycomb and in F-honeycomb. It was found that with $\Delta z = 60$ mm, however, there was greater rotation of B-honeycomb and it was mainly F-honeycomb that collapsed.

Figure 12 shows the state of deformation in section XY at location AA shown in Fig. 10. The black lines and black dotted lines show the respective location after deformation of B-honeycomb and F-honeycomb. With $\Delta z = 150$ mm and 80 mm, both B-honeycomb and F-honeycomb are collapsed.

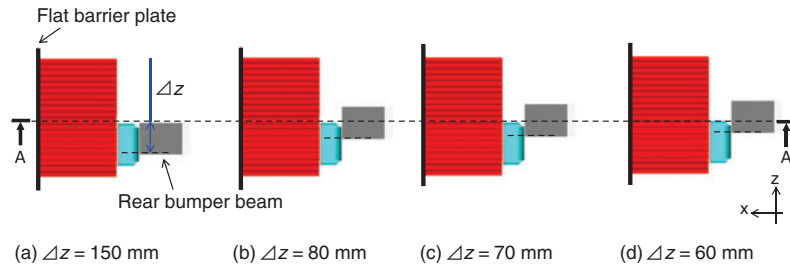


Fig. 10 Barrier and bumper beam overlap amount

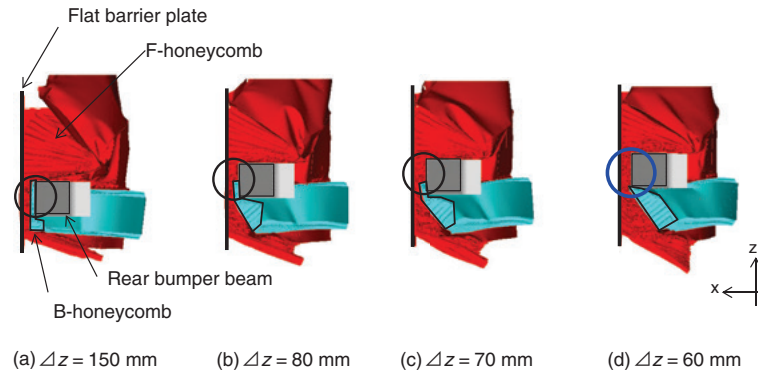


Fig. 11 Barrier deformation in section XZ

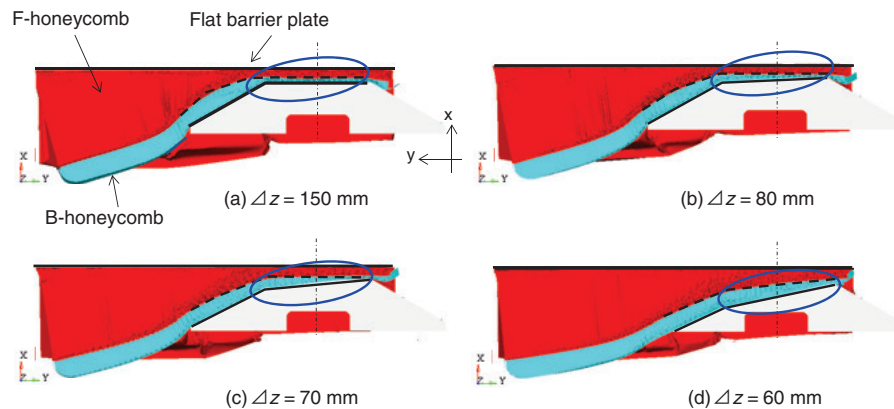


Fig. 12 Barrier deformation in section XY

It is apparent that when the vertical overlap decreases from 80 mm, however, there is less deformation of B-honeycomb inside the blue outline.

It was found from the above results from analysis of the barrier deformation in sections XZ and XY that with a vertical overlap of 80 mm or more, both F-honeycomb and B-honeycomb deform, and at 60 mm or less, deformation occurs mainly in F-honeycomb. An intermediate state of deformation was also shown at 70 mm. It was found from this that a vertical overlap Δz from 60 mm to 70 mm makes it more likely that the F-honeycomb will collapse and the rear bumper beam will be brought into contact with the flat barrier plate.

Figure 13 shows the changes in load input to the left and right rear frames plotted by overlap amount. From the lower load phase to the transitional phase, a change from (a) to (b) occurs in every case in the figure. At $\Delta z = 60$ mm, the change from the transitional phase to (c) occurs as the B-honeycomb collapsed more quickly, and the load distribution from that point on is nearly equal. At 70 mm, an equal load condition is again restored after (d). However, an equal load condition is not achieved even in a higher load phase at 80 mm and 150 mm, and the transition to (e) takes place with the relationship $F_{xnc} < F_{xc}$ remaining true. It was found from these results that $\Delta z \leq 70$ mm is an approximate guide for vertical overlap.

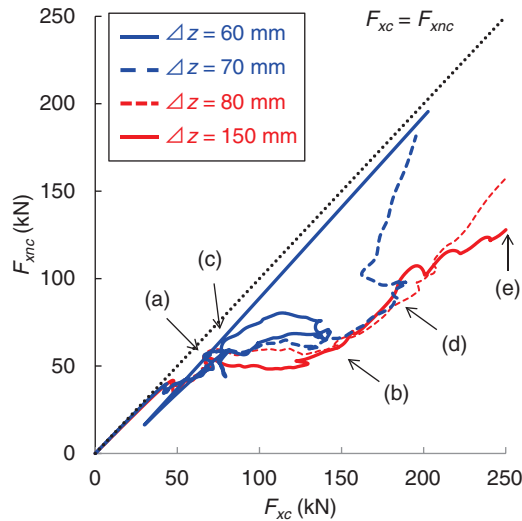


Fig. 13 Load balance of frames for different overlap amounts

4. Verification of Load Distribution Effectiveness

4.1. Practical Implementation of the New Rear Bumper Beam

In the course of demonstrating the validity of results achieved by investigation to this point, an investigation

was made into the practical implementation of a prototype that would fulfill the rear bumper beam design conditions described in section 3 and satisfy all the requirements for the design space of mass-production vehicle as well as manufacturability. As shown in Fig. 14, a shape that assures a clearance of 105 mm or more, as shown in section 3, was realized by providing multiple curved portions. As a manufacturing method that provides practical implementation of such a geometry, stretch bending⁽⁹⁾ of extruded aluminum material was adopted.

First, the formable range was predicted by theoretical calculations. The two constraint parameters for forming are the curvature R_3 and the length L_3 between the bending segments of the rear bumper beam shown in Fig. 14. The length of R_3 needs to be 300 mm or more, and $L_3/2$ needs to be 450 mm or more. The distance L between the two frames was set at 1100 mm, the same value as for mass-production vehicle, and L_2 needs to be 50 mm or more in order to provide a flat surface for the attachment points the rear frames. This means that the upper limit for $L_3/2$ is $(1100 - 2 \times 50)/2 = 500$ mm. Based on these forming requirements, the rear bumper beam was fabricated using the dimensions shown in Fig. 14.

4.2. Test Conditions

A prototype rear bumper beam was fabricated according to the conditions described in the previous section and was subjected to individual part testing. This used the drop weight test machine at the Hasaki Research and Development Center of Nippon Steel Corporation, which is capable of measuring the input load to the frames from the rear bumper beam and can also record imagery of the deformation.

Figure 15 presents images that show the test setup. The rear bumper beam was fixed in place on a flat plate with load cells interposed. The barrier was attached to the drop-weight and allowed to drop freely in the vertical direction. The status of barrier deformation was also recorded using a high-speed camera.

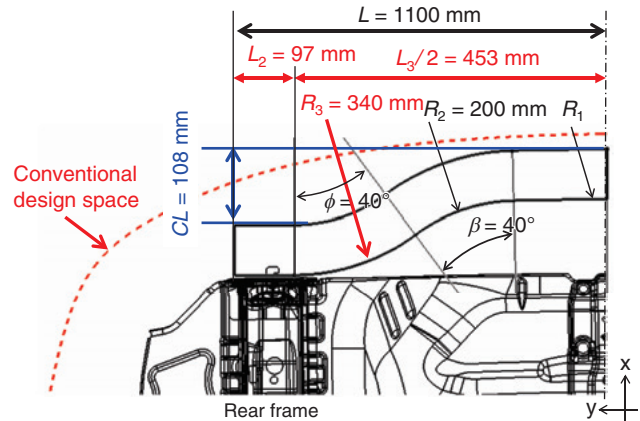


Fig. 14 Design space and parameters for stretch bending

The lower load phase test was conducted using a rear bumper beam with the conventional structure and a prototype of the new structure, and the results were compared. The energy was calculated from the bumper and barrier stroke amount when the reaction force reached 120 kN, and the test input energy was defined as 20 kJ.

The prototype differs from the rigid rear bumper beam in that the beam undergoes deformation. When the higher load phase test was conducted, therefore, a model simulating the prototype was created and verification of the vertical overlap was performed anew under the same conditions as described in Section 3.4. The results provided for a figure of 90 mm as a general guide to the overlap amount, and the test was therefore conducted under the two conditions of 80 and 90 mm. The input energy when impact occurred was obtained by adding the condition for the lower load phase to the energy needed to collapse the barrier. This total was 75 kJ.

4.3. Lower Load Phase Test Results and Discussion

The test results were examined and discussed with reference to the effectiveness of load distribution in the lower load phase due to the flat section of the rear bumper beam and the clearance. The solid red line and solid blue line in Fig. 16 show the relationship between F_{xnc} and F_{xc} with the conventional structure and F_{xnc} and F_{xc} with the prototype respectively. The results for simulation of the prototype are also given by the dotted blue line. The load tendencies in the simulation generally match with the test results, substantiating the validity of the model implemented in the present research.

There is also a solid black line in the figure when the total of the loads input to the left and right rear frames reaches 120 kN. The arrows mark the timing for when the conventional structure and the prototype respectively reach

120 kN. With the conventional structure, the input load difference between the left and right frames was 45 kN, while with the prototype, the difference was only 3 kN. This indicates that a load input close to symmetrical was successfully achieved.

Figure 17 shows the state of barrier deformation 20 msec after impact. Image (a) shows the conventional structure and image (b) shows the prototype. With the conventional structure, the barrier deforms in a shape that follows the rear bumper beam geometry. With the prototype, however, the clearance marked by the blue circle has been secured and a load distribution that is close to symmetrical has been realized. These results successfully demonstrate that the rear bumper beam designed in the present research can realize symmetrical load distribution.

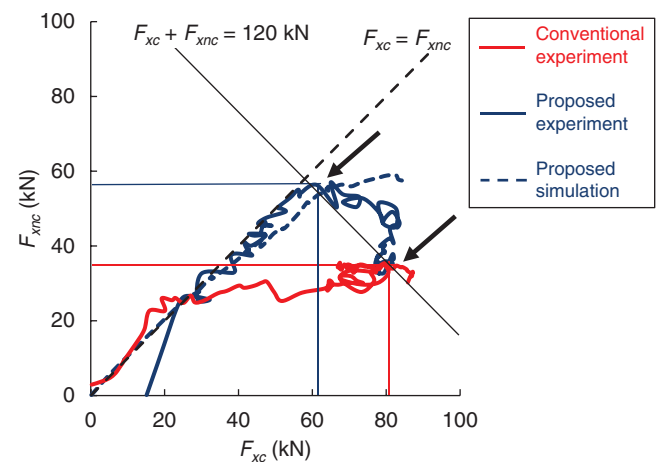


Fig. 16 Comparison of load balances with conventional and proposed bumper beams

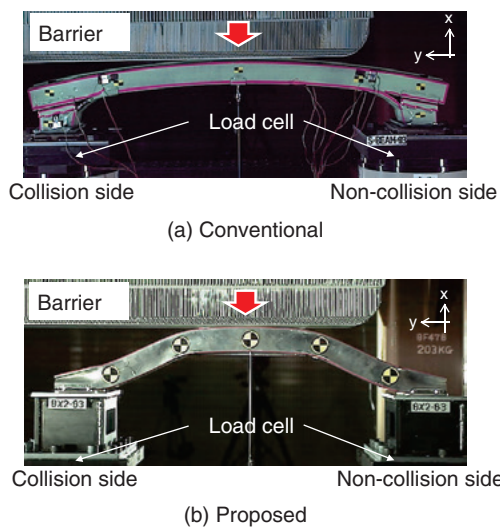


Fig. 15 Set up for drop test of bumper beams

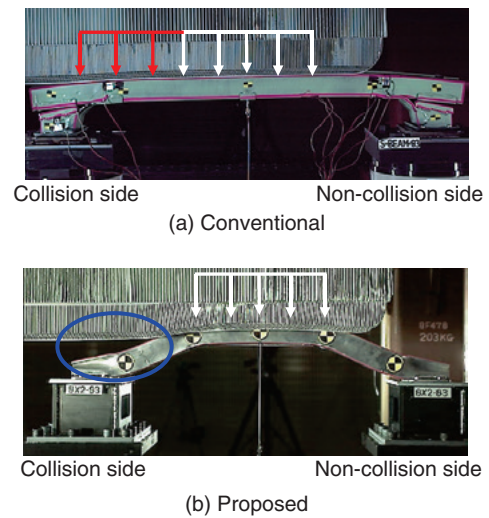


Fig. 17 Tested conventional and proposed bumper beams

At the same time, the validity of the length of the flat section of the rear bumper beam and of the magnitude of the clearance provided at both ends have also been verified.

4.4. Higher Load Phase Test Results and Discussion

The next step was verification of the effectiveness of the load distribution in the higher load phase. Figures 18(a) and 18(b) show the load balances on left and right at $\Delta z = 80$ mm and 90 mm, respectively. The intervals marked (1) in the figures are considered to be transitional phases. For 80 mm, this phase was continued until F_{xc} reached near 100 kN, and for 90 mm, near 170 kN. In either case, the transitional phase was passed and then, as shown by the black circles marked (2) in the figures, the load input again recovered to nearly symmetrical. As stated in Section 3.3., there is general agreement on the tendency toward symmetrical load input with collapse of the F-honeycomb and even in the higher load phase.

Figures 19(a) and 19(b) show section XZ of the deformed barrier at $\Delta z = 80$ mm and 90 mm, respectively. It was successfully confirmed that in either case the F-honeycomb collapsed and the rear bumper beam reached the flat barrier plate.

The portions colored blue in the figures show the approximate positions of the B-honeycomb after deformation. The dimensions given in the figures are the distances from the flat barrier plate to the upper end of the B-honeycomb. Comparison shows that this distance is 30 mm greater when $\Delta z = 80$ mm. This is thought to happen because the vertical overlap at 80 mm is smaller so that the rear bumper beam transitions to a condition that deforms the F-honeycomb more quickly. This is substantiation that the reason for the difference in the extent of the transitional phase is the difference in the amount of barrier deformation.

The above successfully demonstrates that having the F-honeycomb collapse and having the flat barrier plate come in contact with the rear bumper beam results in symmetrical load input even in the higher load phase.

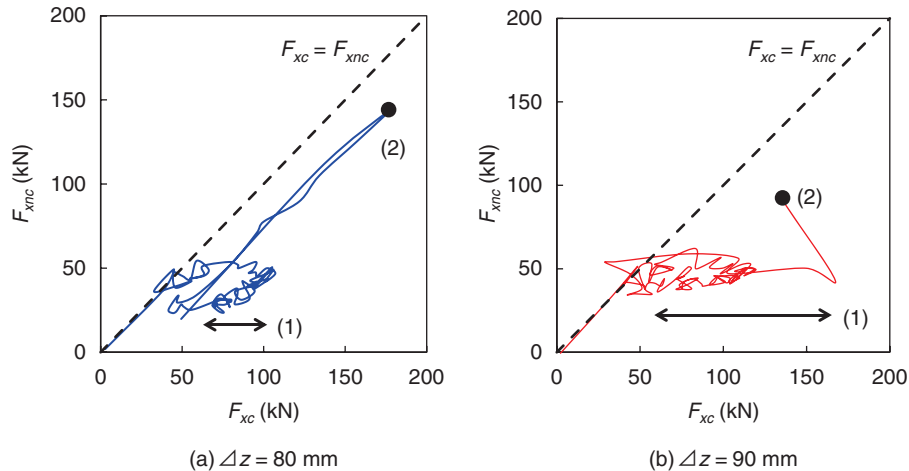


Fig. 18 Comparison of load balances with different lap lengths

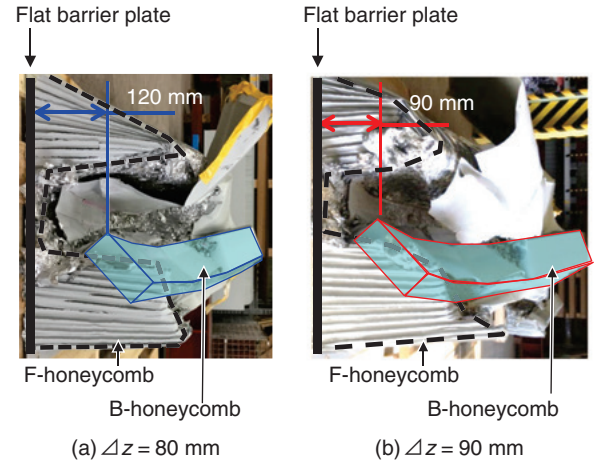


Fig. 19 Comparison of tested barriers with different lap lengths

5. Conclusion

A rear bumper beam was developed that is capable of reducing the input load difference between left and right rear frames under the test conditions of FMVSS 301R, which is a US regulation addressing rear-end collisions. Clarification was obtained of the conditions whereby load distribution is enhanced by the flat section of the rear bumper beam and the clearance provided at both ends of the beam. It was also clarified that load distribution is made possible even in a higher load phase by configuring the B-honeycomb and rear bumper beam to have a smaller vertical overlap.

The prototype rear bumper beam with the new structure was used to conduct drop tower test. This demonstrated that the input difference between left and right could be reduced from the lower load phase to the higher load phase.

It is anticipated that this technology will help enhance energy absorption by the non-collision side frame, and it appears likely to be usable even in next-generation vehicle bodies, which will probably be heavier.

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Mechanism of Light Weight Sound Insulation Material Using Thin-film Cells

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ABSTRACT

Weight reduction of the sound insulation material used to enhance cabin quietness is being advanced for the purpose of reducing vehicle weight. Sound insulation material with a structure of double walls with an intermediate layer of porous material between them is frequently used. There are reports from previous research that the use of thin-film cells instead of porous material can maintain similar sound insulation performance while enabling weight reduction. However, since the mechanism of sound insulation by thin-film cells is not clearly understood, in the present research, the question of why thin-film cells possess the same sound insulation performance as porous material was examined, with a focus on the propagation speed of sound waves transmitted through thin-film cells (apparent sound speed). The relationship between sound insulation performance and apparent sound speed was also formulated as an equation in order to obtain adequate sound insulation performance, and a method of deriving the apparent sound speed from the internal structure of the thin-film cells was devised. By means of the above examination of the mechanism, findings were obtained to enable performance design of lightweight sound insulation material using thin-film cells.

1. Introduction

Due to further heightening of the demand for reduction of the environmental burden from automobiles, progress is being made in reducing vehicle weight in order to enhance fuel economy performance. There is also the widespread adoption of electric vehicles, which has been accompanied by further growth of customer demand for quietness.

One of the methods used to enhance quietness is the application of acoustic insulation material. The main indicators of performance for acoustic insulation material are the vibration suppressing performance, which indicates how much the material can damp vibration; sound absorption performance, which indicates how much the material can absorb the energy of sound waves; and sound insulation performance, which indicates how much the material can block the transmission of sound waves⁽¹⁾. Sound insulation structures include the single wall, the double wall with air in the intermediate layer, the double wall with porous material that has breathable porous material inserted between the two walls, and others.

Figure 1 shows an example of the sound insulation structure generally used for automobile floors. In order to enhance the sound insulation performance of steel panels in

automobiles, a double wall with porous material structure using porous material and sheets of air-impermeable material is frequently adopted. Methods for further enhancing sound insulation performance include increasing the thickness of the steel panels, increasing the thickness of the porous material, increasing the areic mass of the air-impermeable sheet, etc. In general, weight reduction and sound insulation performance are mutually contradictory.

It has been reported in previous research that the use of a double wall with thin-film-cell structure that has thin-film cells inserted as an intermediate layer provides lighter weight than the conventional double wall with porous material structure while also yielding similar sound

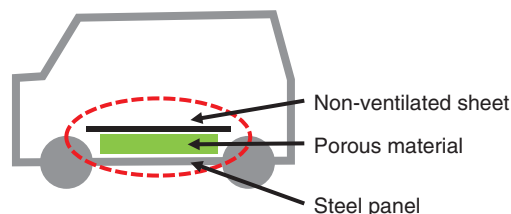


Fig. 1 Sound insulation structure of car

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insulation performance⁽²⁾. Figure 2 shows an example of thin-film cells, which are rows of cylindrical thin-film cells that include air.

Previous research has not clarified why the double wall with thin-film-cell structure using air-impermeable thin film that includes air can provide sound insulation performance similar to that type of structure using porous material.

The sound insulation performance of a double wall with porous material can be predicted using the Biot model⁽³⁾. The Biot model is a model of acoustic characteristics that takes into account the sound of the propagation through air of incident sound waves as they pass through the void portions of a porous material, the sound of their propagation through a solid body as they pass through framework components, and the interaction of these sounds. The parameters of the Biot model include flow resistance; viscous characteristic length, which is related to acoustic energy loss; thermal characteristic length, which is related to the amount of acoustic energy converted to heat, material damping, Young's modulus, and so on. There have been explanations of the mechanism of sound insulation performance that used these parameters. However, thin-film cells composed of thin film and air differ from porous material in that those components are heterogeneous materials so that their mechanism cannot readily be explained using the Biot model.

It is also known, however, that sound insulation performance can be enhanced by using a gas in the intermediate layer of the double wall with air for which the sound speed is slower than air⁽⁴⁾. It is also known that in porous material, the tortuous path length of the void portions through which sound passes is longer to enable the apparent sound speed to be lower than the sound speed in air⁽⁵⁾. This is said to be one of the reasons that the double wall with porous material structure has better sound insulation performance⁽⁶⁾. From this it can be inferred that apparent sound speed in the intermediate layer is one factor in the mechanism of sound insulation performance.

For the present research, therefore, the focus has been on the speed of sound wave propagation (apparent sound speed) as they are transmitted within thin-film cells in



Fig. 2 Thin-film cells

examining the mechanism whereby the double wall with thin-film cells provides sound insulation performance similar to the double wall with porous material. If this investigation could make it possible to predict performance by a simple and easy method, then it could serve as a guideline for examining specifications at the initial stage of performance design.

2. Relationship Between Sound Speed and Sound Insulation Performance

2.1. Comparison of Sound Insulation Materials

Figure 3 shows the single wall, double wall with air, and double wall with porous material structures. Figure 4 shows the sound insulation performance of these structures actually measured using a reverberation chamber. The sound insulation performance is shown as transmission loss, for which higher values indicate higher sound insulation performance. In the case of the double wall with air structure, sound insulation performance is enhanced relative to the single wall when the thickness of the intermediate layer is 100 mm or more, as in the double windows used in building construction. In the case of the thinner layers about 10 mm thick, as when used in automobiles, however, the figure decreases. On the other

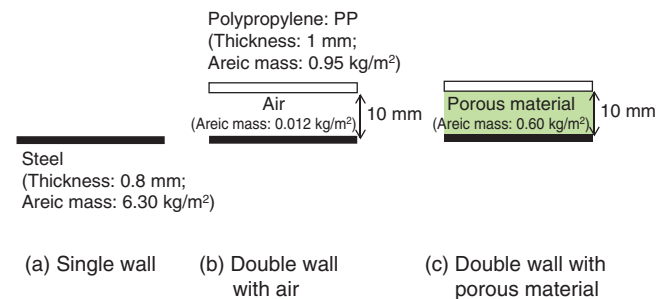


Fig. 3 Structure of sound insulation

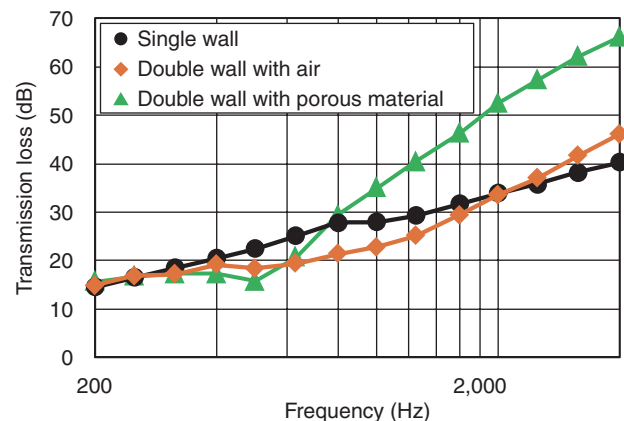


Fig. 4 Transmission loss

hand, the sound insulation performance is known to be enhanced when porous material is inserted into the thin intermediate layer. Here, the mechanism of this double-wall structure will be explained first.

2.2. Apparent Sound Speed and Sound Insulation Performance in the Double Wall with Air Structure

With a double wall with air, an incident plane wave with the incident angle θ_i and sound speed C_i will have refraction angles $\theta_n (= \theta_i)$ and sound speed $C_n (= C_i)$ in intermediate layer n . According to Eq. (1), a larger incident angle will have a greater apparent sound speed expressed as $C_{n-\theta n}$. This phenomenon occurs regardless of the material in the intermediate layer.

$$C_{n-\theta n} = \frac{C_n}{\cos \theta_n} \quad (1)$$

For example, Fig. 5(a) shows an incident plane wave with an incident angle of 0° and sound speed C_i of 340 m/s, and Fig. 5(b) shows an incident plane wave with an incident angle of 45° and sound speed C_i of 340 m/s. In (a), the plane wave simultaneously arrives at the bottom surface of the intermediate layer, so that the sound speed of the intermediate layer is unchanged at 340 m/s. In (b), a portion of the oblique incident plane wave arrives at the bottom surface of the intermediate layer more quickly, so that the sound speed in the perpendicular direction $C_{n-\theta n}$ has a greater apparent value, which according to Eq. (1) is 481 m/s.

With the double wall with air, a resonance is generated for which the areic mass of the wall is the mass and the intermediate layer acts as a spring. Its frequency f is expressed in Eq. (2).

$$f = \frac{1}{2\pi \cos \theta_n} \sqrt{\frac{(m_1 + m_2) \rho C_n^2}{m_1 m_2 l}} \quad (2)$$

ρ : Density (kg/m^3) of intermediate layer
 C_n : Sound speed (m/s) of intermediate layer
 m_1, m_2 : Respective areic masses of the double walls (kg/m^2)
 l : Distance (m) between the double walls
 θ_n : Refraction angles ($^\circ$) of intermediate layer

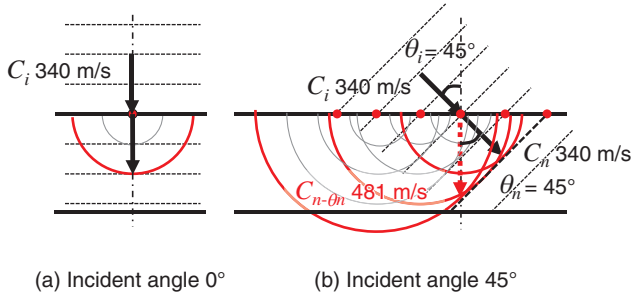


Fig. 5 Sound speeds depending on incident angles

For example, with the double wall with air shown in Fig. 3(b), the changes in sound insulation performance resulting from differing incident angles and sound insulation performance when the incident angles are random calculated from the transfer matrix method will be as shown in Fig. 6. When there is a single incident angle, the distance between the double walls is fixed so that there is one resonance frequency, and the sound insulation performance is higher at higher frequencies. As the incident angle grows larger, the apparent sound speed becomes greater according to Eq. (1) so that, in accordance with Eq. (2), the resonance frequency becomes higher and the sound insulation performance becomes lower. When sound insulation performance is measured using a reverberation chamber, the incident angles are random, resulting in the resonance frequency assuming all values from incident angles 0° to 90° , and reducing sound insulation performance as the calculated values show in Fig. 6.

2.3. Apparent Sound Speed and Sound Insulation Performance of Double Wall with Porous Material

Since porous material has a long and tortuous path, the plane wave takes more time to pass through the porous material and the apparent value of the sound speed will be lower⁽⁵⁾. This apparent sound speed due to distance is designated C_{di} .

In this case, an incident plane wave at incident angle θ_i and sound speed C_i will become a plane wave propagated at refraction angles θ_{di} inside the porous material according to Snell's law as shown in Eq. (3)^{(6), (7)}.

$$\frac{\sin \theta_i}{C_i} = \frac{\sin \theta_{di}}{C_{di}} \quad (3)$$

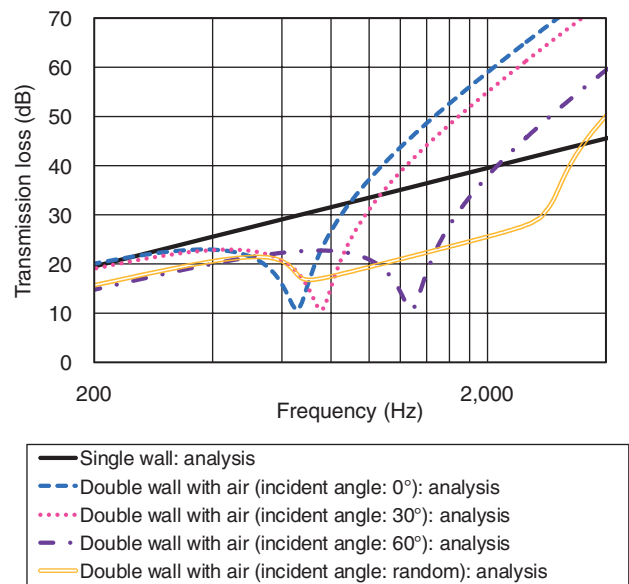


Fig. 6 Incident angles and transmission loss

Figure 7 shows an incident plane wave at incident angle θ_i and sound speed C_i that passes through porous material with the apparent sound speed C_{di} due to the distance.

According to Eq. (1), the apparent sound speed $C_{di-\theta di}$ resulting from the refracted plane wave becomes greater as expressed here in Eq. (4).

$$C_{di-\theta di} = \frac{C_{di}}{\cos \theta_{di}} \quad (4)$$

When the apparent sound speed of the intermediate layer is lower even in cases where incident angles are random, the refraction angles approach 0° , producing sound insulation performance with a higher value close to that shown in Fig. 6 for the incident angle of 0° .

In other words, when the apparent sound speed of the intermediate layer is lower, the sound insulation performance will be higher.

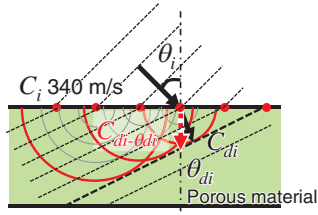


Fig. 7 Refraction angles depending on porous material

3. Mechanism of Apparent Sound Speed Reduction in Thin-film Cells

3.1. Apparent Sound Speed of Thin-film Cells

According to previous research, the double wall with thin-film cells and double wall with porous material structures had similar sound insulation performance. It was inferred from this that thin-film cells were like porous material in having lower apparent sound speed.

The apparent sound speed of both structures was then calculated from normal incidence sound absorption coefficient measurements (ISO 10534-2) using a sound impedance tube with a diameter of 100 mm. Samples were

measured with a thickness of 100 mm and Fig. 8 shows the calculated apparent sound speed. Even though the thin-film cells are almost exclusively air, the apparent sound speed was less than the 340 m/s of air and was similar to the approximately 200 m/s of porous material.

3.2. Time Delay of Sound Waves Due to Thin-film Transmission

Reasoning that the low apparent sound speed in thin-film cells was due to the time delay that occurred when the sound waves were transmitted through the thin film, the time delay of the sound waves was calculated. Figure 9 shows a conceptual drawing of the measurement method. Figure 9(a) shows the case without thin film placed between the sound source and the sound pressure measurement point, and Fig. 9(b) shows the case with thin film placed. The time until sound pressure was propagated to the measurement point was measured and the difference between times with and without thin film was calculated as the time delay of the sound waves.

Figure 10 shows the relationship between the time delay of sound waves due to the thin film and the number of thin films. It was found that increasing the number of thin films produced a greater time delay of sound waves. The time delay per single thin film was determined from the first order approximation curve in Fig. 10 to be 0.032 ms.

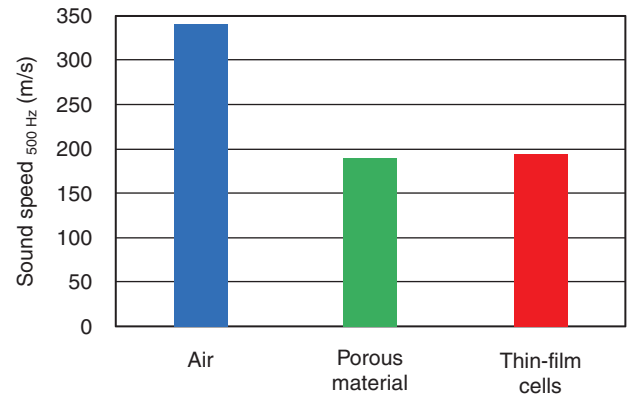


Fig. 8 Sound speed

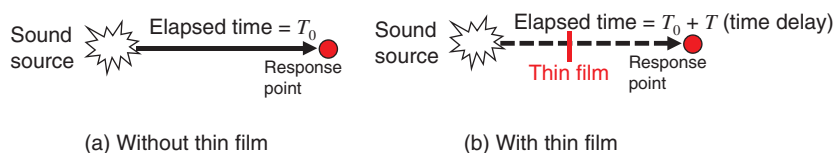


Fig. 9 Measurement of time

3.3. Reduction in Apparent Sound Speed Due to Thin-film Placement

From the fact that a time delay occurs in sound waves due to thin-film transmission, it can be reasoned that the apparent sound speed will decrease even more if multiple thin films are placed in the intermediate layer.

Figure 11(a) shows a plane wave that is obliquely incident to a double wall with air structure. The larger the incident angle, the higher the apparent sound speed $C_{n-\theta_n}$, so that the sound insulation performance decreases. On the other hand, Fig. 11(b) shows a plane wave that is obliquely incident to a double wall structure that has thin films placed in-plane. The larger the incident angle, the greater the number of thin films passed through, so that a time delay occurs in the sound waves and the apparent sound speed of the intermediate layer decreases. Taking this as the apparent value of sound speed C_{de} due to time delay, the apparent sound speed is expressed as $C_{de-\theta_{de}}$, which is lower than $C_{n-\theta_n}$ in (a), so that the sound insulation performance can be considered to become higher than in (a).

Given the above examination, the mechanism by which a double wall with thin-film-cell structure possesses sound insulation performance similar to that provided by porous material was reasoned to be due to the decrease in apparent sound speed from the time delay of sound waves resulting from thin-film transmission.

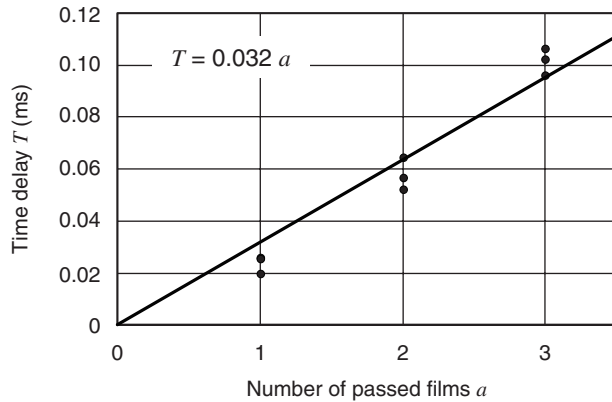


Fig. 10 Time delay of sound by number of thin films

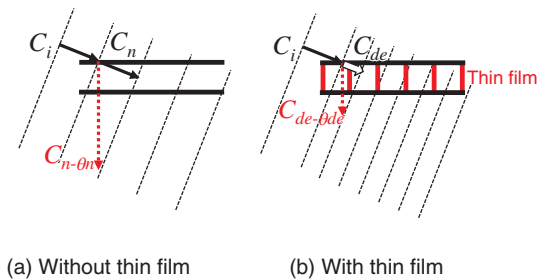


Fig. 11 Oblique incidence

4. Method of Verification

For direct verification of the hypothesis about this mechanism, the apparent sound speed of the intermediate layer using thin film would need to be determined. When the incident angles are random, however, since the apparent sound speed of the intermediate layer cannot readily be measured directly, the relationship between a structure using thin films and the apparent sound speed was formulated as an equation. Next, the relationship between apparent sound speed and sound insulation performance was formulated as an equation and the apparent sound speed that provides sound insulation performance similar to the double wall with porous material structure was calculated. Finally, a structure intended to realize an apparent sound speed that provides sound insulation performance similar to that of a double wall with porous material structure was created. By taking actual measurements of the sound insulation performance of the created structure, the validity of the hypothesis that sound insulation performance is enhanced by the time delay of sound waves caused by thin-film transmission was verified.

4.1. Formulation of an Equation for Apparent Sound Speed in Structures Using Thin Films

First, the relationship between a structure using thin films and apparent sound speed is formulated as an equation. Figure 12 shows a schematic diagram of thin-film arrangement. The thin-film structure is defined as having a height of l m, which is set as equivalent to the distance between the double walls, and the interval between thin films as y m. The number of thin films in a direction perpendicular to the wall surface is b (which is 2 in Fig. 12).

A plane wave that is incident to the thin-film structure with incident angle θ_i and sound speed C_i will have refraction angles $\theta_n (= \theta_i)$ within the thin-film structure. The distance l' that the wave travels through the thin-film structure is expressed by Eq. (5) and the time T' taken in traveling that distance is expressed by Eq. (6).

$$l' = \frac{l}{\cos \theta_n} \quad (5)$$

l : Height (m) of thin-film structure

θ_i : Incident angle ($^\circ$)

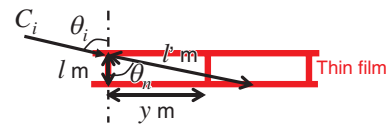


Fig. 12 Film arrangement

$$T' = \frac{l}{C_i} + at \quad (6)$$

a : Number of thin films passed through

t : Time delay per thin film (= 0.032 ms)

Here, the number a of thin films passed through is expressed by Eq. (7).

$$a = \frac{l \tan \theta_n}{y} + b \quad (7)$$

Therefore, the apparent sound speed C_{de} due to the time delay of sound waves passing through a thin-film structure is expressed by Eq. (8).

$$C_{de} = \frac{l}{T'} \quad (8)$$

Because a larger incident angle results in higher apparent sound speed, the apparent sound speed $C_{de-\theta de}$ from Eq. (1) can be expressed as in Eq. (9).

$$C_{de-\theta de} = \frac{C_{de}}{\cos \theta_n} \quad (9)$$

When the incident angles are random, the average sound speed $\overline{C_{de-\theta de}}$ is expressed by Eq. (10).

$$\overline{C_{de-\theta de}} = \frac{\int_0^{\frac{\pi}{2}} C_{de-\theta de} d\theta}{\int_0^{\frac{\pi}{2}} d\theta} \quad (10)$$

For the present research, the apparent sound speed was determined by seeking the average of incident angles from 0° to 78° ⁽⁸⁾ at 1° intervals using sound field incidence under conditions considered to be similar to those of an actual field.

Based on the above, the apparent sound speed can be determined by taking the thin-film structure height l and the thin-film arrangement interval y in the in-plane direction as parameters.

4.2. Formulation of an Equation for the Relationship between Apparent Sound Speed and Sound Insulation Performance

In order to determine the apparent sound speed that yields the desired sound insulation performance, the relationship between apparent sound speed and sound insulation performance was formulated as an equation.

Figure 13(a) shows the model structure to be formulated in an equation. The relationships of sound speed, refraction, and sound insulation performance in a structure with a total of three layers consisting of an intermediate layer inserted into a double wall structure are to be formulated as an equation. In actual fact, while the

intermediate layer will not necessarily be uniform, here it is deemed to be so.

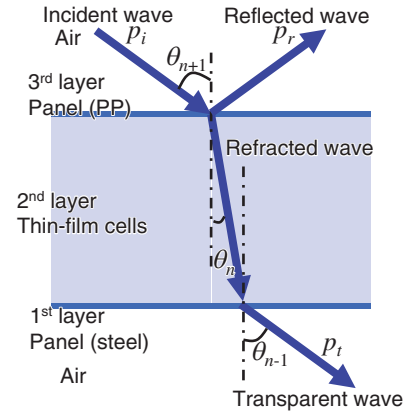
The intermediate layer was generalized as layer number n in a total of m layers through which a plane wave progresses. Figure 13(b) shows the generalized structure.

4.2.1. Transfer matrix method for the intermediate layer

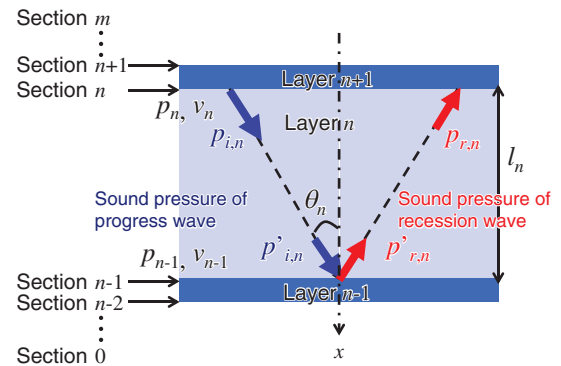
When a plane wave progresses through porous material or through a gas-like layer that is air-permeable, it becomes subject to resistance that depends on the particle velocity. In such cases, the amplitude and phase of the plane wave will change. On the hypothesis of a plane wave, the relationships of the sound pressure p_n and particle velocity v_n at cross-section n (on the incident side) of the media at layer number n , and the sound pressure p_{n-1} and particle velocity v_{n-1} at cross-section $n-1$ are respectively expressed in Eqs. (11)-(14).

$$P_n = P_{i,n} + P_{r,n} \quad (11)$$

$$v_n = \frac{P_{i,n} - P_{r,n}}{W_{x,n}} \quad (12)$$



(a) Three-layer structure



(b) General structure

Fig. 13 Model structure

$$p_{n-1} = p'_{i,n} + p'_{r,n} \quad (13)$$

$$v_{n-1} = \frac{p'_{i,n} - p'_{r,n}}{W_{x,n}} \quad (14)$$

$p_{i,n}$: Sound pressure (Pa) of the progressing wave at cross-section n

$p_{r,n}$: Sound pressure (Pa) of the receding wave at cross-section n

$p'_{i,n}$: Sound pressure (Pa) of the progressing wave at cross-section $n-1$

$p'_{r,n}$: Sound pressure (Pa) of the receding wave at cross-section $n-1$

$W_{x,n}$: Complex characteristic impedance when the plane wave is propagated in the x direction in layer number n of the media

$p_{i,n}$, $p'_{i,n}$, $p_{r,n}$, and $p'_{r,n}$ are determined from distance attenuation and can be expressed by Eq. (15).

$$\begin{aligned} p_{i,n} &= p'_{i,n} e^{jk_{x,n}l_n} \\ p'_{i,n} &= p_{i,n} [\cos(k_{x,n}l_n) - j\sin(k_{x,n}l_n)] \\ p_{r,n} &= p'_{r,n} e^{-jk_{x,n}l_n} \\ p'_{r,n} &= p_{r,n} [\cos(k_{x,n}l_n) + j\sin(k_{x,n}l_n)] \end{aligned} \quad (15)$$

$k_{x,n}$: Wave number

l_n : Thickness (m) at layer number n

Sorting out Eqs. (11)-(15), the relationship between sound pressure and particle velocity at cross-section n and cross-section $n-1$ can be expressed by Eq. (16). Here, $T_{n,n-1}$ is the transfer matrix.

$$\begin{aligned} \begin{Bmatrix} p_n \\ v_n \end{Bmatrix} &= T_{n,n-1} \begin{Bmatrix} p_{n-1} \\ v_{n-1} \end{Bmatrix} \\ T_{n,n-1} &= \begin{bmatrix} \cos(k_{x,n}l_n) & jW_{x,n}\sin(k_{x,n}l_n) \\ \frac{j}{W_{x,n}}\sin(k_{x,n}l_n) & \cos(k_{x,n}l_n) \end{bmatrix} \end{aligned} \quad (16)$$

Here, when $l_n \ll \lambda_{x,n}$, since the equation $k_{x,n}l_n = 2\pi \frac{l_n}{\lambda_{x,n}}$ is very small, it can be approximated as in Eq. (17).

$$\cos(k_{x,n}l_n) \cong 1, \sin(k_{x,n}l_n) \cong k_{x,n}l_n = \frac{\omega l_n}{C_{x,n}} \quad (17)$$

Therefore:

$$T_{n,n-1} \cong \begin{bmatrix} 1 & jW_{x,n}k_{x,n}l_n \\ \frac{j}{W_{x,n}}k_{x,n}l_n & 1 \end{bmatrix} \quad (18)$$

$$k_x = \frac{\omega}{C_{x,n}}, W_{x,n} = \rho_n C_{x,n}$$

$C_{x,n}$: Sound speed (m/s) in the x direction in layer number n

Therefore:

$$T_{n,n-1} = \begin{bmatrix} 1 & j\omega\rho_n l_n \\ \frac{j\omega l_n}{\rho_n C_{x,n}^2} & 1 \end{bmatrix} \quad (19)$$

Given that $C_{x,n} = C_n \cos\theta_n$ and volume elastic modulus of $\rho_n C_{x,n}^2 = E_n$ at layer number n ,

$$T_{n,n-1} = \begin{bmatrix} 1 & j\omega\rho_n l_n \\ \frac{j\omega l_n}{E_n \cos^2\theta_n} & 1 \end{bmatrix} \quad (20)$$

And from $E_n = \frac{l_n}{K_n}$:

$$T_{n,n-1} = \begin{bmatrix} 1 & j\omega\rho_n l_n \\ \frac{j\omega}{K_n \cos^2\theta_n} & 1 \end{bmatrix} \quad (21)$$

ρ_n : Density (kg/m³) of layer number n

K_n : Spring constant (N/m) at layer number n

θ_n : Angle (°) of plane wave at layer number n

The spring constant K_n of layer number n is determined by FEM^{(2),(9)}.

The angle θ_n of the plane wave at layer number n in Eq. (21) is determined from the difference in the sound speed at the boundary surface according to Snell's law, Eq. (3)'.

$$\frac{\sin\theta_{n+1}}{C_{n+1}} = \frac{\sin\theta_n}{C_n} \quad (3)'$$

θ_{n+1} : Angle (°) of plane wave at layer number $n+1$

C_{n+1} : Sound speed (m/s) in layer number $n+1$

C_n : Sound speed (m/s) in layer number n

Here, taking into account the sound speed in the intermediate layer was enabled by creating a model that incorporates Eq. (3)' in Eq. (21).

4.2.2. Transfer matrix method for the wall plates

The wall plate transfer matrix $T_{n,n-1}$ is expressed in Eq. (22)⁽⁴⁾ by the mechanical impedance $Z_{k,n}$ per unit area at layer number n , given the hypothesis of a plane wave.

$$T_{n,n-1} = \begin{bmatrix} 1 & Z_{k,n} \\ 0 & 1 \end{bmatrix} \quad (22)$$

Here, the mechanical impedance $Z_{k,n}$ is expressed by Eq. (23).

$$Z_{k,n} = \gamma_{k,n} + j2\pi f \bar{m}_n \left[1 - \left(\frac{f}{f_{c,n}} \right)^2 \sin^2 \theta_{n+1} \right] \quad (23)$$

$$f_{c,n} = \frac{C_{n+1}^2}{2\pi} \sqrt{\frac{\bar{m}_n}{B_n (1 + j\eta_n)}}$$

$\gamma_{k,n}$: Viscous damping coefficient per unit area of wall plate
 $\bar{m}_n$: Areic mass (kg/m²) of wall plate
 $f_{c,n}$: Coincidence limit frequency (Hz) of wall plate at layer number n
 B_n : Bending rigidity (Nm²) of wall plate per unit area
 η_n : Loss factor of wall plate

4.2.3. Transfer matrix method for laminated layers as a whole

The transfer matrix for the total number of layers m of the laminate as a whole is expressed by Eq. (24), which is the product of the individual transfer matrices.

$$T_{m,0} = T_{m,m-1} \cdot T_{m-1,m-2} \cdots T_{n+1,n} \cdot T_{n,n-1} \cdot T_{n-1,n-2} \cdots T_{1,0} \quad (24)$$

In the case of a double wall with thin-film-cell structure, there is a total of three layers (the steel-panel layer, the thin-film-cell layer, and the PP-panel layer), as in Fig. 13(a), so that it is expressed as the product of the three transfer matrices.

4.2.4. Sound insulation performance of laminated layers as a whole

The relationship of the sound pressure and particle velocity at cross-sections 0 and m (on the incident side) for the total number of layers m of the laminate as a whole is expressed in Eq. (25).

$$\begin{Bmatrix} p_m \\ v_m \end{Bmatrix} = T_{m,0} \begin{Bmatrix} p_0 \\ v_0 \end{Bmatrix} \quad (25)$$

$$T_{m,0} = \begin{bmatrix} T_{m,0}^{(1,1)} & T_{m,0}^{(1,2)} \\ T_{m,0}^{(2,1)} & T_{m,0}^{(2,2)} \end{bmatrix}$$

Given the above, the transmissivity τ can be expressed by Eq. (26).

$$\frac{p_m}{p_0} = T_{m,0}^{(1,1)} + \frac{T_{m,0}^{(1,2)}}{z_0} = \frac{1}{\tau(\theta)} \quad (26)$$

The transmission loss $TL(\theta)$ at incident angle θ_i can be expressed by Eq. (27).

$$TL(\theta) = 10 \log_{10} \left[\frac{1}{\tau(\theta)} \right] \quad (27)$$

When incident angles are random, the average transmissivity $\bar{\tau}$ at incident angles from 0 to $\pi/2$ can be

expressed by Eq. (28) using hemispherical integration⁽⁴⁾. For the incidence here, as well, incident angles from 0° to 78° using sound field incidence were employed and the average transmissivity was calculated.

$$\bar{\tau} = \frac{\int_0^{\pi/2} 2\pi \tau \sin \theta \cos \theta d\theta}{\int_0^{\pi/2} 2\pi \sin \theta \cos \theta d\theta} \quad (28)$$

From the above, the transmission loss TL is expressed by Eq. (29).

$$TL = 10 \log_{10} \left(\frac{1}{\bar{\tau}} \right) \quad (29)$$

Figure 14 shows the relationship between sound insulation performance and apparent sound speed calculated using Eq. (29), where the spring constant of the intermediate layer is 9,400 N/mm, together with the actual measurement values for the sound insulation performance of a double wall with porous material. This confirmed that when the apparent sound speed is about 200 m/s, the resulting figure for sound insulation performance will be similar to that of the double wall with porous material used in the present research.

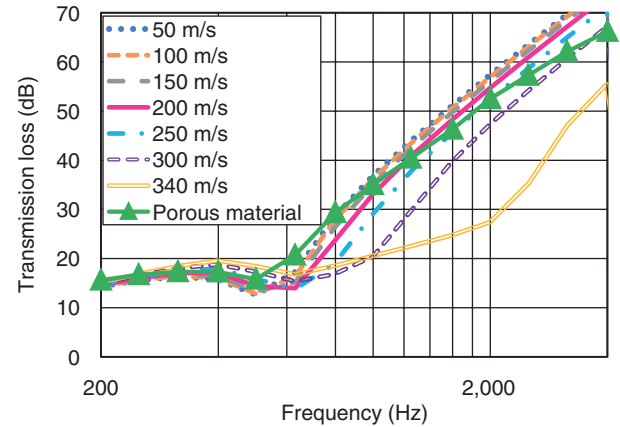


Fig. 14 Sound speed and transmission loss

5. Verification Results and Discussion

5.1. Verification by Structure Using Thin Films

Figure 15 shows the structure used for verification. Thin-film cells made primarily of polyethylene with a thickness of 0.1 mm were used and a structure was created that has cylindrical cells of 30-mm diameter and 10-mm height, containing air, at 4-mm intervals. When this structure is applied to the schematic diagram in Fig. 12,

the thin-film cells are placed at intervals of 17 mm, and the apparent sound speed of this structure is calculated using Eq. (10), the result of which is an estimated 216 m/s. In addition, the areic mass was 33% lighter in weight (0.5 kg/m^2) than the conventional double wall with porous material.

Figure 16 shows the actual measured sound insulation performance for the double wall with porous material and the actual measured sound insulation performance for the double wall with thin-film-cell structure estimated to have an apparent sound speed of 216 m/s, the sound insulation performance in the case of the apparent sound speed 216 m/s derived by formula.

Figure 16 indicates that generally similar results are achieved for sound insulation performance of a double wall with porous material structure, for sound insulation performance by the created double wall with thin-film-cell structure, and for sound insulation performance derived by formula.

Another structure was also created to confirm whether or not it would be possible to predict the performance of a different structure. This other structure was composed of a row of cylindrical cells of a 30-mm diameter and 5-mm height, containing air, at 4-mm intervals. Calculation of the apparent sound speed of this structure yielded an estimate

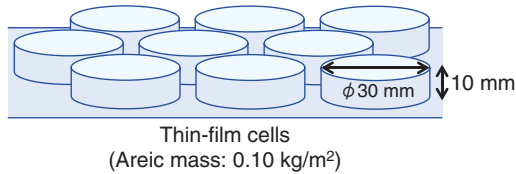


Fig. 15 Designed thin-film cells

of 153 m/s. Figure 17(a) shows actual sound insulation performance measurements for double walls with thin-film-cell structures of the heights 10 mm and 5 mm. Figure 17(b) further shows the sound insulation performance at the apparent sound speed calculated from those quantities as derived by formula. Since the structure of height 5 mm has a higher spring constant than the structure of height 10 mm, the resonance frequency is higher.

Similar trends were obtained from Figs. 17(a) and 17(b) for the actual measured sound insulation performance of the created double wall with thin-film-cell structure and the sound insulation performance determined by formula.

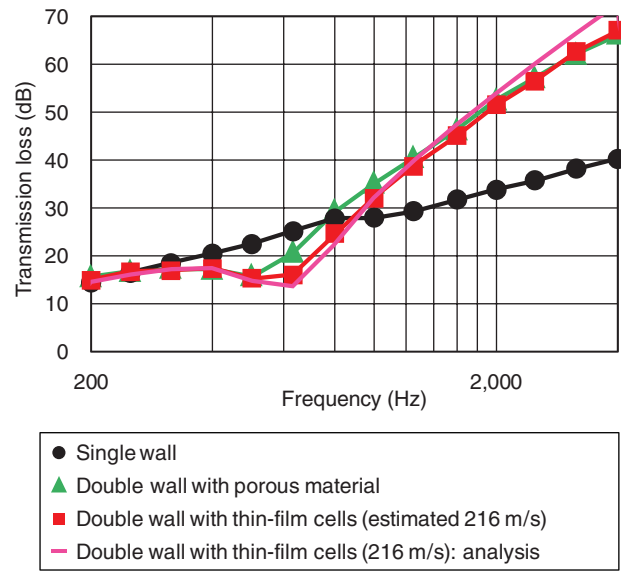
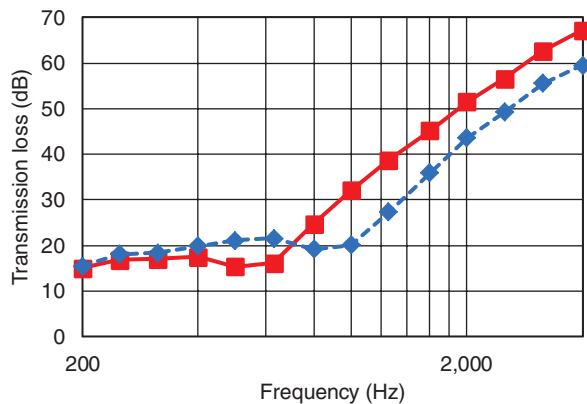
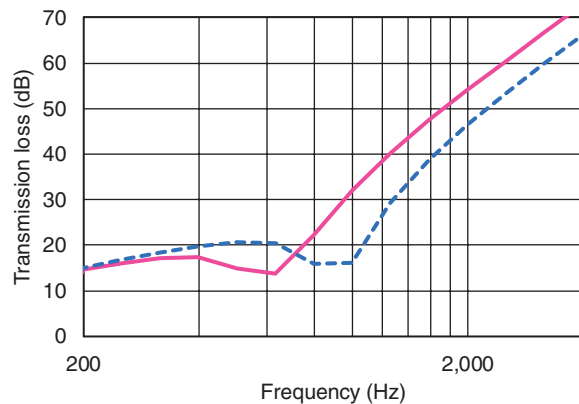


Fig. 16 Transmission loss in designed thin-film cells



Design	
■	ϕ : 30 mm; l : 10 mm (estimated 216 m/s)
◆	ϕ : 30 mm; l : 5 mm (estimated 153 m/s)

(a) Experimental



Design	Spring constant (N/mm)
— ϕ : 30 mm; l : 10 mm (216 m/s)	9,400
- - ϕ : 30 mm; l : 5 mm (153 m/s)	24,000

(b) Analysis

Fig. 17 Transmission loss of double wall with different design of thin-film cells

5.2. Discussion

In the present research, the mechanism of a double wall with thin-film-cell structure was examined with a focus on the apparent sound speed in the intermediate layer. As a result, it was confirmed that the sound insulation performance calculated from the decrease in apparent sound speed caused by sound-wave time delay due to thin-film transmission realized values close to actual measurement results. The hypothesis was that thin-film cells produce sound insulation performance similar to that of porous material because the time delay of sound waves due to thin-film transmission causes the apparent sound speed to be lower, making the apparent sound speed become similar to that of porous material, and this hypothesis was judged valid.

The detailed mechanism of the double wall with thin-film cells is thought to comprise various complex phenomena, including the interaction of thin-film cells and the air inside them, reflection from the thin-film-cell walls, wave interference originating in the thin-film cells, differences in thin-film-cell materials, and so on. While a full grasp of this mechanism has not necessarily been achieved, the results of the present verification show that sound insulation performance and the apparent sound speed of the intermediate layer can be judged to be in close correlation, enabling these findings to be considered useful in the performance design of structures using thin films.

6. Conclusion

An examination was conducted of the mechanism of sound insulation in a double wall with thin-film-cell structure.

- (1) A method was devised for deriving the apparent sound speed in a double wall with thin-film-cell structure from the intervals between thin films and the height of the cells.
- (2) When a plane wave is more obliquely incident to a structure using thin films, the number of thin films passed through will be greater and the apparent sound speed will be lower.
- (3) The sound insulation performance calculated from a decrease in apparent sound speed that results from the time delay of sound waves caused by thin-film transmission will have a value similar to that of the actual measurement results.

Through the present research, it has become possible to conduct a quantitative evaluation of the sound insulation performance provided by a double wall with thin-film-cell structure. Detailed elucidation of the mechanism will require verification of the interaction of thin-film cells and the air inside them, the reflection from thin-film-cell walls, wave interference originating in the thin-film cells, and other such factors. However, this method will serve as relevant knowledge for the performance design of light weight sound insulation material using thin-film cells.

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Editorial Afterword

Before anything else, I would like to express my sincere respect for everyone who submits a paper to the Honda R&D Technical Review despite the demands of their busy day-to-day schedule. Manuscripts submitted to our publication are first reviewed by in-house technical experts, following which they are proofread and corrected by the Technical Paper Committee. Finally, the Honda R&D Technical Review Editorial Committee determines their suitability for publication. These multiple processes improve the quality of the papers, and then they go to publication. Working on a tight schedule, the staff members involved hold repeated discussions and make repeated corrections. It is sometimes the case that a specific focus is selected just before the deadline for publication. I must express my respect not only for our authors, but for all the in-house technical experts and committee members who have committed their time and energy to these processes. I believe that your conscientious efforts not only increase the quality of our papers, but also increase the ability of their authors to grasp the logical thrust and essence of their contention. It is my hope that in the future there will be more and more engineers who seek to become their best by persisting in quiet and steady efforts while enjoying the process of working with all of you. And finally, let me address myself to any engineers, both part of the Honda team and outside the company, who might read this issue. Should you have the opportunity to talk to our authors about any of the technologies discussed herein, I would be delighted if you would offer frank opinions and rigorous advice on the topic.

Wakato YAMAMOTO

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