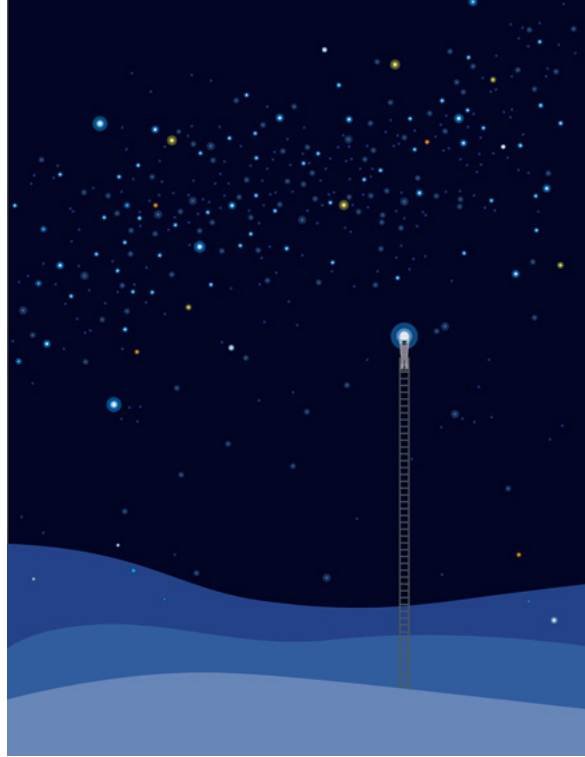


Honda R&D

Technical Review



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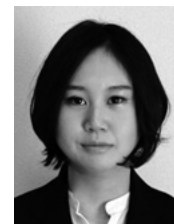


Comment on the Cover

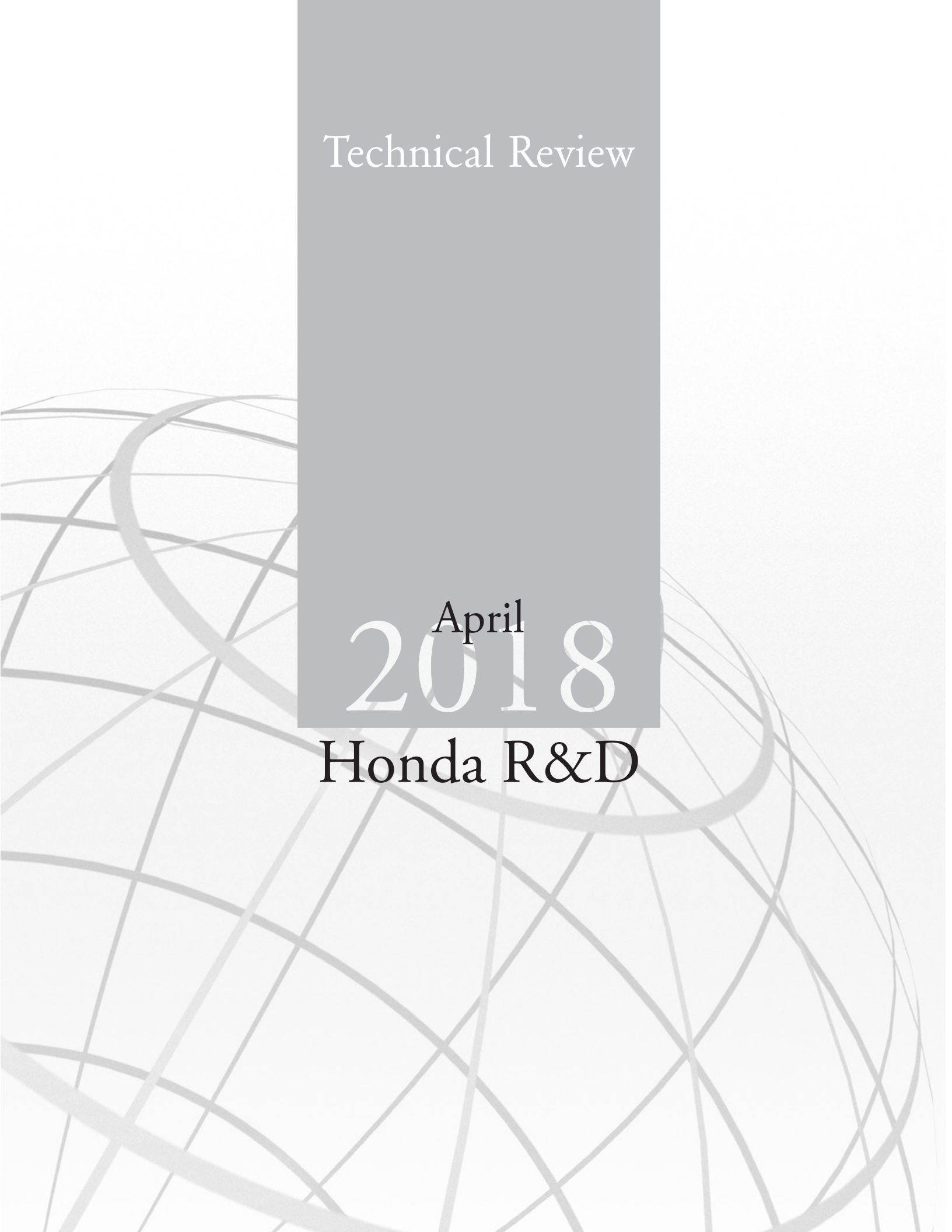
Our ancient ancestors drew lines connecting the stars shining in the night sky to create constellations. By this means, they came to understand these heavenly bodies, which showed them their directions as they traveled.

I think of each individual technology as being like a star.

The technologies that are the outcomes of our day-to-day research come together, forming a unique constellation known to us as the product. As I engage with research and development, it is my belief that by shaping the world, these technologies show humanity the direction in which to proceed.



Power Products R&D Center
Yu SAITSU

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.

Technical Review

April
2018
Honda R&D

CONTENTS

Introduction of Honda R&D Innovation Lab Tokyo	Masaki UHEYAMA, Masatoshi SEKIGUCHI	1
--	---	---

Introduction of new technologies

Concept Creation and Styling Design in the X-ADV	Omi IIDA, Daniele LUCCHESI, Maurizio CARBONARA	16
---	--	----

Development of Rechargeable Power Source LiB-AID E500	Yasuhiro NAKADA, Go FUJIKAWA, Yoshiharu NAWATA Masashi KAI, Kosuke YAMANA, Yuya KATO	32
--	---	----

Development of 2.0 L Engine for New Accord Hybrid	Takeshi WAKAMATSU, Koji YOSHIMOTO, Motoyasu SAKAGUCHI Yoshiharu ISHIGAMI, Nobuyuki AKAISHI, Kenji KUBOTA Shinsuke IZUMI, Kenji NAKAMURA	38
--	---	----

Development of Variable Cooling System Aimed at Fuel Economy Improvement of Air-cooled Engine for Scooters	Tomokazu KOBAYASHI, Kazuyuki KOSEI, Satoshi IJIMA	45
--	---	----

Vibration Reduction Technology with Mount Rubber for Outboard Motors BF4/5/6	Yasukata KOHASHI, Takeshi OKADA, Yoshihiro HARADA	53
---	---	----

Development of Rear Bumper Beam Using Thermoplastic Glass Fiber-reinforced Plastic	Tomoya YABU, Shigeto YASUHARA	60
---	---	----

Crosswind Stability Simulation Technology for Performance Design in Model Base Development of Mass-production Vehicles	Takayuki TOYOSHIMA, Yoshitomo AZEKATSU, Naofumi IKEDA	66
--	---	----

Degradation of Structure Strength by Welding Heat Effect for Hot-stamped Material	Hisayasu OOKA, Tomohiro NOMURA, Masahiro KAWAZU	74
--	---	----

Development of New US Evaluation Course in Takasu Proving Ground	Ryuji ASADA, Takekatsu MATSUKURA, Eiji KARASAKI Hiroyuki KUDO, Ko KATO	82
---	---	----

Technical papers

Development of Gap Mold Technology for RTM of CFRP Parts	Hiroyuki KANNO, Hiroshi KIYOMOTO, Bungo NISHINO, Yohei KAJIURA Takayuki TAKATSUKA, Masahiro ANZAI, Kohei MATSUMOTO	88
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Introduction of Honda R&D Innovation Lab Tokyo

Masaki UEYAMA*

Masatoshi SEKIGUCHI**

ABSTRACT

The Honda R&D Innovation Lab Tokyo in Akasaka Biz Tower was established for product development in new areas related to artificial intelligence technology.

The standpoint of the people engaging in research and development was put first in creating this lab facility. A variety of different thoughts and hopes were therefore incorporated through open-minded collaboration that involved the architectural design firm and construction contractors.

Those thoughts and hopes were given concrete form in various ways. In addition to color, acoustics, and lighting design, there are discussion wagons and Dokodemo White Boards for a more effective use of space, smart frames surrounding them, stools with built-in storage space for water containers and other furniture, the displays of Honda items on bookshelves and glass walls for stimulating creativity, objects used to indicate the directions being taken in initiatives, idea generation-support systems, and other such implements and furnishings.

As a result, the Honda R&D Innovation Lab Tokyo received a New Office Promotion Award from the New Office Promotion Association.

1. Introduction

Remarkable advances have recently been made in artificial intelligence⁽¹⁾. In a field of technology that is making such rapid progress, co-creative work through open, generous exchange with researchers at universities and other companies is considered to be effective. Therefore the Honda R&D Innovation Lab Tokyo (hereafter referred to as HIL-TK) was established for the purpose of product development in new fields related to artificial intelligence, and it was situated in Akasaka, which is convenient for transportation. This laboratory was built through open-minded collaboration that involved the architectural design firm and construction contractors, and it incorporated a variety of ideas intended to realize a work-friendly environment. The result has been very highly regarded, and it has received the New Office Promotion Award⁽²⁾. The first part of this paper describes the course of events leading up to the realization of HIL-TK, and the last part introduces the laboratory with the thoughts and hopes built into it. The purpose of the paper is to provide a reference for the creation of new research facilities in the times ahead.

* R&D Center X

** Wako Administration Division



Fig. 1 Entrance to Honda R&D Innovation Lab Tokyo

2. Concept

2.1. Key Words, Directions, and Conceptual Images

The thoughts and hopes that informed the process of designing HIL-TK was “to bring about a change in Honda’s

R&D labs from this point forward.” This first involved isolating the key words that represent HIL-TK.

Full immersion
Dejima (gateway island)
Open
From non-existence to existence
Move Fast
Innovation
Tackle even the foolhardy challenges
Cheerful and energetic

Next, the statements that HIL-TK was intended to convey inside and outside of the company were put together in orderly form:

- ✓ Escape from the business of selling off hardware that has been pursued so far, and transform into a company that engages in innovation.
- ✓ Generate innovation at the same rapid-seeming pace as software venture companies.
- ✓ Switch from in-house only development to openness and flexibility to engage in development through open innovation.

As a further step, the conceptual approach to apply in designing the HIL-TK space was put into organized form on the basis of those statements.

Given the likelihood that administrative processing will be shifted over to computers (AI) in the times ahead⁽³⁾, it is going to become more important for researchers to engage in creating new value. It appeared likely, therefore, that they would need to create a place where they could do their work, and they would need the flexibility to go on changing with the times. This view is expressed in Fig. 2.

2.2. Site

In order to turn new technology into products, it is desirable for the developers to situate themselves at a location where there is an active exchange with people from inside and outside the company. There they should expose themselves directly to trends in society and stimuli of various kinds, and absorb it all in themselves. In order to carry on active exchanges with a variety of different people and generate new ideas, it will be important - even in the present era of advanced information telecommunications -

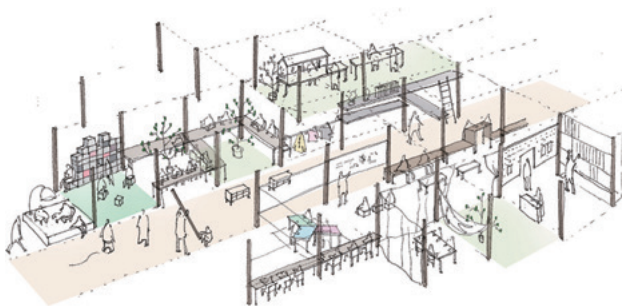


Fig. 2 A laboratory that we create ourselves and upload, and that continues to grow

Table 1 Constraints imposed by a high-rise building and responses to those constraints

Constraints	Responses
Low ceilings and limited floor load capacity	Use existing laboratories for large objects. Take visual steps to address oppressive ceiling feeling.
Building entry through flapper gates feels bothersome	Leave door to entrance area open
Feel out of touch with the changing time and seasons	Use lighting to represent the changing time and decorative plants that also function as partitions to produce a sense of the seasons
Area is limited	Use equipment and fixtures creatively for conferences, experiments, and other such functions

for people to actually meet face to face and discuss matters with each other. The laboratory site selected for that purpose was the 27th floor of Akasaka Biz Tower located where people and information accumulate in the Tokyo city center.

2.3. Constraints and the Incorporation of Constraints in Specifications

The constraints imposed by location in a high-rise building, shown in Table 1, were incorporated in the specifications. Construction was carried out so as not to inconvenience other building residents, with work involving noise and vibration limited to weekends, and late night to early morning hours on weekdays. As a way of shortening construction time, therefore, effective use was made of the existing floors, ceilings, and walls, which required on-site work, while the furniture that people come into direct contact with on an everyday basis was specially designed to create contrasts with the overall features of the space.

(1) Field of vision

A unified space was created by not building any new interior walls. People would be able to see outside through a window as long as they stood up, and feel as though they could set their gaze to a distant view, toward the future, instead of feeling stuck inside a deep, narrow space like an octopus pot. The heights of the furniture items were also kept even for that purpose. The space was configured to guide people's view away from awareness of the low ceilings.

(2) Colors

Taking on the challenge of something new generally involves uncertainty. Since the colors that people are exposed to on an everyday basis are important elements in determining how they feel, a bright, warm color scheme was applied to the space as a whole to stimulate feelings of vitality. The design visualizes a space in which people will tend not to feel gloomy even when they are disappointed because things are not going well⁽⁴⁾.

(3) Acoustics

The aim was to create a space in which lab personnel could fully immerse themselves in their work. Widespread use was made of materials selected for sound-absorbing

properties so that people could converse in normal voices and hold conversations more easily without interference from reverberating sounds.

(4) Lighting

In order to lessen glares on computer displays, areas near windows were made into refreshment areas and “free address” areas, which are sections with unassigned seating. The lighting was also designed to allow people to sense the passing of time during the course of the day.

(5) Meeting rooms and testing rooms

In order to express a feeling of openness, walls and doors were made from transparent glass that does not block people’s views.

(6) Devices and arrangements to induce realization

Numerous refreshment areas and “free address” areas were set up so that people could hold discussions and conversations in different atmospheres.

Sidebar: Designers favor dark colors

Looking stylish or having a high-quality appearance is important for the interior decoration of shops that deal in luxury goods, as well as in residences for the wealthy. Such places are inundated with grays and dark colors. This is definitely stylish. It would be out of the question, however, to block the windows at HIL-TK, where natural light comes pouring in through windows surrounding the space on all sides. HIL-TK is a place intended, from the very start, for bringing new things into being. Making it dark may make it calm, but being all calmed down would be counterproductive. Activity to bring new things into being calls for a space where the mind is vigorously engaged. The designers were told in no uncertain terms that grays were not allowed.

2.4. Promotional Structure

The Preparation Project was organized for launching HIL-TK. The promotional structure shown in Fig. 3 was arranged so that all information would be gathered in the HIL-TK Preparation Project. This was intended to keep information from becoming tangled up in complexities and to speed up decision-making.

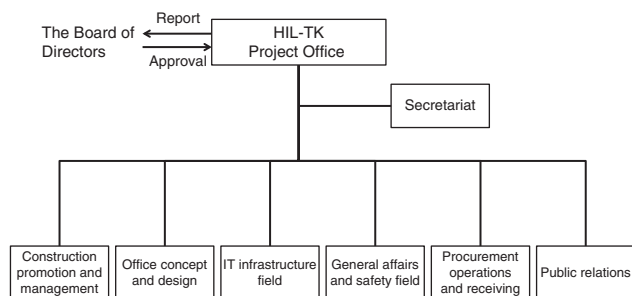


Fig. 3 Structure for promoting HIL-TK

2.5. Construction on the Three Realities Principle

Temporary partitions were installed in some floor sections before construction started. Temporary office areas were set up in those sections and regular research and development work proceeded while the HIL-TK specifications were being studied. It was as though the preparatory team set up camp on the very place where construction took place, and they studied how to make effective use of the site characteristics on the spot. The schedule is shown in Fig. 4, while Figs. 5 and 6 show the site before and after construction, respectively.

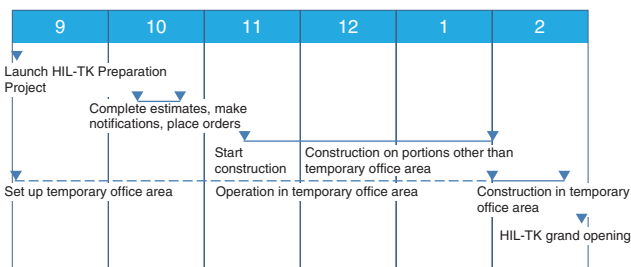


Fig. 4 Schedule leading to grand opening



Fig. 5 On-site study location before construction



Fig. 6 Same location after construction

This study and the confirmation of construction work were carried out by the following:

Regular meetings: meetings held once per week with design firms and construction contractors

Working groups: separate study meetings held once per week on IT systems, electric power, and furniture

Confirmation meetings: held as needed for on-site checking and confirmation of purchased furniture and prototypes

Conducting the study of specifications at the construction site allowed for immediate checking and confirmation of the layout, relative placement, and other aspects of furnishings and fixtures. This enabled decisions and actions to be taken on the spot. The result was that construction was successfully completed in an extremely short time. It was truly a case of putting into practice the Three Realities Principle of going to the actual place (genba), finding the actual source of the issue at hand (genbutsu), and basing your actual decision on reality (genjitsu).

2.6. Overall Layout of HIL-TK

As shown in Fig. 7, HIL-TK is divided into an entrance area, which is used for meetings with partners of collaboration and other such activities, and a work area, which is used for activities that require confidentiality management. Table 2 shows the features of each area.

Table 2 Entrance area and work area

Location	Name	Overview	Figure
Entrance area			
	East Meeting Room	Meeting room for about 10 people at windows on east side	Fig. 10
	Green Meeting Room	Meeting room for 10 people	Fig. 11
	Collaboration Room 1, 2	Rooms fit about 4 people each	Fig. 13
	Presentation Area	Space that can be enclosed in glass	Fig. 14
	East Cafe	Space usable for simple meetings and briefings	Fig. 9
Work area			
	Work desks	"Free address" trapezoidal desks open for use by all in the office and rectangular desks with assigned seats	Fig. 21, 22
	Central Cafe	Refreshment area located in central area	Fig. 36
	West Cafe	Refreshment area at northwest corner	Fig. 30
	High Counter	Free space along windows on north side	Fig. 23
	Sofa Seat	Free space along windows on north side	Fig. 24
	West Meeting Room	Meeting room for 12 people at windows on west	Fig. 26
	Small Meeting Room	Meeting rooms for about 6 people on west side	Fig. 26

3. Description of the Entrance Area

3.1. Entrance and Objects

The HIL-TK entrance doors shown in Fig. 1 are left open from 09:00 to 18:00 to signify open-mindedness. The first thing that visitors see at the entrance is the Honda R&D Innovation Lab Tokyo name plate. The wall facing that has a display area for objects that show what HIL-TK wants to

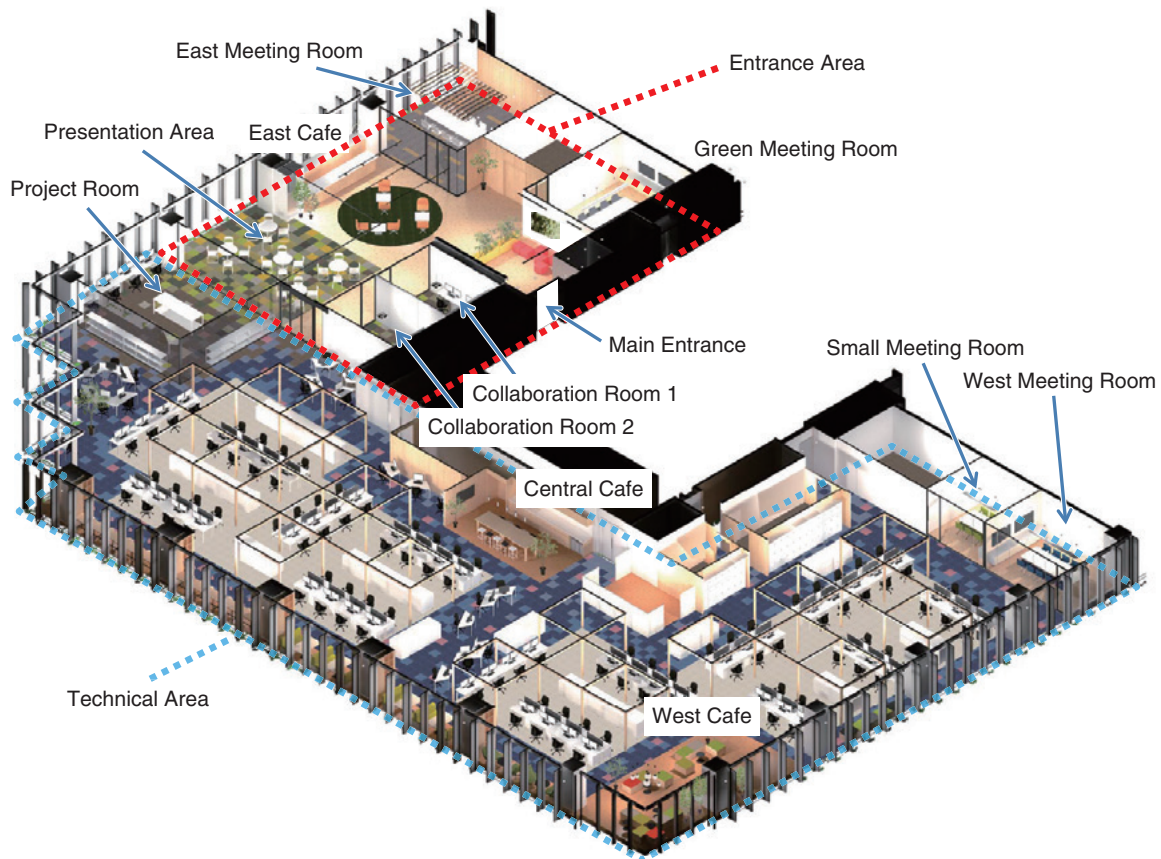


Fig. 7 Overall layout

achieve. This is shown in Fig. 8.

“Fake” objects are not used as substitutes for real things. The thinking is rather that the laboratory should seek to accomplish things that can only be embodied in something that is fake. These objects represent the determination to bring into existence and make available to society something that does not presently exist in the real world.

A photograph of a vineyard appears on the white wall along the far right. This expresses the will to create something that does not presently exist. A fake grape tree protrudes three-dimensionally with leaves and branches from the photograph. These signify the fake tree’s emergence into the real world. Finally, that grape tree bears fruit in the form of peaches, apples, and citruses, representing something that is not possible in the natural world.

3.2. East Cafe with Glowing Rings and Open Ceiling

Placed directly across from the entrance and facing it is a counter where refreshments can be prepared for visitors. This is called the East Cafe. The glowing rings are hung above it.

Looking down from HIL-TK, people have a view of the National Diet Building and the Imperial Palace. This view commonly makes people turn their thoughts to Japan’s future. That is something of great importance. Out of the desire to have people look even farther into the distance, however, HIL-TK has the glowing rings hung there to guide people’s gazes upward (Fig. 9).

This window faces eastward, so gazes guided upward from there look out over Tokyo Bay and beyond it, across the Pacific Ocean to Silicon Valley, then further across the United States and the Atlantic Ocean to Europe. Then from there, the view extends through India and China, circumnavigating the world. This outward gaze extending globally is the desired object. That is the intention embodied in this arrangement.

Part of the ceiling is open overhead, but this is not in

imitation of stylish shops. People are apt to think that their todays will continue into their tomorrows, and that no major changes will take place in the world around them. The ceiling is deliberately left open just in this area as a reminder that what people generally expect to find - i.e., a ceiling overhead - suddenly may not be there anymore. It is a hint to be aware that there is no knowing what will happen tomorrow.

3.3. Meeting Rooms

The meeting room walls are white and made so that magnets can stick to them. All of these walls can be used as white boards. The idea for this came from an episode in the life of the company founder Soichiro Honda, who was so engrossed in discussion one time that he made a drawing that extended right onto the floor. The point here was to create an environment that makes it easy to pursue a discussion at any time.

The partition between Collaboration Rooms 1 and 2 was made movable, so that the two rooms could be used as one. These rooms were given this name because they were envisioned as generally being occupied by creators and



Fig. 9 East Cafe with glowing rings and open ceiling



Fig. 8 Objects in entrance



Fig. 10 East Meeting Room

researchers from outside the company who had come to collaborate on projects here.

3.4. Glass Partitions

The laboratory is a place where Honda members can work at the boundary between the company and the outside world, so they can pick up direct impressions of what is happening in society. There they can sense the things that do not yet exist, that people are seeking deep in their hearts. They can realize that these are the things people want, and create them in order to bring wonder and joy to those people. This is not an effort that Honda members can pursue on their own. It depends on an open-minded, creative collaboration with people outside the company. As an expression of this open-mindedness, therefore, even the walls that mark off the border between the work area for HIL-TK personnel and the area where visitors can enter freely are made transparent. As shown in Fig. 12, the seats in the work area are clearly visible through these walls.

While there are work matters that personnel have to be careful about keeping out of view, because of possible concerns that something might be seen and copied by outsiders, and these personnel have been more concerned

about it than anyone, there is no reason to think that a passing glimpse of their work will result in the competition taking the lead over Honda. If the competition takes the lead in something, it is because the people whose work was glimpsed were moving too slowly. This approach also amounts to an expression of the determination at HIL-TK to reconsider former ways of working and, because the open approach is being adopted, to move forward and work at a blazing pace.

3.5. Upside-Down Graphics

The doors and walls of meeting rooms within HIL-TK are also made with transparent glass.

This does not mean, however, that people in a meeting will not feel uncomfortable if they are completely visible from the outside. In order to reduce that feeling of being exposed, graphics have been worked into the glass at an eyesight level.

However, these are not just to block the view. In order to suggest the importance of looking at things from various different perspectives, the graphics show a map of the world with the usual top and bottom reversed, together with a map that has the North Pole at the center (Fig. 13).

3.6. Presentation Area

This is a space for holding special events. Ordinarily it is used as a place for holding meetings, but the area can be surrounded with movable glass walls and the window can have curtains closed, or screens lowered over it, to create an area suitable for holding presentations with a projector. The area can seat 20 people around round tables or 35 people when chairs are placed without tables. If the movable glass walls are taken away, an event for 100 people can be held. At the HIL-TK grand opening held on February 28, 2017, this area was used to hold a press conference for invited mass media and journalists. Figure 14 shows a lecture being given by Prof. Edward Albert Feigenbaum, the noted authority on AI expert systems, who was invited to speak.



Fig. 11 Green Meeting Room



Fig. 12 Transparent glass wall



Fig. 13 Graphics on walls of Collaboration Rooms 1 and 2



Fig. 14 Scene of a talk being given in the presentation area

4. Description of the Work Area

The work area has no doors installed except for the two meeting rooms and the project room. This is done partly to encourage exchange among HIL-TK personnel by making it easy to look across the area and see where people are. It is also to provide for good circulation throughout an organization that is not primarily hierarchical.

4.1. Work Area Specifications

Wooden flooring can make an area noisy from people's footsteps and from the reverberations of people's conversations. It can also necessitate major replacement work when the flooring needs maintenance. The floor in the work area was therefore carpeted.

The use of highly sound-absorbent carpet enables laboratory personnel to talk freely without worrying about the noise. The buzz of people in discussion also generates an appropriate acoustic environment that allows people to communicate openly in a space that feels as unconstrained as walking through a forest. Out of consideration for when the carpet may become terribly soiled, it is installed in squares that are 50 cm on each side, as visible in Fig. 15, to allow easy replacement. This is also a measure intended to reduce future maintenance expenses.

Sidebar: A Story of People Who Take on Challenges

An initiative to build up a new world may seem overly bold.

If existing research centers up to now are likened to luxury ocean liners, then HIL-TK is nothing but a little rowboat. That boat, however, belongs to people who are taking on the challenge of heading out onto the vast blue sea of new business.

The ocean is the source of life, and on it these people

may reach uninhabited islands where trees grow, branches extend outward, vegetation flourishes, and flowers bloom. There, the people build houses for themselves out of driftwood they find on the beach.

This kind of story was used to configure the materials and colors of the work area. The passageways are carpeted in blue, representing the ocean. The places where personnel do their work are colored ivory, representing the beach.

4.2. Project Room

HIL-TK does not provide spaces for displaying past research results or products. This project room is a laboratory for products that are going to be supplied to the world. In other words, these are things that will become the legacy of the future, and this research and development work is carried on in a space placed deliberately to be visible to visitors.

It should be apparent from Fig. 16 that there is nothing to block off this room from the entrance area. There is a wall of transparent glass through which people can see into the work area on the other side. This is another place that is formed by the HIL-TK philosophy of openness and innovation. There is also an anticipation that having people



Fig. 15 Work area scene



Fig. 16 Project room viewed from the reception area

from outside the company see experimentation being carried on will serve to stimulate the formation of ideas that bring further development.

4.3. Smart Frame

Boundaries made up of wood pillars and called smart frames were installed around the work areas. These allowed the areas to be freely divided into separate spaces. Inside the boundary is a region where people can immerse themselves fully in their work. Outside the boundary is a region where people can move and do different things for a change of pace. By making these kinds of sensory demarcations of spaces, a sense of team unity is generated. As can also be seen in Fig. 17, the smart frame pillars are of uniform height and have conspicuous grain. Having the pillars lined up directs people's gaze away from the low ceilings, and this was another intended effect.

The smart frame has steel beam as the structural material covered with a veneer. The surface is covered with a resin coating in order to give the feel of genuine wood while keeping soiling to as low a level as practical. Envisioning that desk positions will be moved to keep up with changes in work, the smart frame is constructed as a Rahmen structure with a rigid frame that is not fixed to the floor. This allows easy extension or removal of the frames in single units composed of three-meter spans.

4.4. Dokodemo White Board

A lightweight frame weighing 5 kg was devised to which a white board can be freely attached, with magnets, at any height. This allows white boards to be attached easily at any part of the smart frame. At HIL-TK, this is called the Dokodemo White Board. This realizes a space where discussion can be carried on while making notes anywhere within the area.

4.5. Discussion Wagons

Discussion wagons were placed to the sides of the seats. These are work platforms equipped with storage

space. The surface is made of melamine resin, which is slightly rough to the touch but withstands somewhat rough handling without being damaged. This means that people can feel free to use the wagons as work platforms without restraint. The wagons are built with the capability to meet the laboratory's changing needs, and have casters attached to make them easy to move. The tabletop was set at a height that allows people to work at a computer while standing, or to gather around the wagon for a meeting. In order that people will not have to pay attention to any extraneous concerns during discussion, the drawers are made without any protruding parts that clothing might catch on. A space that toes will fit under was added around the bottom of the wagon to avoid the discomfort of stubbed toes. Many prototypes were made and discussions held around them in order to work out the distance between people facing each other across the wagon, to decide the storage capacity and external dimensions, to determine the shape of handgrips on the drawers, and so on, so as to encourage vigorous discussion. The result was a collaborative work that achieved a fusion of architectural design, which mainly involves looking at objects from a distance, and automobile design, which involves a more close-up handling of objects.



Fig. 18 Dokodemo-white board



Fig. 17 Smart frame



Fig. 19 Discussion wagons

The layout is configured to enable concentration with a sense of speed. If people are facing their desk and working on programming, for instance, they can turn right around to reach for something, to do something, or to discuss something without having to break their chain of thought. This may be why it is not unusual to see people gathered around a discussion wagon holding a meeting even though a meeting room is open for their use.

4.6. Desks

It is common at HIL-TK for people to use two computer displays and to have more than one computer close at feet, so that desks need to have enough width from side to side. People also want desk construction to include places where wiring, power adapters, and so on can simply be fitted in from above, leaving the desk surface uncluttered. However, commercially available desks have hidden wire management grommets with such narrow space that people would get their fingers pinched. It also proved not to be easy to find desks that were easy to use and also had a high-quality feeling. The upshot was that HIL-TK had matching



Fig. 20 Meeting scene taking place around discussion wagons

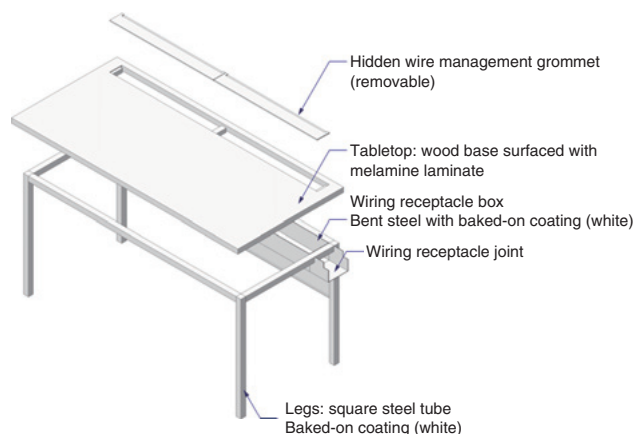


Fig. 21 Schematic drawing of desk

desks built both for meeting rooms and work areas, taking care with the shape of the hidden wire management grommets, providing enough clearance, rounding the edges, and so on. Coloring was kept to a bare minimum in order to facilitate concentration on work. Since computers and their displays are mostly black, the chairs were also made black while the desks were made white to create a bright, cheerful atmosphere. The same material with an identical thickness was also used for the discussion wagon tabletops placed around the work areas, and the Dokodemo White Boards were unified by use of the same white color as well. Efforts were made to help avoid flooding the area with a profusion of different colors.

On the other hand, the desks built for work done by planning divisions and supervisory personnel, which can be handled using a single notebook computer, are configured in a trapezoidal shape. This removes those parts of the desktop where people's hands will not reach and therefore keeps the working surface from becoming cluttered with things.

These trapezoidal desks can be placed singly, but as shown in Fig. 7, three can be placed together to form a half-moon shape or they can be placed in other of numerous different layouts. The desks in HIL-TK, including those in the meeting rooms, were made with common specifications for hidden wire management grommets and tabletops as a measure to reduce the fabrication cost.

4.7. Free Address Area

The area facing the northern windows was designated a free space. This was set up as a place where personnel could switch into a different frame of mind. It is furnished with high counters and colorful seats of easily adjustable heights. A privacy panel is placed so that people sitting there will

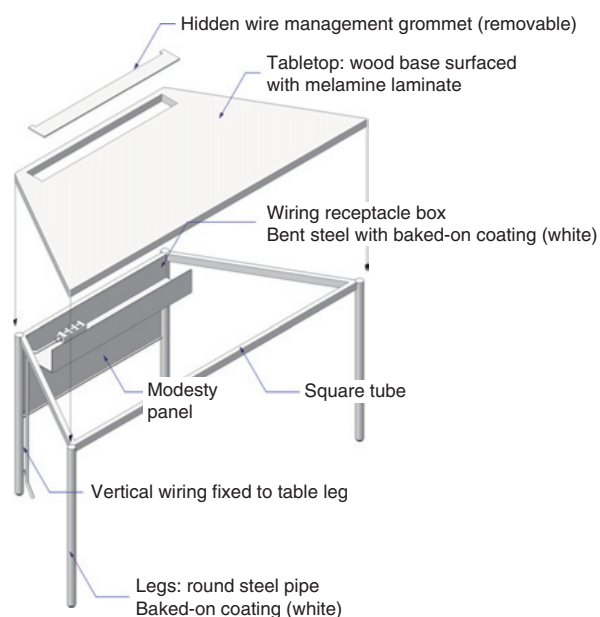


Fig. 22 Schematic drawing of trapezoidal desk

have their bodies, from the knees down screened from view from outside the windows. The far edge of the counter is also given a raised rim so that pens or other objects cannot fall off in front of the windows. Pains were taken to make these and other such arrangements so that people will be able to immerse themselves fully in their work without having to think about extraneous matters.

The area next to the high counter is furnished with sofa seats. The area beside the windows is a free space where people can hold discussions in an atmosphere of calm. It is for meetings and for refreshment, and it is rare to find an open seat. The space under the seat allows for storage of water bottles for disaster readiness, like the colorful stools to be described later. This also contributes to the effective use of space.

4.8. Honda's Bookshelves

The five large columns at the windows in the north area have bookshelves installed around them.

Books are made with words that have been sifted through the gaze of their authors and editors, and when perusing them, there is something good about being able to naturally read the passages around the parts one wanted

to find out about, as well. For research and development, books have been collected that are accumulations of knowledge on themes relating to forms in communication, the body and food, nature and people, culture and aesthetics spanning the past and the future, and other subjects not typically seen as part of research and development. Among them are books that can be considered historic works, such as the Whole Earth Catalog, various paperbacks on current topics, large format books, comic books, picture books, and photographic anthologies. "Honda's bookshelves" contain 600 or more volumes as a device to inspire new ideas by the fortuitous stimulation of reading or browsing.

4.9. Meeting Rooms for HIL-TK Personnel

The West Meeting Room is located by the windows on the west side, far from the entrance area. The Small Meeting Room is located beside it. (In Fig. 26, the right side is toward the west.) The seats in the Small Meeting Room are orange in color, and in the West Meeting Room they are light green. The color scheme was made light and cheerful to encourage active discussion.

The glass in these two meeting rooms contains representations of the history of tools. This is to show



Fig. 23 High counter



Fig. 25 Bookshelves

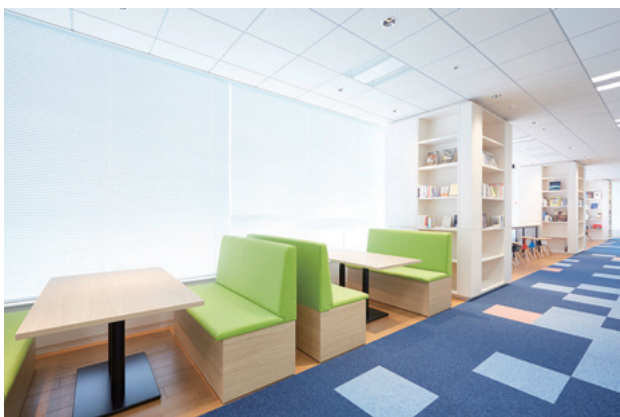


Fig. 24 Sofa seats



Fig. 26 Small Meeting Room and West Meeting Room

respect to the things created by people of preceding generations, as well as in hopes of stimulating inspiration in the people working here (Fig. 27).

A stone tool is placed at the far left as the oldest category of tool made by humankind. This stone tool was discovered through the persistent efforts of a lone individual at a location later designated the Iwajuku archaeological site. This is one of the stone tools in the collection of the Aizawa Tadahiro Memorial House that rewrote the archaeology textbooks⁽⁵⁾. This artifact is etched first in order to make the point that HIL-TK personnel are called on to take up challenges even against what is accepted as common sense, without being constrained by common knowledge, academic institutions, or established theories.

Cooking over an open flame can be extremely challenging, since the surface of the food may be charred while the inside is still raw. If water placed in an earthenware container is used to boil the food, however, the temperature will not rise above 100°C. All that is necessary is to control how long the food is boiled, so cooking becomes extremely simple. An earthenware vessel was therefore etched into second place as a tool that can be considered to have brought about a revolution in cooking.

When people are conveying information, the spoken language they use will disappear when those speakers are gone. When people mediate the communication, the information tends to degenerate. Written letters can record communication accurately, and are, in a sense a tool that can transcend time. Therefore written letters are shown as tools in the third place, and in this case the letters are Egyptian hieroglyphics representing intelligence.

Printing technology expanded the propagation of knowledge from just some people to the public at large, and mass printed matter enabled information to be conveyed all around the world. This was an information revolution during the Renaissance that is comparable to the internet today. Printing type is therefore etched in the fourth place

as a tool that transcends space.

Prof. Edward Albert Feigenbaum, who kindly agreed to serve as an advisor to R&D Center X, is also a fellow of the Computer History Museum in Silicon Valley. This museum has an abacus on display as an early calculating device. In the fifth place, therefore, an abacus is etched as a tool for making calculations.

When a tool for making calculations and a tool for making records information are combined, or in other words, when logic elements and memory are combined, what they make is a computer or artificial intelligence. What is shown in the sixth place, therefore, is a conceptual image of artificial intelligence.

The last thing to be etched in this series is a question mark. The expectation is that as people enter and leave these meeting rooms, they will consciously wonder, every time, what they themselves should make to follow after the revolutionary tools created by preceding generations.

4.10. Colorful Stools

Colorful stools have been placed in the West Cafe and in front of the objects at the entrance, among other locations. It takes more than any ordinary effort to fulfill an intention to bring to reality something that does not presently exist or cannot possibly exist. People who attempt it may have to go through uncountable numbers of unsuccessful attempts along the way. It seemed preferable to have a bright, cheery atmosphere in which to face up against challenges of that kind, so stools upholstered with colorful fabric have been placed here and there.

A further functionality is built into these stools. HIL-TK has laid up three days' worth of water and provisions in readiness for a disaster period when some personnel may be unable to travel back to their homes. The water alone amounts to approximately 1.5 tons, so finding a place to store it is a major task. It was decided, therefore, to store water inside the stools in bottles for use in water dispensers. Products like this were not conveniently available on the market, so these too were built for that purpose.

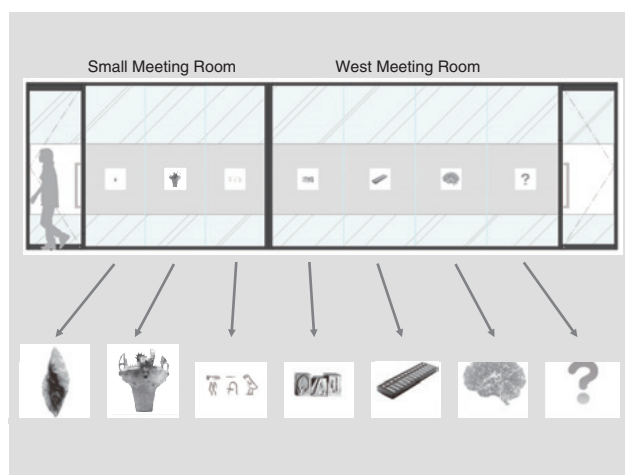


Fig. 27 Stone tools, earthenware, hieroglyphics, printing type, abacus, AI, ?



Fig. 28 Water bottle being replaced

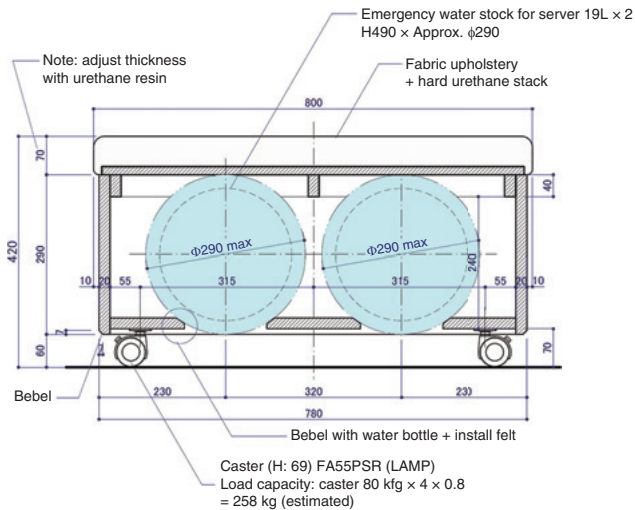
The following specifications were set for the stools:

- (1) Seat surface height at a level suitable for relaxed sitting
- (2) Thickly cushioned seat for comfortable sitting
- (3) Bright colors to induce cheerful feelings
- (4) Casters for ease in moving
- (5) Construction that allows for ease in placing and removing stored water bottles
- (6) Construction that does not damage the surface of stored water bottles

The stools store water bottles that are 290 mm in diameter, and the seat height was kept to 420 mm to allow for comfortable sitting. Not only do the stools in their four colors (blue, green, orange, and yellow) make for an effective use of space, they also serve as a visible reminder that heightens the awareness of disaster preparedness.

4.11. West Cafe

From the northwest corner, there are sweeping views of the State Guest House and the greenery of the Akasaka



Source: NOMURA Co., Ltd., design drawings for Honda R&D Innovation Lab Tokyo

Fig. 29 Stool structure

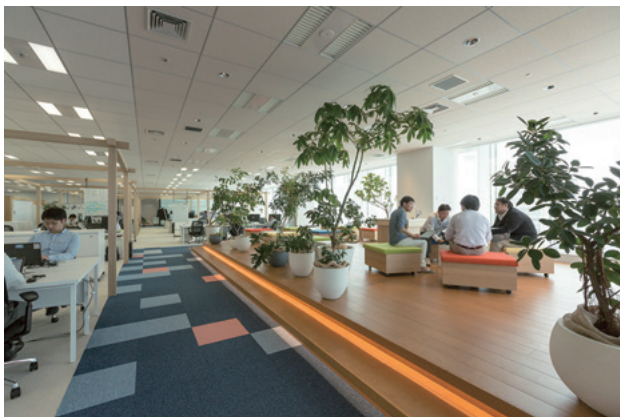


Fig. 30 Meeting scene in West Cafe

Imperial property. This corner was made into a cafe, with plants placed in connection with the green from the outside view, the floor raised, and numerous colorful stools placed around it.

This area was designed for refreshment and relaxation, but the fact is that personnel can often be seen holding meetings here. In an unforeseen but fortunate use, the cafe spontaneously became a place to hold meetings, taking advantage of the open, relaxed atmosphere which is unlike the meeting rooms.

Sidebar: Pay Attention to the Professional's Technique

Designers produce appealing-looking drawings. Even where a real room is cramped, perspective drawings can make it look like an expansive, roomy space. This is the kind of work only professionals can do. The reaction when a person sees the actual place is disappointment: “How can it be this cramped in here?” Figure 32 shows a perspective view that makes the area look very spacious, but those who were conducting studies on-site would not be deceived. With the drawing in one hand and a strip of packing tape stretched across the floor, verification takes very little time. This is just the kind of thing that makes on-site study an



Fig. 31 West Cafe



Fig. 32 Perspective view of West Cafe

advantage.

As it happens, the photograph of the West Cafe taken by a professional photographer is also very appealing-looking. It is every bit the equal of the perspective drawing. Professionals have amazing skills.

4.12. Lighting

When people spend the whole day indoors under artificial lighting in a space without windows, there is a risk that their internal biological clocks will be affected. The control mechanism for this circadian rhythm is of great importance, as indicated by the fact that the Nobel Prize in Physiology or Medicine in 2017 was awarded for the elucidation of this mechanism⁽⁶⁾. The circadian rhythm is powerfully influenced by light. Working till late at night under strong white artificial light can make people restless after they get home, and it has also been pointed out that sleep disorders can be caused by this⁽⁷⁾. At HIL-TK, therefore, lighting that makes use of the changes in natural light was adopted.

Figures 33 to 35 show how the color of the lighting changes from daytime to evening to night.



Fig. 33 As seen in the daytime



Fig. 34 As seen in the evening

Wood-grained flooring material was used for the window frame on the north side and for the cafe floor, and the part of the ceiling near the window was given a reddish tinge. Then lighting with colored light bulbs was installed. Though this coloring is not noticeable under strong sunlight during the day, the dusk-like coloring is emphasized when the sun starts to go down. This allows people to gain a natural sense that the day is ending.

4.13. Central Cafe

This cafe was located next to the work space in an arrangement that clearly conveys which space is for concentration and which space is for relaxation. The cafe is an expansive space located on the other side of the carpet, which is colored blue as a conceptual image of water. By contrasting with the monotone coloring of the work space, the cafe uses the lighting of colored light bulbs and large amounts of wood to produce an atmosphere that naturally makes people want to stop in for a while. Given that HIL-TK is intended to create products that have a high-quality feel, items of solid wood were purchased for the desks and seats that personnel come into direct contact with. The cafe has become a favorite spot for meetings held with a change of mood.

A refrigerator, coffee maker, and tea dispenser are set out in this area. Sometimes people take breaks here, but the assumption is that personnel are also likely to go to the West Cafe to take their breaks while looking out at the view. It is anticipated that people will obtain something to drink here and then take the trouble to walk with their drink a few steps farther to that other spot where the intensities of work will recede and they can relax on a break, perhaps falling into a natural conversation with people they do not work with.

4.14. Hirameki Engine

As the deployment of AI in society shifts memory and analysis from people over onto AI, increasing value is likely to be placed on people as the originators of ideas. At



Fig. 35 As seen at night

HIL-TK, therefore, an experimental idea generation-support system called the Hirameki Engine has been installed in the Central Cafe on a trial basis. This is an arrangement in addition to the establishment of various free spaces and cafes where people can go for a refreshing change of pace.

It has been said that inspiration visits people on three things⁽⁸⁾. That is, it comes to people when they are riding on a horse, lying on a bed, or sitting on the toilet. This is explaining that the time when people are released from their concentration is when they can gain sudden insight. The idea is that the mechanism for inspiration takes the thoughts people have been having on a subject and the various concepts that people have in their heads, and then combines them in a random, unconscious way. It may be that only when the unconscious determines that this process has turned up a good idea does the inspiration rise up to consciousness⁽⁹⁾.

The Hirameki Engine is used by inputting one group of words that indicate matters which have been occupying a part of a person's attention. The engine then randomly throws up words that are unrelated to that group onto the display. This is a mechanism for obtaining clues for ideas from startling combinations that people would not think of for themselves that the engine puts together fortuitously. The unrelated concepts here are limited to things that people already have in their own heads or that they happen to see or hear while on a walk or on other such occasions, but the Hirameki Engine can isolate words randomly from across a broader range by performing internet searches. In this way, the engine broadens the range of the ideas. It is anticipated that people looking at the Hirameki Engine in the Central Cafe will be visited by sudden insights.



Fig. 36 Central Cafe and Hirameki Engine

5. Evaluation from Outside the Company

As described above, a variety of different measures were designed into HIL-TK, and ever since the grand opening, many requests to tour the facility have been sent in from

inside and outside Japan. Many visitors have been received at HIL-TK, including members of foreign embassies seeking to facilitate corporate collaboration, members of corporations and academic groups looking for information to use in planning new laboratories of their own, and so on.

HIL-TK was also honored with the 30th Nikkei New Office Promotion Award presented by the New Office Promotion Association. This came about because of a remark made by a person collaborating on the project from outside Honda. At a stage when the laboratory was nearly complete, this person said, "Since you've realized a space as splendid as this, you should consider applying for a design award." Thinking that if an application was to be made, then it might as well be for an authoritative award, and an application was made to the only national-level office-related awards program, supported by the Ministry of Economy, Trade and Industry and organized by the New Office Promotion Association. The judges gave very high ratings to the discussion wagons and other furniture as a fusion of architecture that is viewed and automobile design that is operated. They rated it so highly that they actually urged HIL-TK to market these items. The application therefore successfully resulted in receipt of the award.

The New Office Promotion Award is given on the basis of documentary review, and an additional on-site review by the head of an institute of architecture together with university professors and professors emeritus of architecture and design. These 12 experts spent an hour and a half conducting a rigorous investigation of HIL-TK. This is therefore a very high-quality award, and not something that can be obtained simply by seeking it. The judging is not based simply on the attractiveness of appearance, but examines such matters as whether or not the office gives the impression of providing the people who work there a comfortable environment that allows ample psychological breathing space, and whether the office incorporates innovative measures and arrangements to encourage ways of working that stimulate sensibilities and heighten creativity.

HIL-TK sees this award as an appreciation of how the aims of the people involved in the project have been realized.

6. Conclusion

HIL-TK was established in Akasaka for the purpose of product development in new fields related to artificial intelligence technology.

In an open-minded collaboration that involved people from inside and outside the company in the process of creation, a variety of different and innovative ideas were given form in HIL-TK. These include the objects that indicate directions to be taken with the new things created, stools that combine the function of storage space for water containers, smart frames used for the demarcation of spaces, Dokodemo White Boards, discussion wagons, Honda's

bookshelves, glass walls that encourage different ways of seeing things, displays of the history of tools that provide stimuli for thinking about what should be created, the Hirameki Engine that is an idea generation-support system, and so on.

As a result, HIL-TK received a New Office Promotion Award from the New Office Promotion Association.

Despite the short time allowed for construction, the project team composed of members from NOMURA Co., Ltd., Takachiho Products Co., Ltd., UNIVERSAL ENGEISHA Co., Ltd., at light laboratory, KAYAC Inc., and BACH Ltd., together with Honda personnel, engaged in exhaustive discussion to create something good. By making prototypes and repeatedly going through the process of confirmation, the team developed relationships of trust so that everyone involved was able to press the project forward not with the formalities of insiders and outsiders but on the first-name basis of people who can freely throw out their views and push each other to reach higher levels. This effort produced a space that evolved far beyond the concept envisioned at the start.

The image of what was achieved constitutes the first open innovation aimed for and executed by HIL-TK.

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Concept Creation and Styling Design in the X-ADV

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ABSTRACT

X-ADV was developed as a new 750 cc class motorcycle model targeting European customers. In this model, we aimed to further expand the joy of movement for customers in the mature market in Europe. The concept and styling design were begun to be investigated voluntarily before the development started. First, we conducted a survey targeting customers in Europe and derived the product concept “Go Everywhere with Excitement.” The intention is that it is a commuter motorcycle with ‘Adventurer spirit’ that allows smart movements in the city on weekdays and invites them to adventure on holidays. The direction of the styling design was set to represent the attributes of the four-wheel sport utility vehicles, expressing toughness and protections for the rider. A concept model was created for verification of this direction. In that model, taking into consideration the riders’ physiques and postures, the attributes of protection that makes it looked like the motorcycle is protecting the rider was expressed. Furthermore, in order to verify whether the set directionality is acceptable to customers, the concept model was exhibited at European motor shows and hearings were conducted. As a consequence, we could get customers’ understanding, and we gained highly favorable evaluation results as well. Furthermore, based on this result, the commercial production of this model was decided and styling designs for mass-produced cars were implemented. The developed model of the X-ADV captures the customers’ mind with the unprecedented concept and styling and is favorably accepted in the market.

1. Introduction

The X-ADV is a model developed as a 750 cc class motorcycle based on a new concept. It has functions suitable for commuter use that offers an easy handling just like scooters, and driving performance that enables riding on a rough road and an enjoyable long distance cruise (Fig. 1).

This model was developed aiming at expansion of the joy of mobility for customers in Europe where the culture of using motorcycles, for living their daily lives and for getting pleasures, has been taking root. Before getting into details of styling of the X-ADV, the circumstances before the development of this model started will be explained.

First of all, I will describe the outline of the European motorcycle market. In addition, I will touch on the outline of the crossover models that currently occupies a large market portion in the major markets in Europe. The European motorcycle market had greatly expanded due to the economic boom after the monetary union, but after the European debt crisis in 2008 the market shrank, of which impact continued until 2012, when we started planning this model. Until that year of 2008, the number

of customers who can afford two or more motorcycles had been increasing, and the number of motorcycles owned had continued to rise. One of the motorcycles they owned was a super sports model, suitable for sporty running on roads and/or in a circuit, or a touring model that can travel at high speed comfortably over long distances. In other words,



Fig. 1 The X-ADV (production model)

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** Honda R&D Europe Italia s.r.l.

those were motorcycles to enjoy running with an expensive, high power engine. The other motorcycle they had was a scooter used for daily commuting.

However, with the deterioration of the economy since 2008, the markets of super sports models and touring models have greatly decreased. In association with this economic decline, the voice wishing for a model with “a versatile crossover concept” that combines the enjoyment of running and the convenience of day-to-day commuting had been strengthened. Honda responded to this change in market circumstances and began to develop a multi-use motorcycle model, and the model was put into the market. The VFR1200X (Fig. 2) is a representative model of such multi-use models. The model of this category is easy to use in urban driving for commuting, and it is also a model that can run on both paved road and off-road area enjoyably.

As mentioned above, changes were taking place in the motorcycle category market. However, similar changes had not been occurring in the scooter category, which is another big market.

One of the assumed reasons for this is that the market size of the models called maxi-scooters among scooter categories did not decrease greatly even after the economic crisis of 2008. Maxi-scooter is a 500 cc class scooter excellent in daily use, and it was widely used for commuting. In addition, the maxi-scooter has high versatility being capable of providing comfortable performances not only in use in urban areas but also in high speed cruising.

Based in Rome, Italy, Honda R&D Europe Italia s.r.l. has a survey and planning team (hereinafter referred to as “HRE-I team” or “the team”) and is conducting market research and product planning within the European region. This team had a conviction for a possibility that new values had been emerging under the influence of environmental changes of the market in the scooter category as well, even though no changes seemed to be witnessed in the present

situation. With that in mind, we started investigation of the market, on our own initiative, aiming at a goal of providing a new pleasure of mobility for scooter users.

2. Customer Survey

2.1. Direction of Vehicle Model Concept - Study Results Acquired by Interviewing Target Users -

To start with, HRE-I team asked users in France and Italy, which are the major markets in Europe, what are the functions or performances that they think important as inevitable characteristics or they just feel attractive, when they use conventional maxi-scooter models. Furthermore, in this user survey, we interviewed them also asking whether there is any demand for something different from those already provided by existing models, or something that had not been provided so far.

As a result, it was found out that the group of users who are using maxi-scooters mainly for daily commuting are satisfied with the functions and the design.

Users who belong to this group unchangingly want to purchase and use maxi-scooters that inherit the same characteristics current models have, and they do not have any particular desire for seeking something new.

On the other hand, the users using maxi-scooters for touring on their leisure time, in addition to commuting, are hoping to further expand their accessible areas to a variety of places that are currently not reachable by existing models. “If the scooters could be transformed beyond the vehicles just providing driving capabilities for paved roads or for cruising on highways, and if the scooters could make us possible to visit hotels or camping sites that are only reachable through rough roads in mountain areas or through roads along sandy coast areas, the scooters would increase our enjoyment of riding in off-urban areas.” In the interviews, we got a lot of such answers.

Furthermore, interviews asking preferences in vehicle



Fig. 2 The VFR1200X

styling design were also conducted to the users of maxi-scooters having interest in touring.

Many of the interview results showed that, if the motorcycle could offer accessibilities to the places that cannot be reached by conventional models, in accordance with that, a new styling design representing an adventurous atmosphere is desirable.

The results of these surveys revealed that there are two different groups of maxi-scooter users, and they also revealed that there exists an unrecognized potential market in which they desire the scooter with a new value of offering a wider accessibility to virtually anywhere they want.

2.2. Conceptual Direction of Styling Design

After completing the aforementioned survey, we gathered and organized the opinions from users, and discussed the direction of the entire styling design.

As described earlier, the vehicle we were targeting was a scooter that, same as current maxi-scooters, can provide the functions for offering comfortable commuting in daily use and performances that enable sporty driving. In addition to that, our proposing target vehicle should have functions to provide enjoyable running in natural environments, such as running through coastal areas or mountain areas, in their leisure time. Based on the results of the study, we clarified factors required for the design of the target scooter.

- (1) The vehicle body should have a sturdy and robust design to inspire the users to have a dream that anyone can go anywhere with it.
- (2) The detailed designs should make users imagine the assured stable riding even in roughed roads, and, for that it is naturally expected for the vehicle it be equipped with long-stroke shock absorbers, firm suspension systems and protectors for a rider.

The direction of our styling design was set to propose a new scooter that is differentiated from conventional maxi-scooters by crossing features of off-road motorcycles over those of scooters while satisfying two requirements mentioned above.

3. Determining Design Concept and Vehicle Packaging

3.1. Concept <Go Everywhere with Excitement>

The direction of styling design described above includes a lot of elements that have HRE-I team members feel sympathy through their daily experiences such as commuting by motorcycles or scooters and enjoying touring in their leisure time. If a scooter is equipped with suspension systems as sturdy as those applied to off-road motorcycles, riders can drive with a sense of security with a margin of maneuvering, which cannot be provided by scooters in their daily commuting driving on roughened road surfaces. Moreover, it expands the areas of their accesses when touring. The value was defined as our core

concept expressed by the phrase “Go Everywhere with Excitement” with an ambition of representing it by styling design that offers customers excitements only explorers can experience.

Furthermore, as a phrase that concretely describes the concept, we set up the phrase of “Commuter’s motorcycle that holds adventurers’ spirit that tempts users into adventurous experiences away from day-to-day lives while performing a smart mobility in cities on weekdays” and, with that in mind, we undertook the study of the vehicle styling design.

3.2. Vehicle Packaging

In line with the concept of bringing about an excellent riding performances together with functional features of scooters, HRE-I team members determined three requirements described below as indispensable elements for the vehicle design, so that elements that make users feel unique characteristics of off-road motorcycles are expressed through visual representations as well as through the functionalities.

- (1) The riding position should be designed to realize the posture of raised upper-body to secure a high viewpoint and the handle grip points should be located so as to keep widely spaced arrangement to keep the freedom of control of vehicle movements by the rider.
- (2) It should be equipped with suspension systems that ensure the secured riding even on roads with rough surfaces.
 - a. Secure minimum ground clearance and suspension stroke comparable to those of crossover motorcycles.
 - b. Large diameter tires with on-off type tread pattern should be adopted.
 - c. Spoke wheels adapting to tubeless tiers should be adopted in order to realize a riding with supple maneuvering responses and easy maintenance.
 - d. Adoption of inverted front forks with 41 mm diameter, which symbolize powerfulness, and a front brake with double discs with calipers radially mounted.
- (3) The styling design should make users feel the potential to offer light maneuvering, while giving an impression of sturdiness, and it should be tempting to have them motivated to “go anywhere.”

Furthermore, in order to provide an easy riding even in driving on a rough road without requiring any special driving skill, a low-gravity-centered front-tilted two-cylinder 750 cc engine that features the powerful characteristic of generating a large torque was selected. For the transmission, an automatic transmission (in specific, a Dual Clutch Transmission) was applied. On the other hand, for the storage space, a full face helmet can be stored underneath the seat. As a result of combining these characteristics, it became possible to propose a new category commuters’ motorcycle packaging that also has the touring performance as well as the rough road running performance.

4. Styling Design

4.1. Styling Design Concept

In parallel with the study of the concept of the overall vehicle packaging, we advanced the study of the concept of the styling design that creates a new appeal not found in the conventional categories. For the styling, we wanted to merge the different characteristics that three motorcycle categories have into one. These characteristics are the comfortableness that maxi-scooters have, the nimbleness that off-road motorcycles have, and tough wildness that adventure motorcycles have. We defined the following items as the core values of the styling design. These core values are represented as a concept board shown in Fig. 3.

- (1) Expressing characteristics of maxi-scooters - Reflecting elements that offer comfort -
 - a. The dimensions of the straddled portion, located at the middle of the vehicle body, and the dimensions of the floor step should be set virtually equivalent to those of the NC750D INTEGRA⁽²⁾.
 - b. Within the vehicle body, a space should be secured for the full face helmet storage.
- (2) Expressing characteristics of off-road motorcycles

- Vehicle body proportions that make them imagine feelings of light maneuvering -
 - a. By arranging the tires to be exposed frontward and backward without covering with the parts surrounding the suspension systems, the appearance that the tires are firmly grasping the ground should be created.
 - b. The longitudinal length of the vehicle body is shortened to make it appear floating in a higher position so as to create a trapezoidal body proportion.
 - c. A comfortable riding should be secured and the degree of spatial freedom of the rider should be properly kept.
 - (3) Expressing characteristics of adventure motorcycles - Expression of wildness and toughness -
 - a. The vehicle front area should be constructed so as to have the functional parts directly visible without equipping plastic covering for shielding the handlebar and the gauge unit.
 - b. Adopt twin headlights symbolizing adventure motorcycles.
 - c. Adopt metallic protectors over the foot pegs and the front covers.
- In addition to these, to express its sporty feature throughout the vehicle body, it was decided to apply shape



Fig. 3 Styling concept board

of rugged rocky appearance with mechanical atmosphere, that is on the leading edge of the design trend for adventure type of motorcycles.

With consideration to the styling design elements mentioned above, creation of the styling sketches were attempted.

4.2. Styling Sketches

As mentioned above, the core values are defined being strongly conscious of the expressions of the wild characters symbolizing the challenging attitude against dangers and the sturdy character that supports that attitude, which is what adventure type of motorcycles inherently possess. To deploy the styling sketches, as a specific approach we had already experienced in the styling design for the VFR1200X of a crossover motorcycle model, aimed design work was conducted by implementing the design elements representing the core values into the vehicle packaging to be created.

Being drawn based on the requirements described above, one of the sketches was designed by composing whole vehicle body through creating drawings of the functional parts, such as upper cowls, engine hangers, fuel tank and rear cowls, separately. The proposed sketch created this way is shown as “Proposed sketch A” (Fig. 4).

On the other hand, in the sketch created as another attempt, a longitudinally shortened vehicle body shape was applied to enhance the impression of agile maneuverability. In addition, a beak-shaped upper fender was installed under the headlight unit to produce a feeling of vibrant emotions. Moreover, the design sketch was drawn so as to emphasize the connections of the parts composing the outer surfaces of the body by concealing up the body frames with covers installed around the engine area. The proposed sketch is shown as sketch B (Fig. 5).

Both proposal A and proposal B were the design having lack of coherence in the arrangement of each composing part because of a large distance between the area of front periphery and the seat, even though they were successfully expressing agility and wildness.

The biggest challenge common to these proposals was, because they were both created by incorporating the design motifs from the existing crossover motorcycles, they inevitably caused viewers’ reminiscence of the existing two-wheeled vehicle designs. As a consequence, neither design was suitable for a new concept.

After making these trial sketches, the team members continued drawing sketches while trying various approaches, but we could not defeat the wall “to create a new form that has never existed”. In the end, we just quitted the way of thinking over and over it within the office. Instead, we decided to revisit what we had been seeking to this motorcycle and reinvestigate the origin of our aspiration. For that purpose, we decided to arrange a plan that would help us change our way of creation, through the method of putting ourselves in an environment where users are actually experiencing touring and/or off-road riding. Specifically, we rented a temporary studio located at the foot of the Alps, the renowned area good for motorcycle touring in Italy. We hoped to rebuild an approach method to create our sketches, while watching the landscapes, breathing the air and being contact with the inhabitants there.

Furthermore, we designers ourselves experienced the touring actually running over mountain roads, and, while experiencing that, we struggled to get some new finding, regarding the elements sought for the styling design that makes riders feel excited, which had never existed in our minds before (Fig. 6, 7).

It was the scene in which we saw a local driver operating a four-wheel-drive vehicle. Despite driving on a rough road, the driver was casually dressed in a day-to-day-life wear and overtook us without effort.

The vehicle we come across was a sports utility vehicle (hereinafter referred to as SUV), which is a vehicle in the category of four-wheeled vehicles that provide ease of driving in urban areas and in high-speed cruising, having drivability on bad roads. In Europe, as with some other markets, vehicles in SUV category hold one of the major markets. The concept we sought this time for a new



Fig. 4 Proposed sketch A



Fig. 5 Proposed sketch B

motorcycle was “a motorcycle for commuter use with an adventure spirit that allows users to smartly move in city areas on weekdays and tempts to an adventure in holidays being away from their daily life.” We had noticed that a clue for the creation of our styling design, that meets our seeking concept described above, can be found among the SUV’s styling design elements.

As a result of discussions we had at the studio in the foot of the Alps, we decided to try to develop a styling design with a new direction. The direction we set was not a design making people imagine a tough driving, described as a scene in which a rider, wearing a firm riding gear for protection of his/her body, is driving exposing his body to surrounding dangers, as in off-road or adventure type motorcycles. What we aimed was to incorporate the design elements that make people feel that the rider is protected by the body of motorcycle, just like as in four-wheel drive SUVs.



Fig. 6 Wide- area farm road in central Italy



Fig. 7 Gravel road leading to a town in central Italy

Specifically, a mass feeling of the body, which is formed of solid iron plates applied for rider protection parts such as front bumper, side bumpers and handlebar protector, was represented. At the same time, we tried to express modernity that looks stylish even in a city area with the sketch. The sketch created with these ideas is shown in Fig. 8.

In the design of SUVs of recent years, body parts are constructed so as to make the under-guard and the bumper stand out against engine hood. The same method was applied to our two-wheeled vehicle design, and we tried to create perceptual sensation of the parts connection throughout the vehicle body ranging from the cover on the top of the engine, the gauge unit, the handlebar and to the headlight. In order not to disturb this sense of connection of the parts, we decided to install the windshield separately from the body structure.

Furthermore, in order to express the sturdiness that four-wheeled SUV models have, the surfaces constructing the body shape were arranged in a continuous manner having them seem as if they are made by a single metal panel. By doing that, the whole massive feeling of the total body surfaces was emphasized.

In the design of front part of the body, twin headlights were adopted. In addition, a grille-shaped frame between the headlights, and a frame designed borrowing the form of an automobile bumper arranged around the headlights were adopted. Through application of these design forms, a unique expression of the front mask was created.

Based on these design studies, the HRE-I team selected the drawing shown in Fig. 9 as the final sketch plan. As the next step, we went back to our base office in Rome to advance further ahead creating a three-dimensional model.

5. Making Styling Design Models

5.1. Making Three-dimensional SUV Design with Clay Model

Since the rider’s body is exposed when riding a motorcycle, styling of a motorcycle is designed so as to be balanced with the body of the rider when straddling over the vehicle. Especially, considered with the design direction we set for this particular vehicle, it was important to give a sense of unity expressing that the motorcycle is protecting the rider. We had to create a fully satisfying proportion by constructing a solid body through thorough observations on how the vehicle looks with a rider straddling over it.

Based on the information given through the sketches, we formed the model with clay by putting it so as to represent roughly the desired mass volume of the vehicle body. After that, we carried out the modeling work reflecting necessary functional elements yielded through the confirmations of the seating comfortableness and the positions of riders’ arms and legs, by having riders frequently seated on the vehicle (Fig. 10).

During the early stages of modeling, the point we

specially paid our attention was to make the riding position and shapes of the body and the seat the most suitable for a good maneuverability and freedom of the rider's body

motions when driving on rough surface roads. For that purpose, we took in the knowledge and experiences of the experts of test riding involving in off-road motorcycle

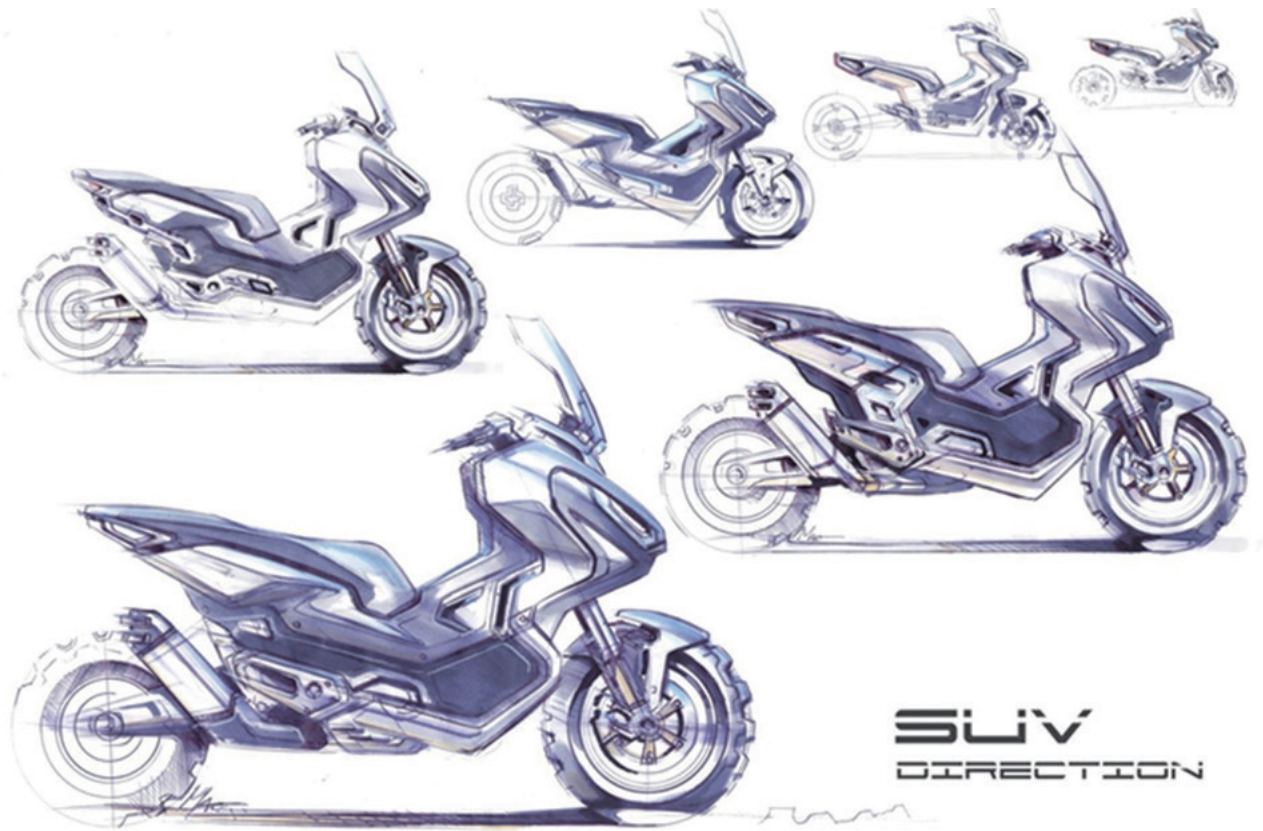


Fig. 8 Key sketches inspired by styling designs of SUVs



Fig. 9 Final sketches

developments.

Moreover, we checked the positional relationships of the feet, knees and buttock of a big rider of 190 cm height and took the whole balance so as not to feel cramped even by big riders in Europe.

Furthermore, in order to ensure comfort for touring driving, the widths of the body and the seat were increased to accommodate buttocks and shoulders of various rider physiques. On the other hand, in order to prevent it from looking dull when viewed from the front quarter, a frame that shifts the position of the windshield was attached to the front cowl portion, and nimbleness produced in the appearance was pursued.

The following pictures are those taken when the clay model was finalized. The longitudinally short-sized body parts and the upstroke shaped muffler express sprightliness. Parts design is made up of rugged shapes that look like protectors, laid out from the front cowl through the floor and the pillion step. This parts design together with movable windshield expresses toughness and mechanical appearance.

For the surface compositions of the body with solid-mass look, the polyhedrons were connected continuously and smoothly. By applying this method, a powerful shape with full of expressiveness was formed (Fig. 11).

5.2. Hard Mockup Model

With the completion of the clay model, the design concept that we had been studying became able to be evaluated as a three-dimensional shape.

By putting this newly designed model into an auto show as a piece of exhibit, the team members wanted to verify the degrees of understanding and sympathy our customers



Fig. 11 Completed clay model

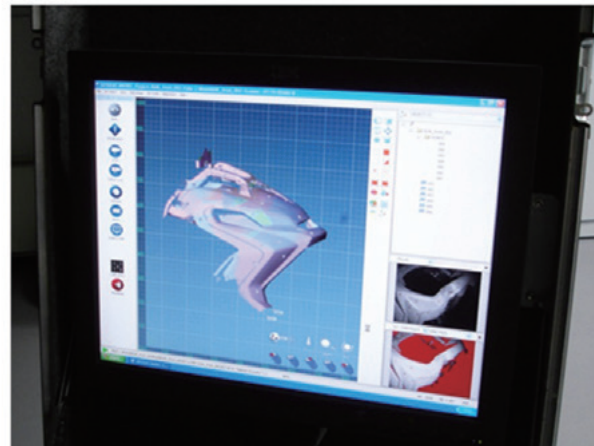


Fig. 10 Riding position checks using clay model before its final finish to investigate dimensions of each part

in the market have regarding our concept. Having that intention, we reviewed the design over the details of each part, and made a hard mockup model that could express the proposed concept at a higher perfection.

First, we measured the outlines of the parts molded with clay, and created three-dimensional data. Using these data, individual parts made from fiberglass, plastics or metals were produced (Fig. 12).

Next, we designed the parts that could not be molded with clay.

Among these parts, examples of distinctively characterized parts in terms of expression of the concept are the windshield and the gauge unit. The structure for moving the windshield consisted of pantograph type of linkage. For the gauge unit, a 7-inch large liquid crystal display was adopted with a rectangular shape to make it look simple. Moreover, a mechanical impression was represented by the stay, which connects the windshield and the gauge unit stay, and the linkage mechanism. By adopting a space surrounded by the frames that make up the stay for the windshield, an effect of helping to represent nimbleness was applied to the structure that tends to appear dull (Fig. 13).

In addition, an aluminum tapered handlebar was adopted that gives an impression of a characteristic of an adventure motorcycle model. The handlebar holder of this vehicle is designed to be a single unit integrating the right and left sides holders that are usually separated. In the middle of this handle bar holder, another indicator unit separate from the gauge unit was placed to enhance information transmitting functionality to a rider. That is, by using this indicator unit, the information that gives convenience and secured feelings when driving in city areas, such as indicators for turn signal operations, engaged or disengaged status indicator of the parking brake and an alarm indicator for ABS, is

provided at the area where a rider can easily recognize, in an integrated manner (Fig. 14). Figure 15 shows the photograph of the completed hard mockup model.

6. Exhibition and Hearing Survey at European Motor Show

What we chose as the sites for the presentation to the public were motorcycle shows held in Italy and France, both of which have a large commuter motorcycle market. That is, they are the EICMA (Esposizione internazionale

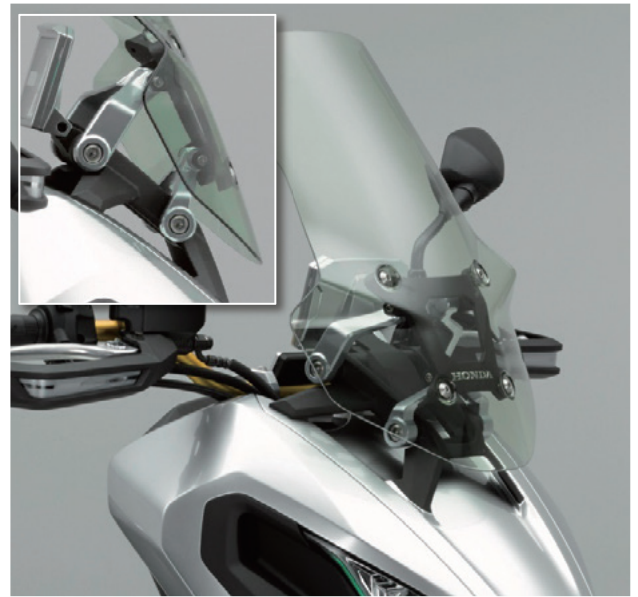


Fig. 13 Movable windshield with pantograph linkage

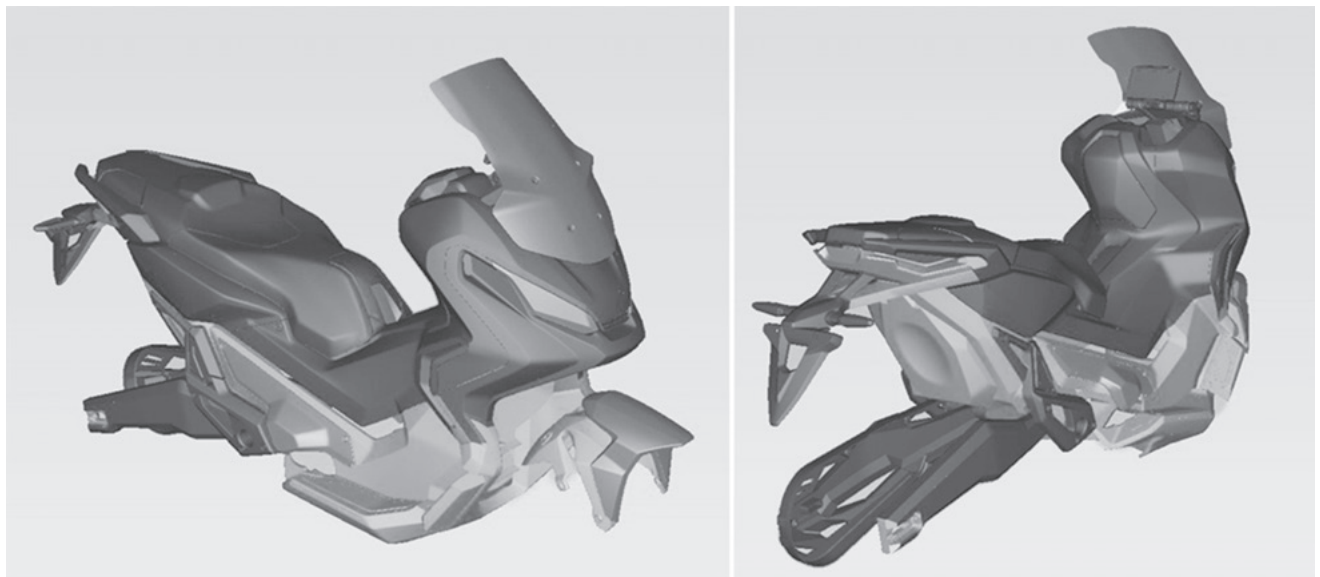


Fig. 12 Three-dimensional data of vehicle body

del ciclo, motociclo, accessori) held in Milan, Italy, and Salon de la Moto Paris held in Paris, France. As mentioned earlier, exhibitions at these shows, coupled with interviews with people visited there, were defined as an important step to verify the evaluations by customers against the concept the team was proposing.

The exhibition booth was designed with an emphasis on conveying a view of a world provided by a motorcycle that has two aspects: comfortable movement in cities when commuting, and freedom of driving through lands full of nature spent in their leisure time. On one side of the exhibition booth, a stone-paved road was re-created. On the other side of the booth, covered with large rounded gravels, a diorama reproducing the camp scene was tailored. Furthermore, in order to emphasize the scenario for each scene, accessories that match with the exhibitions were also designed and displayed (Fig. 16).

For the scene demonstrating being in a town, was prepared a detachable top box that can also be used as a trolley bag. In the center of this top box, the alphabet “X” was arranged symbolizing the concept of crossover. For the side of outdoor scene, a tent and a backpack for storing it were designed and arranged in the display. On the surfaces of these accessories, we arranged the logo type “ADV” which was decided by taking the three letters from the word “adventure,” using silver and green coloring matching the body color of the exhibited model (Fig. 17).

In the exhibition booth designed in this way, the hard mockup model of the vehicle was exhibited. By doing that, we expected the viewers to understand that it is a motorcycle with a specific styling that gives the coolness to be experienced when commuting and the sturdy impression in rural or off-road driving, which had been defined as our aiming concept “Go Everywhere with Excitement.” Using this exhibit, it was tried to verify whether the proposed concept could be received with a favorable impressions by



Fig. 15 Hard mockup model



Fig. 16 Diorama type of exhibition booth expressing Belgian pavement in city and the scene of outdoor



Fig. 14 Display and adjacent area with visibly arranged mechanical parts convenient for commuting

customers.

The survey to the people who saw the exhibited model in the booth was conducted in a form of interviewing. Specifically, we asked about the degree of understanding of the concept, the favorable impression on the design, and the price assumed by the viewer.

The results of the survey are summarized below.

(1) Degree of understanding of concept

The convenience as a commuter's motorcycle, the styling design feeling playful mind, and sporty feelings like those of off-road motorcycles had been understood by the people. It was found out that many of them perceived this motorcycle as a new type of crossover motorcycle.

(2) Attractiveness of design

Attractive styling fitted both of business suits and adventure riding jacket was highly appreciated by many people.

(3) Assumed price

Compared with existing maxi-scooters, the higher ownership value and presence were felt, so there were many answers that price setting equivalent to the motorcycles of the class from 800 cc to 1000 cc is possible.

Confirmed through the results described above, it was verified that European motorcycle users understood the vehicle concept and the styling design of this model as those of a "new crossover motorcycle model," gaining a highly favorable overall evaluation response.

What the team sought for in our concept proposal was a motorcycle that can provide a pleasure of new mobility to the current maxi-scooter users. Two hypotheses obtained in the concept making process, described hereafter, were proved to be correct.

- (1) There is a market of a crossover motorcycle model of an unprecedented category that can run various roads including off-road while providing the convenience of maxi-scooters.

- (2) The four-wheel SUV model has a design that combines modern atmosphere and sturdiness, while ensuring occupant comfort at the same time. By applying this to the design method of motorcycles, it was made possible to realize a design that satisfies both the cool riding in the city and the adventure spirit in a holiday excursion, by a single motorcycle as well.

7. Styling Design for Mass Production Model

As mentioned in the previous chapter, it was able to obtain high evaluation results by users regarding the concept model exhibited at the European motorcycle shows. At the same time, there was a strong demand for releasing this model as a mass production motorcycle. Based on these positive reactions from the market, it was decided to start a project to design mass-production model of this motorcycle.

7.1. Detailed Design of Functional Parts

As mentioned above, high customer evaluation results were yielded for the concept model, and the degree of sympathy for the proposed concept was high. The reason for that was that the specifications and equipment of this concept model were matched with the vehicle category class setting and the proposed direction of the styling design, with appropriate association among them. As a consequence, it is assumed that the presented concept was intuitively understood by the viewers.

Therefore, when designing the mass production model, emphasis was placed on faithfully keeping the design image and the equipment specifications having presented in the concept model as much as possible and reflecting them in the mass-production vehicles as well. It is because we hoped that, by doing so, we wanted to offer that mass production model having features in line with the expectations that our customers had when they saw the motorcycle exhibited as the concept model.

The hard mockup model is shown in Fig. 18, and the mass production model is shown in Fig. 19. From these photographs, it can be understood that the original image is almost faithfully reflected.

A movable windshield is one of the most difficult parts to meet the functional requirements while maintaining the original design.

This windshield is supported by a pantograph type movable stays and is held, as if, floating apart from the front outer contour of the vehicle body. In the hard mockup model, the holding mechanism, actually, was designed to allow only two positions, the highest position and the lowest position, for its fixation, and the fixing mechanism to be applied in the final model had not been decided yet. To cope with this issue, the fixation mechanism and the movable stay, which are installed between the body and the windshield, were designed afresh for the final production model so that it can be fixed at five different heights (Fig. 20). In addition, these parts were designed taking into



Fig. 17 Exclusively designed trolley top case and touring tent with storage case

account the riders' differences in their physiques and the flow of air during riding obtained through a computational simulation.

In the hard mockup model, indicators that appear on the screen of the gauge unit had not been presented in detail. In the design work for the mass production model, they were also designed. Regarding the adjacent areas to the handlebar, considering day-to-day commuting use, the designs adopting many high convenience functions were applied.

The gauge unit was equipped with a speedometer at the center, with a tachometer surrounding it, and indicators to provide variety of information in the periphery. In addition, it was designed to give a sporty atmosphere to the whole display area. Furthermore, a clock with calendar function, a fuel gauge, an ambient air temperature gauge, which are

highly practical for commuting use, were also arranged. In the designs, we tried to design such that these information items can be displayed as large as possible on the liquid crystal surface effectively utilizing the limited area of the display screen. Note that the ambient air temperature gauge also has a warning indicator function for frozen road surface (Fig. 21).

Moreover, a smart key was also adopted to this model. Used with a knob type main switch, it enables to start the engine, and locking and unlocking of the fuel lid and the seat, without an insertion of the key. For this knob type main switch, an original design fitted to the vehicle concept was applied. In other words, this knob type main switch was formed in a symmetrical shape to the longitudinal center line of the vehicle, and the presence of the knob was enhanced by adding a thin ring in chrome color. With



Fig. 18 Exhibited hard mockup model



Fig. 19 Production model

these design techniques, we successfully created a sense of quality being felt when the person is sitting in the driver's seat of a four-wheeled vehicle (Fig. 22).

7.2. Coloring Design

According to the set concept, this model combines two characteristics: cool moving in city and sporty riding on off-roads. In coloring design, the distinctiveness of each characteristic was enhanced by designing multiple color variations that demonstrate the characteristics. This was because it was intended to meet a wide range of demands according to customers' tastes.

Specifically, two color types of coloring group were set: mono-color type and adventure color type. Mono-color type is the color type that comes with a fine quality sense of luxury, which is fitted to the scenes of running through a city wearing a business jacket. The adventure color type is a color type full of dynamism, which is fitted to the scenes

of wildly running on off-roads wearing an adventure riding jacket. Pictures of these coloring designs are included in Fig. 23 that shows whole color types.

For coloring designs that recollect the driving in a city, two types of monotone color types were set. As mentioned earlier, among the possible design approaches for the styling design of the concept model, the SUV design elements applied in automobiles were adopted. The body shapes created by this approach were effectively expressed by adopting the monotone color. For the monotone colors, we set two colors: a metal-toned silver color with strong reflections and shiny appearance (Fig. 23, Type 1), and matte gray which makes feel an atmosphere of tranquility as well as strength (Fig. 23, Type 2). This model has a property of having significant extrusions and dents in the body surfaces, and those are making the whole vehicle body shape look highly three-dimensional. The two selected colors were chosen as those that satisfy the criteria of main body color which can provide luxurious impressions while emphasizing the features associated with town and adventure ridings mentioned above.

For the coloring to give impression of off-road riding, we adopted an off-road sports coloring tailored to the color of the Dakar Rally machine⁽¹⁾. Honda has participated the Dakar Rally since 2013. The reason why we incorporated a race machine color into this model is that the concept of this vehicle is not the one taken over from a scooter model but, aiming to appeal, that it is evolved from the world created by leisure-purposed motorcycle models.

This approach to inherit the coloring image of a rally vehicle has been also applied to one of the coloring derivations of the CRF1000L Africa Twin⁽¹⁾. This model is showing the continued strong sales in Europe, and it is contemplated that a coloring reflecting the scenes of the rally is considered to be one of the colors that customers in Europe prefer favorably.

In styling design, this model has no proportion like off-road motorcycles. Therefore, we applied design techniques



Fig. 20 Windshield in production model



Fig. 21 Gauge unit in production



Fig. 22 Knob type main switch with specification for mass production

to reminisce the rally machine (Fig. 24) and the Africa Twin (Fig. 25) that is the vehicle also expressing that impression. Specifically, a big redesigning was carried out on the white and black stripes, and a unique coloring design was applied. Red and black constitute the body color featuring their strong contrast, and white stripes were garnished with them to express the feeling of lively motions. In addition, metal panels were used for the side covers of the engine and for the skid plate. Engine side covers are easy to be scratched by being rubbed with rider's boots and by being thumped with scattered stones from the road surface. In addition, the skid plate is attached to protect the front part of the engine. By using metal for the parts related to protection functions required for off-road riding, the impression of an adventure machine was further emphasized.

Moreover, the coloring types were set as two color variations. One of them is the coloring featuring scenes of a rally racing, which is previously mentioned, using red as the main color (Fig. 23, Type 3). The other one is the coloring using tricolor scheme consisting of white, blue and red, which is the inherited coloring having been applied to the CRF1000L Africa Twin (Fig. 23, Type 4). By providing these two types of coloring, the adventure character claimed

by this vehicle was made appealing strongly.

In addition, a pet name suitable for claiming a new concept was devised, and a logotype to represent that was



Fig. 24 The Dakar Rally machine



Fig. 23 Variations of coloring

also designed. In order to express the comfortableness of riding as a commuter motorcycle and the pleasure of riding as an adventure motorcycle, the alphabet “X” was placed at the head of the pet name. This “X” means crossover and has been used traditionally in Honda’s crossover type motorcycles. In order to further claim the adventure spirit, ADV was adopted as an abbreviation of “Adventure.” These two words were combined and the vehicle was named X-ADV (eks-ay-dee-vee).

In addition, a logotype for the decided pet name was designed as well. The letter “X” was interpreted as an intersection of roads and expressed by crossing a pair of parallel lines with another oblique line. To give a simple and powerful impression, the character string of “ADV” was given a design based on a black powerful bold typeface (Fig. 26).



Fig. 25 The CRF1000L Africa Twin



Fig. 26 The X-ADV logotype

8. Conclusion

In view of the changes in motorcycle market conditions in Europe after the economic crisis, we endeavored to create a motorcycle that can provide new pleasure to the customers belonging to the existing market of maxi-scooter. Accordingly, a project for proposing a new concept began. From the results of the survey conducted on existing maxi-scooter users, we were able to sense the customers’ new desire. It was a desire for a motorcycle with an unprecedented value. That desired vehicle was a two-wheeled vehicle capable of providing expectations that it can go anywhere, from city driving to off-road riding.

In addition, the styling design required for this new crossover model was realized by applying the design approach of SUV models in automobiles to motorcycles. That was a design approach to have the strength to cope with tough running against bumpy lands while keeping the sophisticated styling atmosphere. By applying this approach, it was made possible to create a styling design that excites the riders’ heart, which has a cool personality that suits the city and evoke the desire to go out of city for an adventure on vacations. The concept model of this vehicle got the opportunity to be presented to customers at the motorcycle shows in Italy and France. At these shows, the concept that the team formulated gained understanding and sympathetic acceptance from the customers, and a decision was made for mass production of this model.

The production model was released in Europe in March 2017 and this motorcycle has been continuing to sell well receiving favorable reviews from journalists and customers (Fig. 27). Based on the responses and evaluation results of these markets, we were convinced that our concept and the styling design incorporating our own ideas reflecting the customers’ opinions have increased the pleasure of motorcycle users in Europe and revitalized the market.

The concept of this model and styling design were created seriously considering the customers’ viewpoints. We hope that this approach of design creation and its



Fig. 27 The X-ADV running through in city and on rough roads

deployment process would be one of the new indicators for product developments and its styling design work in the future.

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O m i I I D A



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Development of Rechargeable Power Source LiB-AID E500

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ABSTRACT

The rechargeable power source LiB-AID E500 was developed by combining a lithium-ion battery and an inverter unit to create a power source that can support various types of electrical equipment used in everyday life.

The goals for this product were a design and ease of use that can appeal to a wide range of users. The use of inverter technology provides an electrical performance that enables a high-quality power supply as well as parallel and assist operation support for electrical equipment with high-starting power. In addition, a lightweight resin full-cover configuration using a monocoque frame structure achieves a compact and lightweight form while at the same time securing strength. Furthermore, enhancement of the cooling structure efficiency and optimization of the fan layout realized a high level of quietness.

1. Introduction

The market penetration rate among individuals for mobile terminals such as smartphones has exceeded 80%⁽¹⁾, and these devices are becoming important in people's daily lives. The capacities of the batteries used in these devices are increasing to enable use for longer times, but it is also not uncommon for mobile batteries to be carried to compensate for insufficient power. There is a growing need for electricity in various situations such as for everyday or leisure use, both day and night, indoors and outdoors, and demand is appearing for power sources that enable people to freely use electricity.

Meanwhile, LED lighting is spreading, electrical equipment is becoming more energy efficient, and devices that can be used with even a little power are proliferating. This is increasing the opportunities for users to want a little electric power in previously unplugged situations.

This paper introduces the LiB-AID E500 (hereafter, "E500") that was developed to meet these demands, and describes the technology used to realize various user-friendly features, such as high-quality electricity output⁽²⁾ with a compact and lightweight form and parallel operation with an engine generator⁽³⁾.

2. Development Goals

2.1. Development Concept

Conventional generator users in Japan purchase generators as power supplies for lighting and tools at

construction and other sites, or for backup applications in the event of a disaster. Therefore, generator usage has tended to be more for commercial purposes than household use. However, diversifying interests are expanding the situations in which electricity is needed on the go, such as glamping, staying overnight in Kei car type RVs, stargazing, and musical activities. Looking at everyday life, digital still cameras and video cameras are used on a daily basis, and electric tools are even used for gardening, mainly by the middle-aged and elderly. However, even in these cases, engine generators are limited to outdoor use and need fuel, oil, and other maintenance, so usage is limited.

A power supply that can meet these various user demands for electricity should be small, lightweight, quiet, and easy to use. In addition, good usability is also needed to support outdoor operating environments such as for music and other outdoor activities (Fig. 1), and for use in living rooms or other indoor or narrow spaces.

The concept for this development was "a new form of portable power supply," and the development goals were as follows:

- (1) Intuitive operation
- (2) High-electricity quality that can support various types of electrical equipment
- (3) Portability that enables convenient carrying

2.2. Design

The E500 took the image of Honda's highly reliable first generator, the E300 shown in Fig. 2(a), as a product that supplies electricity, and applied "Neo Modern Compact

* Power Products R&D Center

Design” as the design concept. “Neo Modern” refers to modernizing the shape of a long-familiar form to create something that is both new yet familiar. A component color scheme and “Compact” design shape were then applied to realize an approachable exterior design that makes users want to freely carry around the product.

A preliminary design with a simple surface quality and configuration was created based on the E300 shape, and terminal processing was applied to create a balanced shape that combines gentle roundness with edges as shown in Fig. 2(b). Here, “Neo Modern Compact Design” was expressed by the combination of the main color in the front and back panels, the gray of the center part, and a shape with more rounded corners.

The cooling performance, mass productivity, and the usability of the socket panel and handle of this preliminary design were then further refined to realize the finished E500 shown in Fig. 2(c).

Black and white were set as less-assertive and more versatile color variations in addition to the red color symbolic of Honda power products (Fig. 3).

The goal of these effects was to achieve use of the E500 by a wide range of users in various situations.

2.3. System Configuration and Features

The main functions of the E500 are power supply and

charging as shown in Fig. 4. The power supply block is equipped with AC output sockets to support various types of equipment, and also DC output USB ports for charging mobile terminals. The charging block (500 g) was made a separate unit to reduce the main unit weight, and can connect to both a household outlet charger and an automobile accessory socket charger.

Figure 5 shows the E500 system, and Table 1 shows the specifications of the completed unit. Combination of a lithium-ion battery, inverter unit, and USB unit achieved a configuration that can output both AC 100 V and DC 5 V, and realized a highly quiet power source that can be used even indoors and at night. The specific features of the E500 are as follows:

- (1) Intuitive interface
- (2) Parallel operation and assist operation to support various



Fig. 3 Color variations

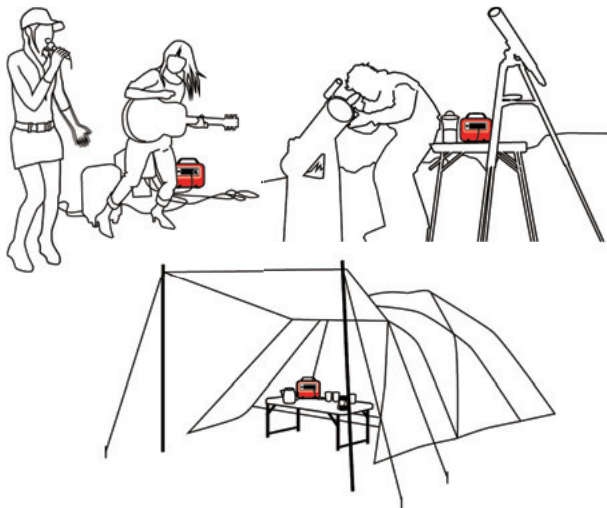


Fig. 1 Image of using the E500

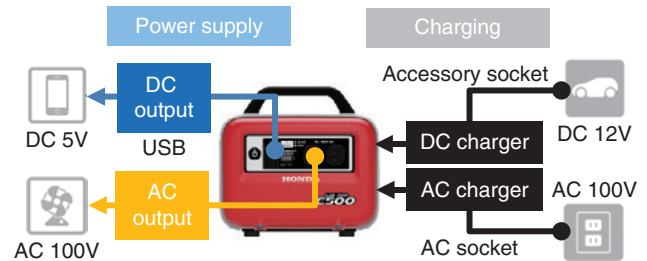


Fig. 4 E500 major functions



(a) E300

(b) Preliminary design

(c) E500

Fig. 2 Design concept

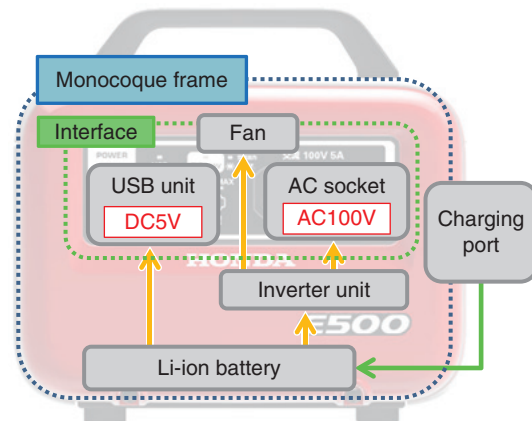


Fig. 5 System configuration

Table 1 Specifications of the E500

Item	Specification
Output AC voltage (V)	100
Frequency (Hz)	50/60
Rated output power (VA)	300
Maximum output power (VA)	500
Output DC voltage (USB) (V)	5
Rated output power (USB) (W)	10 (5 × 2)
Dimensions (L/W/H) (mm)	266 × 182 × 248
Mass (kg)	5.3
Sound power level (dB)	L _{WA} 42
Battery capacity (Wh)	377

types of electrical equipment

- (3) Lightweight (5.3 kg) and strong monocoque frame structure
- (4) Optimized cooling mechanism that realizes a small size and low noise

3. Introduction of Technology

3.1. User Interface

Figure 6 shows the control panel appearances. Figure 6(a) shows the front panel, which arranges the buttons and indications needed when supplying power, and Fig. 6(b) shows the side panel, which arranges the switches and connectors used only for setup before supplying power.

The button layout uses an easily recognizable configuration with the operation order proceeding from left to right based on the user interface principle⁽⁴⁾. In addition, the Power button (round) and AC OUT button (square) have different shapes and the USB ports are located between the buttons to let users intuitively perform smooth and doubt-free power supply operations.

Battery level and electrical output displays, warning lamps that inform of errors, and other indicators are located together in the center of the panel, enabling to check the

E500 operating status at a glance.

Furthermore, the control panel surface uses an embossed membrane, plus tact switches as shown in Fig. 7, to realize both a neat appearance and a good operational feeling.

3.2. Support for Various Electrical Equipment

The E500 can be operated in the two modes of parallel operation and assist operation, which is an expanded form of parallel operation, in order to support various types of electrical equipment. These two modes can be selected by the AC OUT button pressing time.

3.2.1. Parallel operation

The E500 may be unable to supply sufficient power when using equipment with high power consumption. However, the E500 uses parallel operation technology⁽³⁾, so the power of two units can be supplied simply by connecting the units with a previously released special cable, as shown in Fig. 8, to support cases in which the power of one E500 unit is insufficient.

3.2.2. Assist operation

Some types of electrical equipment require starting power in excess of the noted rated power consumption, in the same manner as a motor. Generator users who use

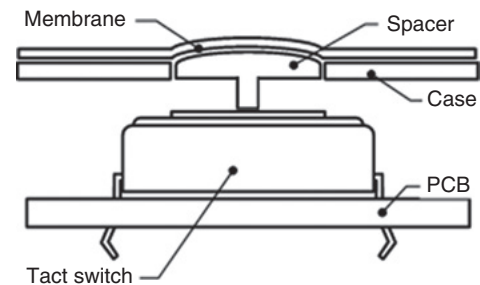


Fig. 7 Structure of buttons on front panel

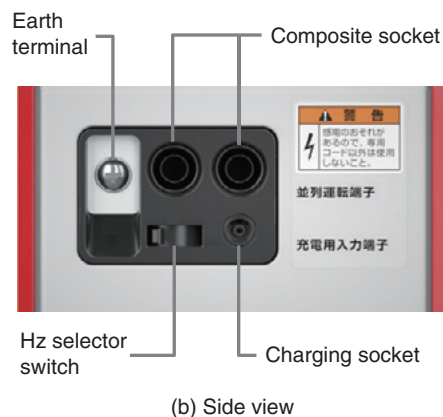
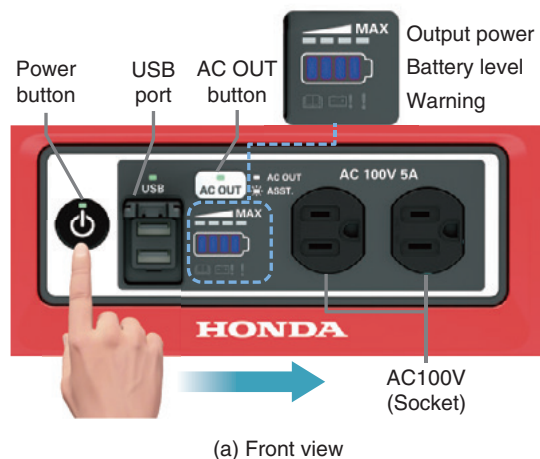


Fig. 6 Control panel design

this type of equipment use the equipment starting power as a criterion for selecting an engine generator, and it may be necessary in some cases to select an engine generator with higher power output than wanted. In response to this need, the E500 can perform assist operation to compensate the power supply of the master engine generator while performing parallel operation with a Honda engine generator (with built-in inverter).

Figures 9(a) and 9(b) show the respective power-sharing loads during parallel operation and assist operation using the E500 and an engine generator. During simple parallel operation, power from the E500 battery is consumed at equipment startup and also during subsequent equipment operation. However, by using assist operation, the E500 only needs to perform assist output for a short time at startup, enabling efficient use of the battery power.

In addition to the previously described parallel operation, assist start-timing detection and power supply adjustment are also needed to realize assist operation. The engine generator output voltage drops during electrical equipment startup as shown in Fig. 10. The E500 performs assist output when it detects that the engine generator output voltage has dropped to a certain threshold value or less.



Fig. 8 E500 parallel operation

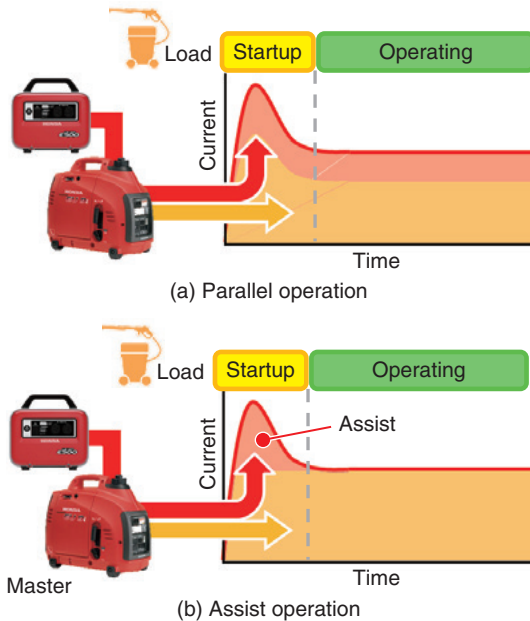


Fig. 9 Parallel operation and assist operation

Unlike normal parallel operation, during assist operation the power supply balance between the E500 and the engine generator is not kept uniform, and instead the E500 output voltage is varied according to the current value flowing to the equipment in order to assist the power shortage of the engine generator.

Figure 11 shows the change in the generated power output when a piece of electrical equipment with a built-in 700 W output motor is connected to a Honda engine generator (EU9i) rated at 900 VA and started up. In this case, the power supplied by the engine generator does not reach the power needed to start the equipment, so the engine generator stops due to an overload. This means that the electrical equipment cannot be used with only that engine generator. Next, Fig. 12 shows the results when the E500 performs assist operation for the same engine generator. The assist function lets the E500 assist (compensate) the EU9i power shortage during equipment startup, enabling to use the equipment.

3.3. Bathtub Type Monocoque Structure

Figure 13 shows the E500 frame structure. In addition to achieving a small size and light weight, the frame also needs to protect the internal electronic parts. Therefore,

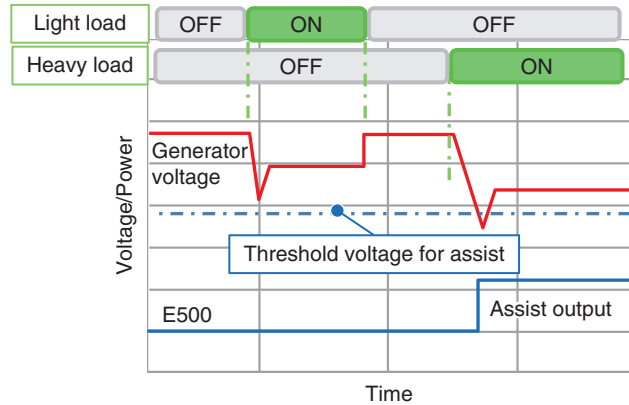


Fig. 10 Assist start timing

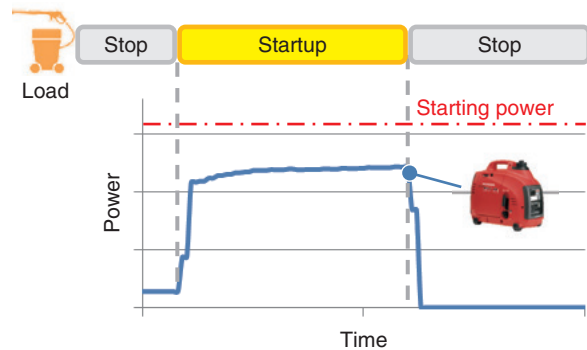


Fig. 11 Generator power shortage for 700 W load

the frame used a two-part monocoque frame structure (lightweight resin full-cover structure) consisting of an upper cover and an under cover, and was given a bathtub shape to increase the strength and protect the internal parts. This free-standing shape reduced the need to fix electronic parts with screws or other fixtures, and also increased the ease of assembly.

Furthermore, structures that support the control panel, inverter, and other parts and cooling air passages were built into the monocoque frame shape. This increased the surface rigidity, making it possible to use lightweight, inexpensive and easily available polypropylene instead of special resin materials.

3.4. Cooling Mechanism

When the E500 transforms the DC voltage of the battery into AC voltage, the internal loss from the battery, inverter, and other parts generates heat, so cooling is needed. The E500 uses the two cooling methods, by frame structure and by fan.

3.4.1. Cooling by the frame structure

Figure 14 shows the cooling structure. A cooling air inlet is provided on the bottom with a cooling air outlet

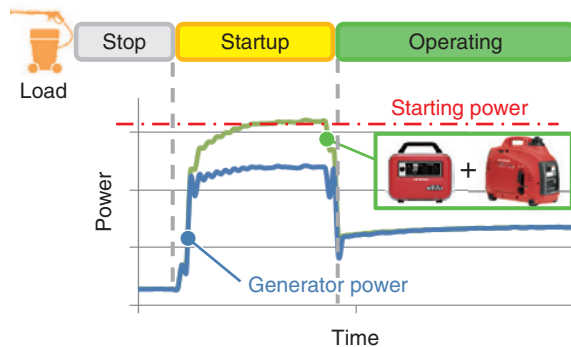


Fig. 12 Result of assist operation

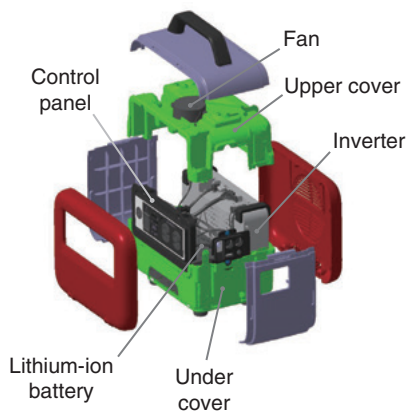


Fig. 13 Monocoque frame structure

on the top to make use of the chimney effect to promote natural ventilation. In addition, the heat generated from the inverter unit is conveyed to the metal case as part of the heat-radiation structure. This enabled an achievement of sufficient cooling without increasing the number of typically used parts such as heat sinks, which helped to reduce the size and weight.

3.4.2. Cooling by a cooling fan

The following three points were reflected to the design specifications to perform efficient cooling.

- Location of the inverter part that reaches the highest temperature at the cooling air inlet
- Formation of local cooling paths near the high-temperature parts of the inverter
- Use of a blower type fan that can secure sufficient air flow even in narrow spaces

Figure 15 shows the numerical analysis results of the flow field inside the chassis during fan operation. This shows that a concentrated flow forms around the local high-temperature part of the inverter and air stagnation around



Fig. 14 Cooling air flow

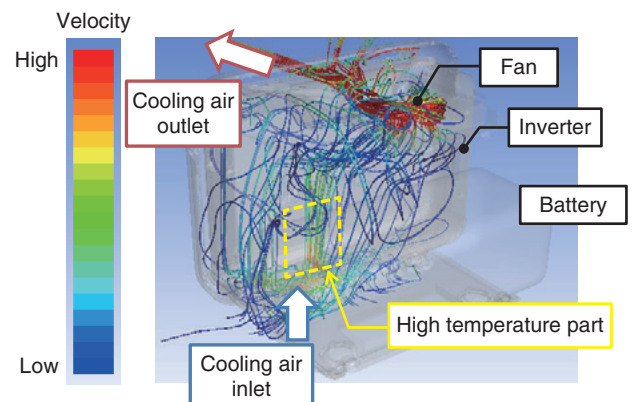


Fig. 15 CFD analysis of internal air flow

the battery is reduced, indicating that the intended cooling air flow is achieved with a single fan. The E500 fan operates only when the internal temperature rises, which helps to minimize battery consumption due to fan operation.

In addition, the fan is located in the center of the chassis, away from the ventilation air outlet in order to shield the fan operation noise. This achieved good quietness performance with a noise value L_{WA} of 42 dB as shown in Table 1. Furthermore, the E500 realizes approximately 50% lower mass and volume compared to competing products with a battery of similar capacity, as shown in Figs. 16 and 17.

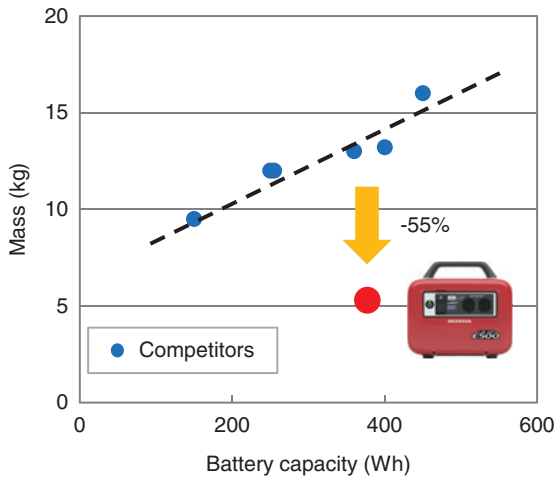


Fig. 16 Comparison of mass with competitors

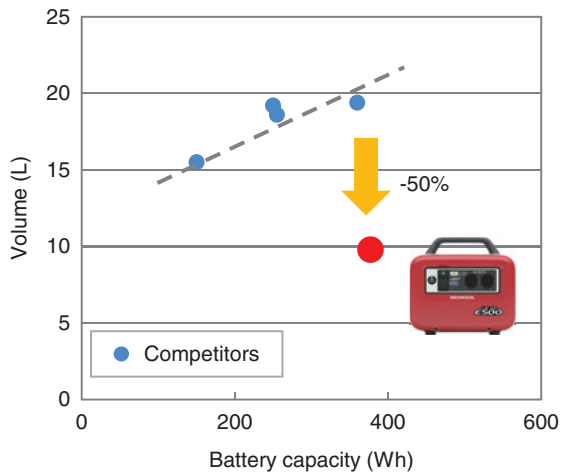


Fig. 17 Comparison of volume with competitors

4. Conclusion

The rechargeable power source LiB-AID E500 was developed by combining a lithium-ion battery and an inverter unit. “Neo Modern Compact Design” was used as

the design concept to realize an approachable design. In addition, design and manufacturing were performed from the viewpoint of usability in consideration of potential use situations, and the following results were achieved.

- (1) Intuitive interface
- (2) Parallel operation and assist operation to support various electrical equipment
- (3) Lightweight and strong monocoque frame structure
- (4) Optimized cooling mechanism that realizes a small size and low noise

The LiB-AID E500 is a product that will become an integral part of people’s lives, and use is expected in various situations to help expand the range of user activities.

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Development of 2.0 L Engine for New Accord Hybrid

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ABSTRACT

A 2.0 L gasoline engine for which the development target was the realization of thermal efficiency of 40% or higher (a first for Honda) has been developed for the new Accord hybrid. As in the case of the previous model, the developed engine employs the Atkinson cycle and the cooled EGR system. In order to further increase theoretical thermal efficiency, knocking has been reduced through the application of mirror finishing to the intake valves and the use of sodium-filled exhaust valves, and the higher compression ratio than the previous model. To reduce heat loss, high-speed combustion has been realized by increasing EGR amount and employing high-tumble-flow ports. Technologies for the reduction of mechanical loss, including low-friction plateau honing and a low-friction balance shaft, have been employed in the other engine framework, helping to enable the realization of a minimum fuel consumption rate of 208.1 g/kWh (thermal efficiency: 40.6%) in the engine unit in isolation.

The verification results of the fuel efficiency performance achieved in an actual vehicle through the use of the newly-developed engine demonstrated a reduction of 1.96 mpg in fuel consumption in the US Combined Mode as an effect of the engine unit in isolation.

1. Introduction

Today, automakers are introducing new powertrains in an effort to increase fuel efficiency in order to reduce automotive CO₂ emissions. At the end of 2012, Honda marketed an Accord plug-in hybrid provided with a two-motor hybrid system⁽¹⁾⁻⁽³⁾. In 2016, Honda added an exhaust heat recovery system to the hybrid system. In order to make it possible to supply hybrid systems to an even greater number of customers, at the beginning of 2018 Honda announced an Accord hybrid provided with a hybrid system designed to promote a more widespread use of the vehicles. The two-motor hybrid (SPORT HYBRID i-MMD) system offers three patterns as driving modes. Pattern 1 is EV Drive Mode. In this mode, the motor is driven using electrical energy stored in the battery. Pattern 2 is Hybrid Drive Mode. In this mode, the motor is driven using electrical energy generated by the engine, via battery assist or charging. Pattern 3 is Engine Drive Mode. In this mode, the vehicle is directly driven using engine power (Fig. 1). The aim in the development of the SPORT HYBRID i-MMD system was to realize a hybrid system offering a

class-topping level of efficiency. A specialized gasoline engine has been developed in the system in order to further increase fuel efficiency.

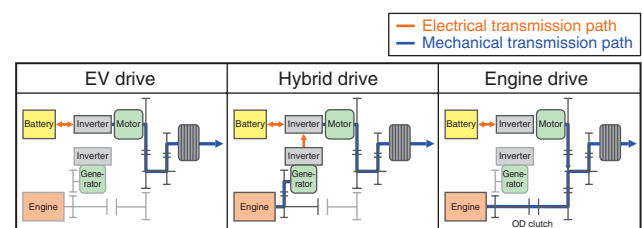


Fig. 1 SPORT HYBRID i-MMD system operations

2. Development Aims

The gasoline engine specialized for hybrid vehicle use was developed in order to satisfy the following targets:

- (1) In relation to reduced fuel consumption, realization of increased fuel efficiency in the Hybrid Drive Mode use range (thermal efficiency: 40% or higher)

* Automobile R&D Center

- (2) Realization of increased fuel efficiency performance in an actual vehicle by means of optimization of the engine operating line.

3. Technologies for Increased Fuel Efficiency Performance

Table 1 compares the specifications of the developed engine and a mass-production 2.0 L full hybrid electric vehicle (FHEV) engine achieving a thermal efficiency of 39.1% (the previous model).

3.1. Technologies for Increased Unit Fuel Efficiency Performance

Based on an analysis of loss in the previous model, the achievement of increased theoretical thermal efficiency, reduced heat loss, and reduced mechanical loss in order to increase indicated thermal efficiency were set as the three focal points for the realization of increased fuel efficiency.

3.1.1. Increased theoretical thermal efficiency

Increasing the compression ratio is effective in increasing theoretical thermal efficiency, but it also results in increased knocking. In order to address this issue, the introduction amount of exhaust gas recirculation (EGR) gas was increased, mirror finishing was applied to the intake valves, and sodium-filled exhaust valves were employed. These measures made it possible to increase the compression ratio from 13.0 to 13.5 with no increase in knocking (Fig. 2).

3.1.2. High-flow-rate EGR system

The introduction amount of EGR gas was increased in order to reduce heat loss. This had an effect in controlling knocking, and was also effective in allowing the realization of an increased compression ratio.

Having set the target of increasing the introduction amount of EGR gas from 17% in the previous model to 23%, the potential for realizing a high flow rate in the EGR system was examined. The value of the flow rate was calculated in relation to a thermal efficiency of 40%.

In order to realize a high flow rate, a new EGR valve was developed. This valve has a larger diameter and balances the amount of gas leakage from the valve seat and the valve responsiveness. A poppet valve shape was employed, and the valve diameter was increased (Table 2). A linear solenoid was employed in the drive section. The coils and the magnetic circuits were redesigned to help ensure the drive power necessitated by the increased valve diameter.

Pressure loss in the EGR passages was reduced in order to boost the effect of the increased valve diameter. The EGR gas introduced downstream from the catalyst passes through the EGR pipe, the EGR cooler, and the EGR gas passage in the water outlet before entering the EGR valve. Following this, the EGR gas once again passes through the

Table 1 Engine specifications

	Developed	Previous
Cylinder configuration	Inline 4	
Bore × Stroke [mm]	81 × 96.7	
Displacement [cm ³]	1993	
Valvetrain (intake)	VTEC and E-VTC	
Valvetrain (exhaust)	Finger rocker arm (with HLA)	
Number of valves	4	
Valve diameter [mm] intake/exhaust	33 (Mirror-surface) /26 (Na-filled)	33/26
Cylinder offset [mm]	6	
Crank journal diameter [mm]	50	
Crankshaft counterweight	Semi-8 (without dent)	4 (with dent)
Compression ratio	13.5	13.0
EGR system	Cooled	
EGR valve flow rate [L/min]	450	230
Water pump	Electric	
Thermostat open valve temperature [°C]	82	78
Fuel injection type	Port injection	
Fuel	Regular	
Maximum power [kW]	107	
Maximum torque [Nm]	175	
Emission regulation	SULEV30	

Table 2 EGR valve specifications

	Developed	Previous
Valve type	Poppet	
Valve seat diameter [mm]	12.5	8.3
Flow at 6.7 kPa [L/min]	450	230
Valve leak [L/min]	< 3	
Response time [msec] from closed state to fully open	≤ 80	

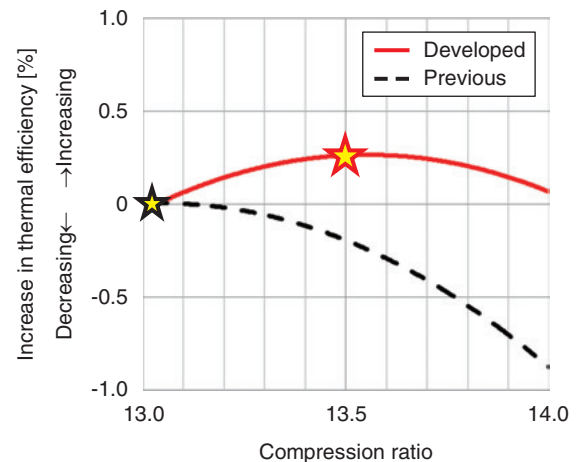


Fig. 2 Increase in thermal efficiency against previous model

gas passage in the water outlet and the cylinder head, and is then reintroduced to the intake manifold.

Figure 3 shows a comparison of the shapes of the EGR passage in the vicinity of the EGR valve, which has a significant effect on pressure loss, for the high-flow EGR system and the previous EGR system.

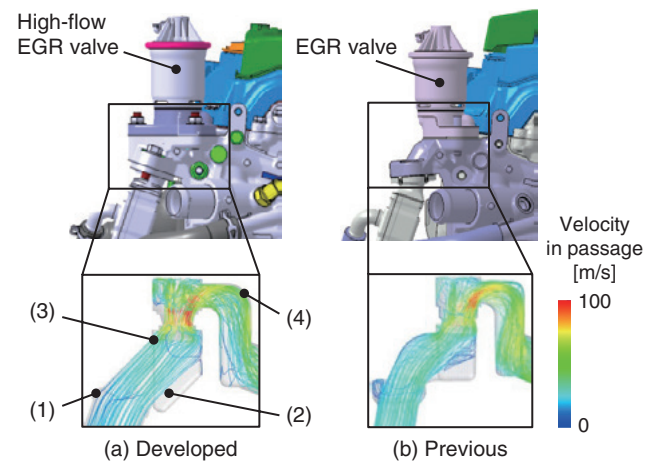
Against the passage shape in the previous system, the following modifications were applied.

- (1) Increase in passage opening to $\phi 21$
- (2) Reduction of unnecessary volume in passage
- (3) Straightening of EGR cooler cone
- (4) Change to R15 in EGR valve passage

These modifications have reduced pressure loss in the passage by 70%.

To respond to increased time loss due to a slowing of combustion with an increase in the introduction amount of EGR gas, a high-tumble-flow port was employed in order to realize rapid combustion even under high-flow EGR conditions.

Figure 4 shows the shape of the port employed in the system. In comparison to the port shape in the previous model, the lower section of the port area directly before the



- (1) Increase in passage opening to $\phi 21$
- (2) Reduction of unnecessary volume in passage
- (3) Straightening of EGR cooler cone
- (4) Change to R15 in EGR valve passage

Fig. 3 High-flow EGR passage

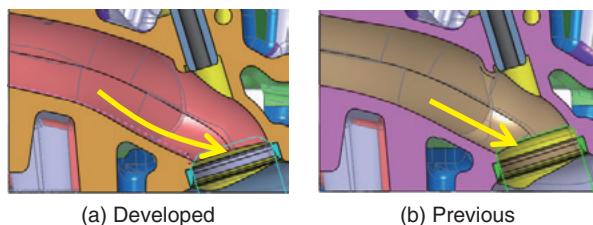


Fig. 4 High-tumble port shape

intake valve swells outwards, increasing the acuteness of the angle of incidence and strengthening the tumble flow. This has increased the tumble ratio at an operating point of engine speed: 2000 rpm and engine load: 120 Nm by 25%, and the turbulent kinetic energy (TKE), which correlates with combustion speed, by 3%. Figure 5 shows the effect in boosting the TKE of the flow.

As a result, the same combustion period as the previous model has been realized (Fig. 6), and it has been possible to reduce heat loss and knocking with no increase in time loss.

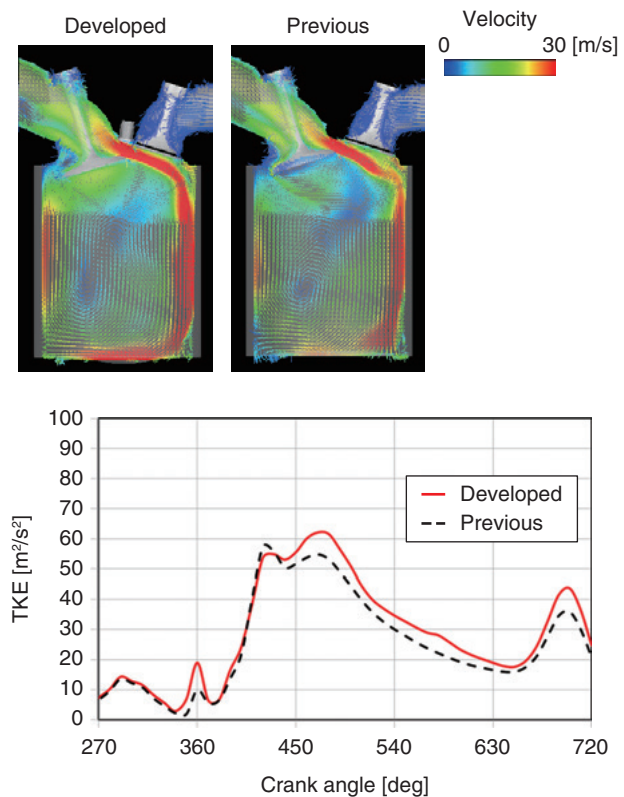


Fig. 5 Results of flow simulation

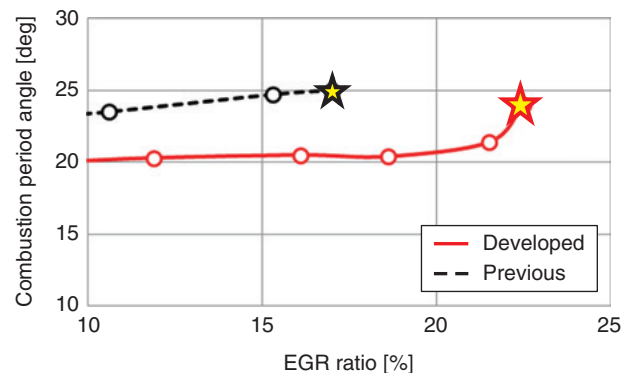


Fig. 6 EGR flow rate and combustion period

3.1.3. Reduction of knocking

The rear surfaces of the intake valve umbrellas were mirror finished and sodium-filled exhaust valves were employed in order to reduce knocking.

In the case of the intake valves, the aim was to reduce surface area and control heat transfer between gases in the surrounding area and the valves by increasing the smoothness of the valve umbrella rear surfaces, which are exposed to the interior of the combustion chamber. The reduction of heat transfer by this means has made it possible to reduce the heat of combustion gases escaping to the cylinder head via the valves, thus reducing heat loss. In addition, because the temperature of the valves themselves is also reduced, the temperature of the intake air is reduced, and this has an effect in reducing knocking [Fig. 7(a)].

In the case of the exhaust valves, valves in which hollow centers are filled with sodium have been employed [Fig. 7(b)]. The aim of this was to promote rapid heat transmission of the areas around the exhaust valves, which are prone to reaching high temperatures, to the stem parts by means of the up-down motion of the melted sodium inside the valves, and to dissipate the heat through the cylinder head water jacket, via the valve guide which makes contact with the valve stem.

The application of these technologies has had the effect of reducing knocking by 0.9 degrees at an operating point of engine speed: 2000 rpm and engine load: 120 Nm. The achieved level of reduction of knocking is shown in Table 3.

Table 3 Amount of mitigation of knocking

Amount of mitigation of knocking		
Valve cooling	Mirror-surface intake valve	+0.3 deg
	Na-filled exhaust valve	+0.6 deg

Table 4 Mechanical loss reduction technology

Part	Item
Cam shaft	Mirror-surface cam journal
Crank shaft	Mirror-surface crank journal
	Increased crank rigidity
Balance shaft	MoS ₂ shot to balance shaft metal
	Change in balance shaft weight and shape
Oil pump	Low-tension oil seal
Piston	MoS ₂ thick coat + Staggered coat
	Change in 2nd ring shape
	Change in land diameter
Chain	Cam chain (application R shape on back face and smoother surface roughness)
	Low-friction chain guide
Block	Low-friction plateau honing

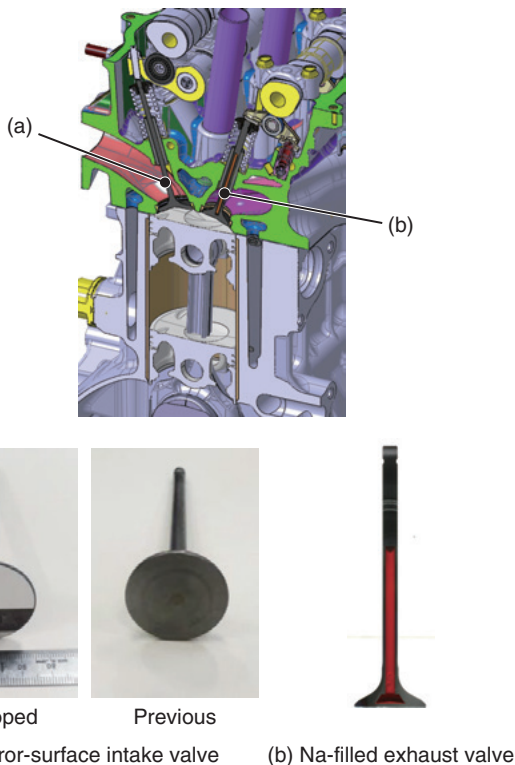


Fig. 7 Valve system

3.1.4. Reduction of mechanical loss

The main focuses for reduction of mechanical loss were the main moving system, including the crankshaft and the pistons, and the valve system, including the camshaft and the drive chain (Table 4).

In the cylinder block, the specifications of the grindstone and the processing conditions employed in plateau honing were modified in order to increase the smoothness of the sleeve surfaces in which the pistons slide at high speed by reducing the maximum height of the roughness of the surfaces, while also increasing the pitch of the grooves, thus reducing mechanical loss (Fig. 8). In addition, because the engine layout positions the balance shaft inside the oil pan, mechanical loss occurs due to the scooping-up of the oil in

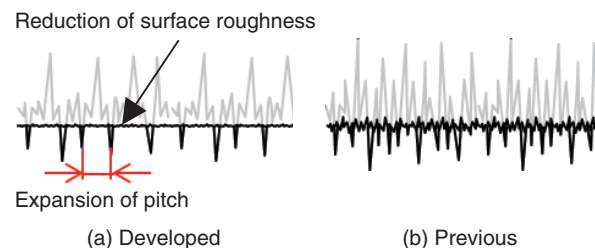


Fig. 8 Low-friction plateau honing

the oil pan when the engine is in operation. As shown in Figure 9, mechanical loss was reduced by creating a flow of oil over the surface of the balance weight by modifying its shape.

By increasing the temperature of the cooling water in order to reduce the viscosity of the lubricating oil, thus reducing mechanical loss and increasing fuel efficiency, the thermostat valve opening temperature has been increased by 4°C, from 78°C to 82°C. This was made possible by the reduction in knocking discussed in Section 3.1.3. This change in the valve opening temperature maintains the water temperature at a higher level from low-load to medium-load operation (Fig. 10), reducing mechanical loss.

As a result, mechanical loss has been reduced by 6.4% against the previous model at an operating point of engine speed: 2000 rpm and engine load: 120 Nm.

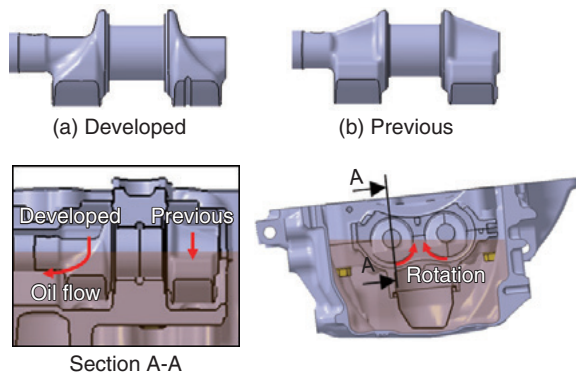


Fig. 9 Change in balance weight shape

3.2. Vibration Responses for Modification of the Engine Operating Line

In the operating domain in which rapid combustion reduced time loss and realized good brake specific fuel consumption (BSFC), the rate of pressure increase was increased, which made the engine vibration also increase. In the previous model, the engine operating line was set so as to balance the reduction of the rumbling sound produced by engine vibration in the complete vehicle with fuel efficiency, and as a result, the engine operating line did not employ the domain in which BSFC was at its lowest, as shown in Fig. 11. In the newly-developed engine, the reduction of vibration by means of modification of the engine framework was studied in order to increase fuel efficiency by making it possible for the engine operating

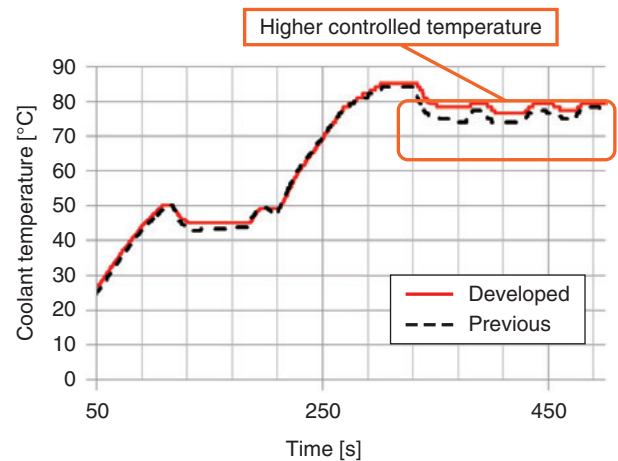


Fig. 10 Change in coolant temperature at cold start

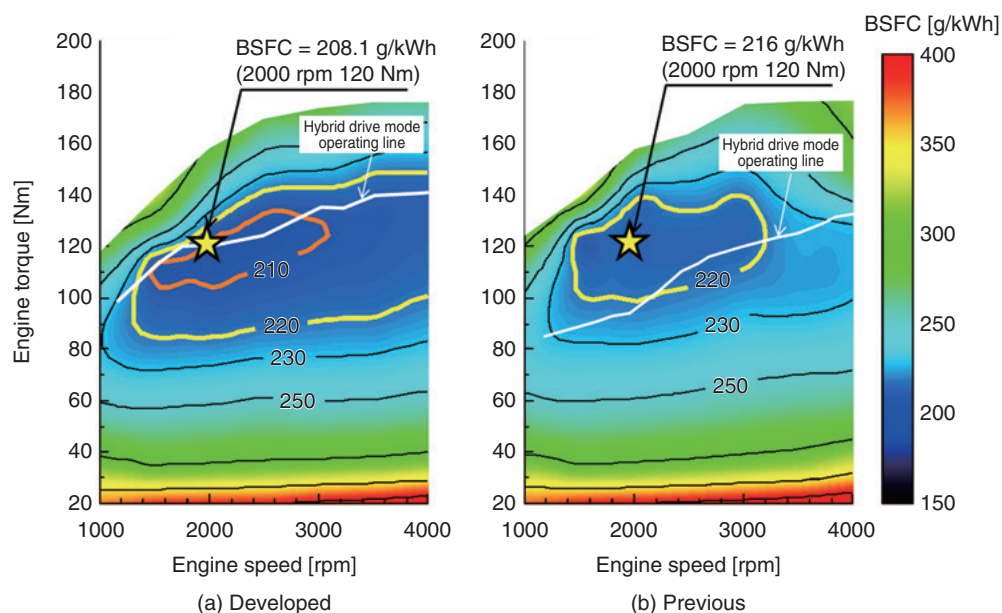


Fig. 11 Fuel consumption performance

line to use the low-BSFC domain and to help prevent increased vibration due to reduced BSFC.

The shape of the crankshaft was modified in order to reduce vibration. Figure 12 shows the shape of the modified crankshaft. In the previous model, the thickness of the shoulder section was reduced in order to lighten the crankshaft⁽²⁾. This approach has been done away with in the developed model, and in addition a web has been employed to increase thickness. Ultimately, the level of vibration of the engine mount attachment points in the 200 to 770 Hz range which affects the feeling of rumble in the complete vehicle has been reduced by 5 dB against the previous model. This is shown in Fig. 13. The studies discussed above made it possible to reduce BSFC while also reducing the level of vibration against the previous model.

3.3. Hybrid Mode Performance

The technological responses discussed above made it possible to realize a BSFC of 208.1 g/kWh (thermal efficiency: 40.6%) at an operating point with an engine speed of 2000 rpm and an engine load of 120 Nm. This represents a reduction of 8 g/kWh in BSFC against the previous model. Figure 11 shows the distribution of BSFC. The white lines in the graphs represent the operating lines in Hybrid Drive Mode, the yellow lines represent the range

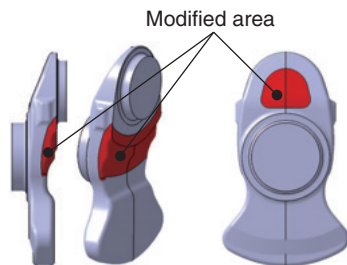


Fig. 12 Shape of modified crankshaft

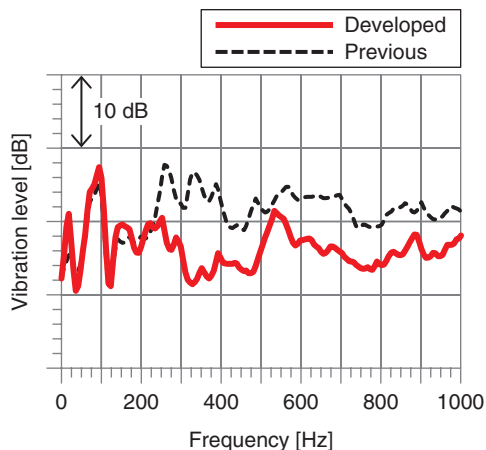
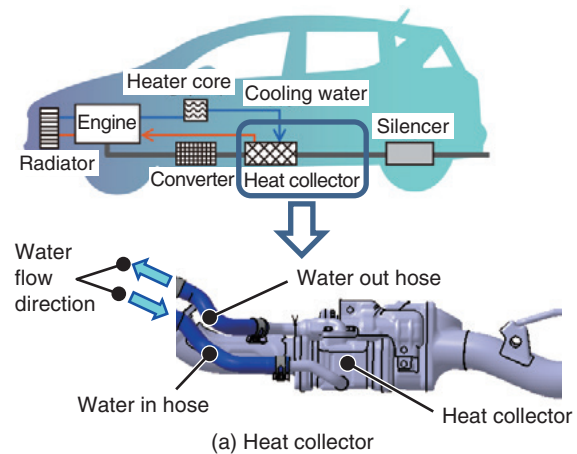


Fig. 13 Engine vibration level

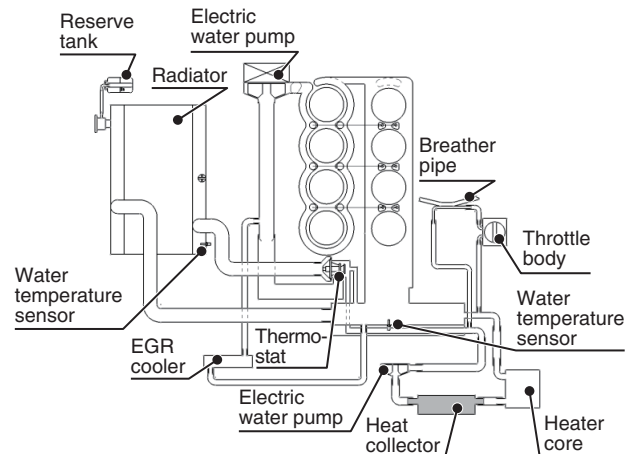
for a BSFC of 220 g/kWh, and the orange line represents the range for a BSFC of 210 g/kWh.

3.4. Actual Vehicle Fuel Efficiency Performance

An exhaust heat recovery system (Fig. 14) has been employed in the cooling circuit to boost the speed of the cooling water temperature increase at cold start, in order to speed up the timing of commencement of EV Drive Mode (Fig. 1). In US Combined Mode, the engine in isolation has the effect of reducing fuel consumption by 1.06 mpg, while the modification of the operating line contributes a reduction of 0.90 mpg, for a combined reduction of 1.96 mpg.



(a) Heat collector



(b) Cooling circuit diagram

Fig. 14 Cooling system

4. Conclusion

The technologies discussed above have been employed in the development of a competitive engine for use in a hybrid system possessing the potential to achieve widespread use. The results of the development can be summarized as follows:

- (1) The application of a high-compression ratio, a high-tumble-flow port, and a high-flow EGR system has made it possible to realize a BSFC of 208.1 g/kWh (thermal efficiency: 40.6%).
- (2) Modification of the engine operating line boosted fuel efficiency performance in the actual vehicle.

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Development of Variable Cooling System Aimed at Fuel Economy Improvement of Air-cooled Engine for Scooters

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Kazuyuki KOSEI*

Satoshi IJIMA*

ABSTRACT

A variable cooling system was developed for a scooter equipped with an air-cooled, four-stroke, and single-cylinder gasoline engine. In this system, slats of the louver, located at the inlet of cooling air, are opened or closed by an oil-temperature-sensitive actuator. These slats shut off the supply of cooling air when the engine is in cold state or is driven with a low load. These operations of the slats help the engine oil temperature increase and the workload of the cooling fan decrease when the vehicle is running with a low load. With those effects, reduction of the mechanical loss is made possible. In addition, shortened warm-up time enables reduction of the injection fuel amount. As a result, fuel economy improvement of 3.3%, when driven in Urban Driving Cycle, was realized.

1. Introduction

Due to the body structure of scooters, driving wind never comes into direct contact with scooter engines. Thus, in forced air-cooled scooter engines, the cylinder head area is cooled by a fan connected directly to the crankshaft: across all temperatures, whether cold or hot, the engine is fed a constant supply of cooling air in proportion to engine speed. Further, engine cooling capacity is set such that the vehicle can be driven without issue even in the hottest and harshest of conditions. For these reasons, the engine is frequently supercooled after cold engine start-up and during low load driving, and driving in this supercooled state decreases fuel economy. This phenomenon is caused by the relationship between engine oil temperature and viscosity: viscosity resistance increases as the driving temperature decreases, in turn increasing the mechanical loss. One solution to this issue is a variable cooling system, in which cooling capacity changes with engine temperature. Such systems are already common in water-cooled engines. Some typical systems use a thermostat to switch the path of circulation for coolant or intermittently use a motor-driven radiator fan. Also, one system specific to four-wheeled vehicles uses openable slats to control the heat released by the radiator⁽¹⁾⁻⁽³⁾. However, to date, no variable cooling systems exist for forced air-cooled engines on two-wheeled vehicles.

In recent years, scooters are rapidly seeing more widespread use in the Asian region which is the major market of smaller two-wheeled vehicles. With the world now looking

to reduce overall CO₂ emissions, the demand is increasing for improved fuel economy in forced air-cooled scooter engines. Given the above background, the authors first studied the losses resulting from constant forced cooling. Then, based on the results, they have proposed a variable cooling system that controls the cooling air volume according to engine oil temperature. The proposed system opens and closes slats installed on the cooling air inlet using a temperature-sensitive actuator that operates when the engine oil temperature reaches a set value. The authors' intention with the system was to prevent engine supercooling for improved fuel economy.

2. Cooling Configuration of the Air-cooled Scooter

Figure 1 shows an external view and the engine mounting position for a motorcycle with an air-cooled engine (hereafter the "air-cooled motorcycle"), and Fig. 2 shows the same for a scooter with an air-cooled engine (hereafter the "air-cooled scooter").

The air-cooled motorcycle is configured such that driving wind will directly hit the cylinder head and cylinder, which are located at the front of the engine and colored red. This structure allows for cooling with driving wind only. Meanwhile, with the air-cooled scooter, the cowl and luggage box cover most of the engine, again colored red. As such, driving wind cannot be expected to cool the cylinder head and cylinder at the front of the engine. To supplement this cooling insufficiency, the scooter air-cooled engine

* Motorcycle R&D Center

is equipped with a fan attached directly to one side of the crankshaft for forced cooling with the generated blown air. This cooling air is continuously blown over the cylinder head and cylinder. The blown air volume depends on the engine speed. Figure 3 shows the mounted location and construction of the cooling fan.



Fig. 1 Air-cooled motorcycle



Fig. 2 Air-cooled scooter

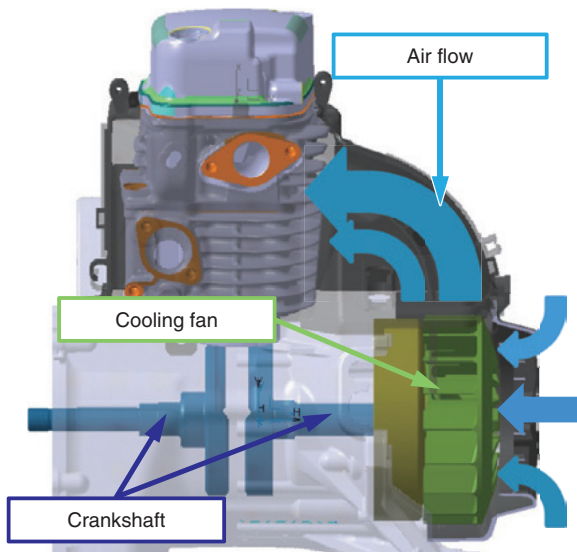


Fig. 3 Location and construction of cooling fan

3. Issues Created by a Forced Cooling Structure

With the cooling air continuously blowing, air-cooled scooters run at lower oil temperatures than air-cooled motorcycles. Thus, air-cooled scooters are assumed to have even greater driving energy loss than air-cooled motorcycles. This section will explore exactly what kind of loss occur due to forced cooling.

3.1. Test Vehicles

Table 1 shows the specifications for the air-cooled scooter used in this study, as well as the air-cooled motorcycle presented in the following clause used for comparison purposes. Both vehicles possess roughly the same displacement, output, and vehicle mass.

3.2. Oil Temperatures while Driving for Different Cooling Methods

The test vehicles described in the previous clause were first put through modal testing before measuring and comparing their oil temperatures. The driving cycle used for testing was the Urban Driving Cycle (UDC) as stipulated in Annex II 2.2.1.1.5 of Chapter 5 in EU Directive 97/24/EC, as amended by Directive 2002/51/EC. UDC is a low load driving cycle which simulates driving in urban and similar other environments. The test drives were performed on a chassis dynamometer with a rolling resistance of ISO 170 kg and a room temperature of $25 \pm 5^\circ\text{C}$.

Upon completion of the UDC test drive, the oil temperature in the oil pan (hereafter T_c) of the air-cooled scooter was approximately 65°C . In comparison, that of the air-cooled motorcycle was approximately 85°C . Therefore, oil temperature was roughly 20°C lower with forced cooling.

This temperature difference is attributed to excessive cooling by the cooling fan and a lack of mechanical heat with no gear shift mechanism or clutch in the oil pan on the air-cooled scooter.

3.3. Issues Created by Forced Cooling

In order to clarify the issues created by forced cooling, first, operating oil temperatures were confirmed for the air-cooled scooter with and without forced cooling to see how much the temperature difference was. For the experiment, two methods were used to stop forced cooling: removing the cooling fan and shutting off the cooling air. For shutting off the cooling air, a closure was placed over the cooling air inlet. The experimental criteria for the air-cooled scooter are listed in Table 2.

Figure 4 shows the change in oil temperature in the oil pan for UDC driving. In the figure, the black line represents the temperature with the cooling fan, the red line that with the cooling fan removed, and the blue line that with cooling air shut off. When driving continuously in UDC both with the cooling fan mounted and removed, temperature was checked when the oil pan oil temperature had sufficiently leveled off.

Table 1 Specifications of experimental vehicles

Item	Forced air-cooled scooter	Air-cooled motorcycle
Engine type	4-stroke single-cylinder	4-stroke single-cylinder
Cooling system	Forced air-cooled	Naturally air-cooled
Bore × Stroke	50.0 mm × 55.1 mm	50.0 mm × 55.6 mm
Displacement	108.2 cm ³	109 cm ³
Compression ratio	9.5	9.3
Fuel supplying system	Fuel injection	Fuel injection
Transmission type	Belt drive (CVT)	4 MT
Maximum power	6.6 kW at 7500 rpm	6.5 kW at 7500 rpm
Maximum torque	9.2 Nm at 5500 rpm	8.8 Nm at 6000 rpm
Curb weight	99 kg	98 kg

Table 2 Experimental criteria

	With forced cooling	Without forced cooling	
	With cooling fan	Without cooling fan (a)	Shut off cooling air (b)
Fan diameter	130 mm		130 mm
Fan type	Centrifugal turbo fan		Centrifugal turbo fan

Both with the cooling fan removed and the cooling air shut off, the oil temperature at completion of UDC driving was approximately 79°C – approximately 15°C higher than that with the cooling fan. Also, when driving continuously in UDC, oil temperature was nearly stable at approximately 70°C with the cooling fan and approximately 103°C with the cooling fan removed. This illustrates that forced cooling is unnecessary when driving in low load conditions.

Next, Fig. 5 shows temperatures of various engine parts with the cooling fan removed when driven at full load (continuous full load at maximum speed). In the figure, the red line represents the temperature of the spark plug seat, the blue line that of the cylinder, and the brown line that of the oil in the oil pan. Note here that for the experiment, full load driving was stopped once spark plug seat temperature reached the maximum plug seat temperature for the air-

cooled motorcycle, shown here in green.

When driven at full load with the cooling fan removed, spark plug seat temperature reached the maximum temperature for the air-cooled motorcycle in approximately 250 seconds. The findings illustrate that forced cooling is essential when driving at full load.

From the test results above, the presumed causes of fuel economy decrease with forced air-cooling are as follows:

- (1) When driving at low loads, oil temperature is low and mechanical loss is high.
- (2) When the engine is cold, the fuel injection quantity is corrected to be higher than that when the engine is warm. Accordingly, more fuel is consumed if the engine is kept cold for extended periods.
- (3) In low load driving, unnecessary cooling fan driving loss is generated.

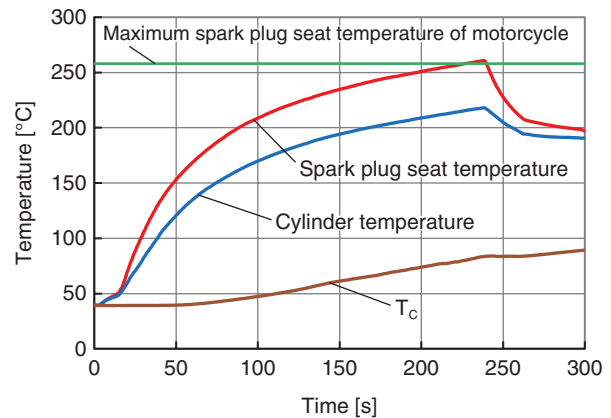


Fig. 5 Temperatures of engine parts when driven at full load without forced cooling

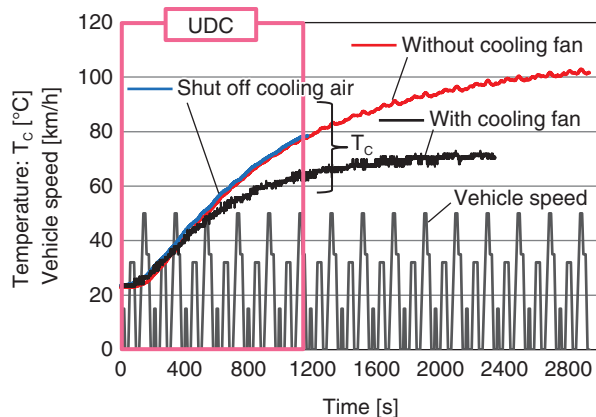
4. Determining Loss due to Forced Cooling

Further testing was performed to determine how much fuel economy decreased due to loss from the presumed causes above. The results for each item are presented below.

4.1. Difference in Engine Mechanical Loss with and without Forced Cooling

The relationship between oil temperature and kinetic viscosity is shown by the red line in Fig. 6. The engine oil used had an SAE viscosity grade of 10W-30 and SJ grade by API standards. In the figure, the green and blue lines represent the relationship between the oil temperature and kinetic viscosity in the oil pan when driven in UDC with the cooling fan removed and with the cooling fan mounted, respectively. With forced cooling stopped, the oil temperature reached 79°C and kinetic viscosity reached 16.8 mm²/s. With forced cooling, the oil temperature reached 65°C and kinetic viscosity reached 26.2 mm²/s.

Next, the difference in engine mechanical loss resulting

Fig. 4 Change in T_c when driving in UDC

from this difference in kinetic viscosity was confirmed. The engine was tested alone using the motoring method. The test results are shown in Fig. 7. At engine speeds of 3500-5500 rpm when driving in UDC, the difference in mechanical loss was 60-110 W.

4.2. Increased Fuel Injection Quantity due to Low Oil Temperature

Next, the impact of difference in oil temperature on fuel injection quantity was confirmed.

The fuel injection systems used in water-cooled engines can generally correct and control the fuel injection quantity based on the parameters of intake air temperature and coolant temperature. In similar fashion, the test vehicles with their air-cooled engines correct and control the fuel injection quantity using the oil temperature parameter. Oil temperature using this control (hereafter T_H) is measured by a sensor mounted to the cylinder head. The changes in T_C and T_H when driving in UDC are shown in Fig. 8. In the figure, the blue line represents the results with forced cooling and the red line those without forced cooling, with bold lines for T_C and thin lines for T_H . As with T_C , there is a difference in the T_H with and without forced cooling: the difference in oil temperature reached upon completion of

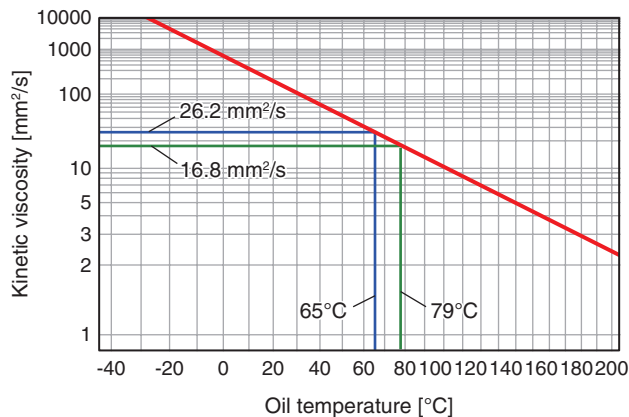


Fig. 6 Kinetic viscosity at various oil temperatures

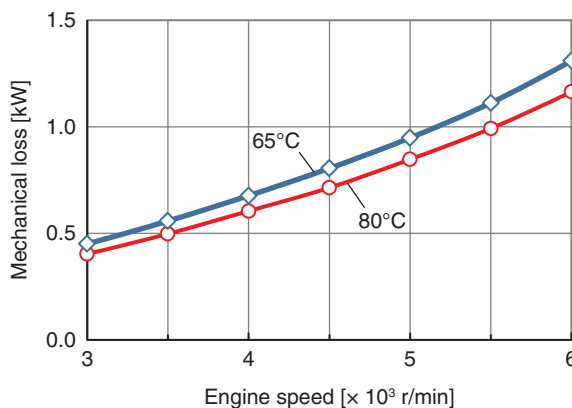


Fig. 7 Engine mechanical loss at various T_C

driving in UDC is approximately 20°C.

Next, the authors confirmed the difference in the correction coefficient of injected fuel (hereafter K_{TW}) as brought about by the temperature difference for T_H . The relationship between T_H and K_{TW} is shown in Fig. 9. The changes in T_H and K_{TW} when driving in UDC are shown in Fig. 10. Here, the bold lines are with no forced cooling,

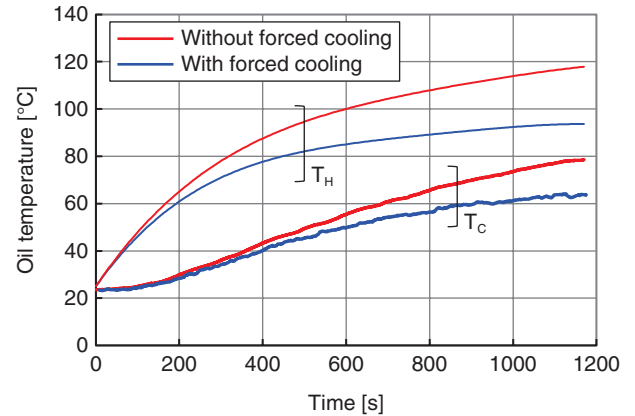


Fig. 8 Change in T_C and T_H when driving in UDC

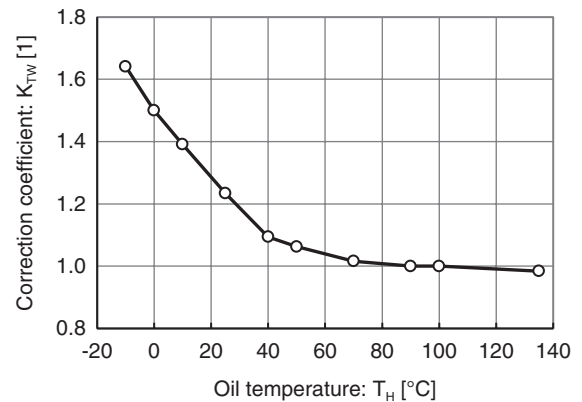


Fig. 9 Relationship between T_H and K_{TW}

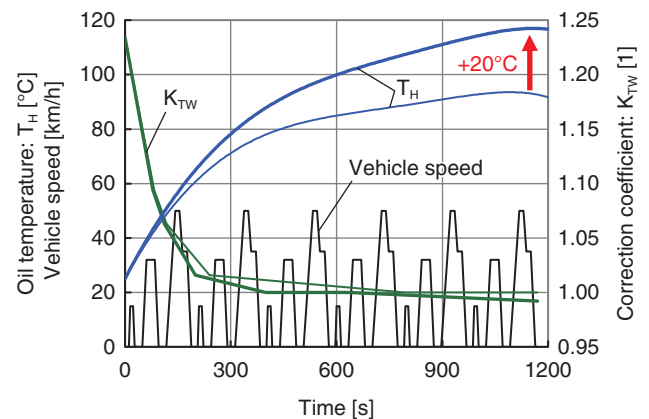


Fig. 10 Changes in T_H and K_{TW} when driving in UDC

and the thin lines are with forced cooling. K_{TW} is a set value with T_H as a parameter. The correction coefficient of the engine with forced cooling takes longer to reach a value of 1. Put another way, it takes longer for the fuel injected with forced cooling to reach the set value than it does without forced cooling. There was a calculated difference of 0.92 mL in correction for injected fuel between the engine with and without forced cooling when driving in UDC. Thus, supercooling lengthens the time the engine is cold and increases injected fuel by 0.92 mL.

4.3. Cooling Fan Driving Loss

In the last step, drive loss of the cooling fan was evaluated. The evaluation was conducted by measuring the mechanical losses of the engine applying motoring method under the three conditions shown in Table 2. The mechanical loss measured without equipping a cooling fan was set as the base value, and the differences between this base value and the results measured in two other conditions, with equipping the cooling fan, were defined as the cooling fan drive losses. The results are shown in Fig. 11.

In the figure, the black line shows the cooling fan driving loss with forced air-cooling, and the red line shows that with cooling air shut off. At an engine speed of 9500 rpm, the cooling fan generated 450 W of driving loss.

Meanwhile, with cooling air shut off, the cooling fan generated 200 W of driving loss at an engine speed of 9500 rpm. This difference is explained by air being sucked through the gap between the crankcase and fan cover, and by air being sucked out of the cooling air outlet when there is negative pressure within the fan cover. Still, cooling fan driving loss is reduced to less than half that with forced cooling.

4.4. Predicted Improvement to Fuel Economy with Mechanical Loss Reduction

Next, the authors will predict how much fuel economy is improved by reducing the loss as calculated through the

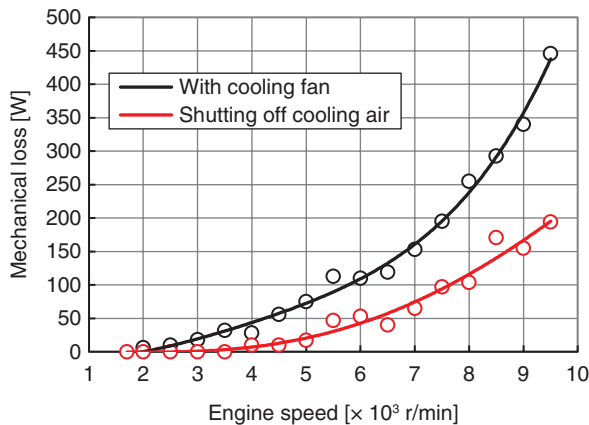


Fig. 11 Cooling fan driving loss at various engine speeds

Table 3 Calculations of fuel economy in UDC

Conditions	Fuel consumption (mL)	Fuel economy (km/L)	Improvement (km/L)
With cooling fan	103.20	57.80	-
Without cooling fan	99.28	60.10	2.30
Shutting off cooling air	99.75	59.80	2.00

preceding section. These predictions were made by finding the cumulative fuel consumption for UDC driving using the engine speed, output, and fuel consumption data from the engine test. The reduction in engine mechanical loss from the increased oil temperature reduced fuel consumption by 1.07 mL. As already mentioned, fuel injection is enriched by 0.92 mL due to the correction coefficient. With the cooling fan removed, fuel consumption reduced by 1.93 mL. With cooling air shut off, consumption reduced by 1.46 mL.

Fuel economy improvement for UDC driving was estimated based on these results. The estimates are summarized in Table 3.

First, for the reference, the engine with cooling fan consumed 103.20 mL in fuel for a fuel economy of 57.8 km/L.

Next, with the cooling fan removed, fuel consumption was 99.28 mL and fuel economy improved 4.0% to 60.1 km/L. Finally, with the cooling air shut off, fuel consumption was 99.75 mL and fuel economy improved 3.5% to 59.8 km/L. Figure 12 shows the breakdown of the fuel economy improvements both with the cooling fan removed and with the cooling air shut off.

Thus, the results from the basic experiments for this study illustrate that forced cooling, while not essential when driving at low loads, is needed when driving at full load. Further, the energy loss from forced cooling for UDC driving was successfully estimated.

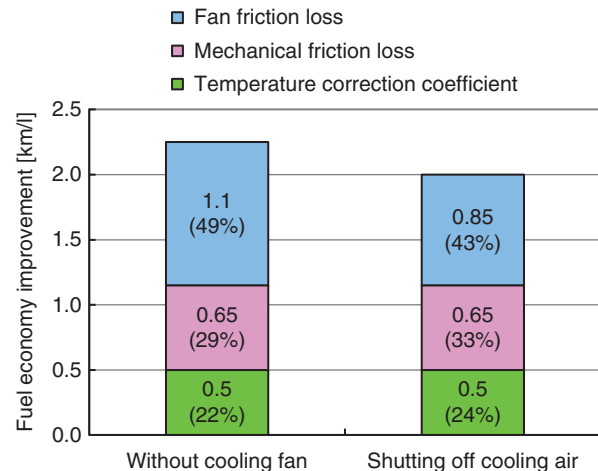


Fig. 12 Detailed fuel economy improvements

5. Investigation of Variable Cooling Systems

Based on the results presented in the previous section, the authors investigated the possibilities of a variable system capable of forced cooling only when needed. Such a system is expected to improve fuel economy when forced cooling is unnecessary.

5.1. Selection of a Variable Method

Two methods were investigated: the first involves using an interrupting mechanism to separate the cooling fan from the crankshaft, and the other uses movable slats to shut off cooling air. The conceivable options for interrupting the cooling fan driving force are application of a motor, electromagnetic clutch, or fluid clutch. Each of these options is used to interrupt the driving force of the radiator cooling fan in water-cooled engines. Applying any of these mechanisms to a scooter engine, however, would require structural changes to the engine that would increase body width and restrict the lean angle when driving. Meanwhile, the air inlet can basically be used to shut off cooling air with structural modifications to the engine side cover components. While this will increase body width, it will not restrict the lean angle. Therefore, in consideration of mountability on the completed vehicle, shutting off cooling air was the method selected in this study.

For shutting off cooling air, there are three conceivable options for the power source to make the slats movable: a thermal actuator, a motor, or a solenoid. Thermal actuators are heat sensitive and require no power. Further, actuators are relatively compact and offer layout advantages for the completed vehicle. This power source is also the most inexpensive option. For motors and solenoids, while relatively lower cost on/off-type units are also available, the requirement of a control CPU still makes them more expensive than thermal actuators. Thus, given the low price demands, motors and solenoids are not suited to use in compact scooters. From the above, a movable louver mechanism using a thermal actuator was selected as the variable cooling system.

5.2. Overview of the Variable Cooling System

The construction of the thermal actuator is shown in Fig. 13.

When in use, the temperature probing point of the thermal actuator is immersed in the engine oil. The thermal actuator is constructed such that wax (shown in purple in the figure) sealed in the temperature probing point expands as the oil in the oil pan rises in temperature to extrude the shaft (blue).

The construction of the variable cooling system is shown in Fig. 14.

The thermal actuator (yellow) is installed on the side of the crankcase. The extruded shaft then operates slats positioned on the cooling air inlet via a linkage mechanism

(within the pink border). Lost motion springs are installed to synchronize the operating angle of the slats. The linkage mechanism is made of PP-GF20.

In this system, the most critical point to ensuring the fuel economy improvements is to maintain the seal when fully closed with no gap between the slats. However, cumulative dimensional errors in the forming of the plastic slats and their driving components could prevent the system from staying airtight. Therefore, the cooling fan driving loss was investigated at various slat clearances (Fig. 15).

No difference in driving loss was observed with no gap and with 0.5 mm gaps between slats. With 1.0 mm gaps, however, a driving loss of approximately 23 W occurred at an engine speed of 9500 rpm. The impact to fuel economy was also estimated using the previously presented method. Fuel economy was unaffected with 0.5 mm gaps but was lowered by 0.02 km/L with 1.0 mm gaps. These results confirmed that the clearance between slats in their fully closed position must be kept to 0.5 mm or lower.

To resolve this issue, the system was structured with lost motion springs fitted to each of the slats so that each slat

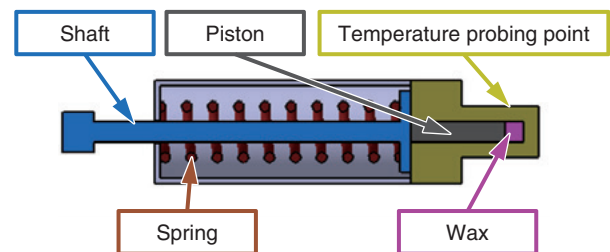


Fig. 13 Construction of thermal actuator

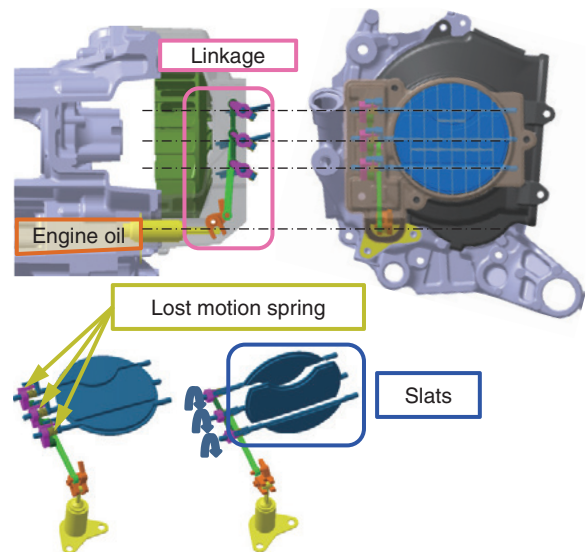


Fig. 14 Construction of variable cooling system

can be closed independently. With this, the three slats can be synchronized without an adjuster mechanism.

Figure 16 shows the relationship between the oil temperature, slat operating angles and generated air flow volume. In the figure, the red line represents the slat operating angles, the blue line the generated air flow volume, and the green line the target air flow volume. The thermal actuator actuates at 97°C . The actuation temperature was set with tolerance for the thermal actuator response delay at the speed with which oil temperature increases when driving at full load. At an oil pan oil temperature of 110°C , the slat angles were set to 73° to ensure the target air flow volume.

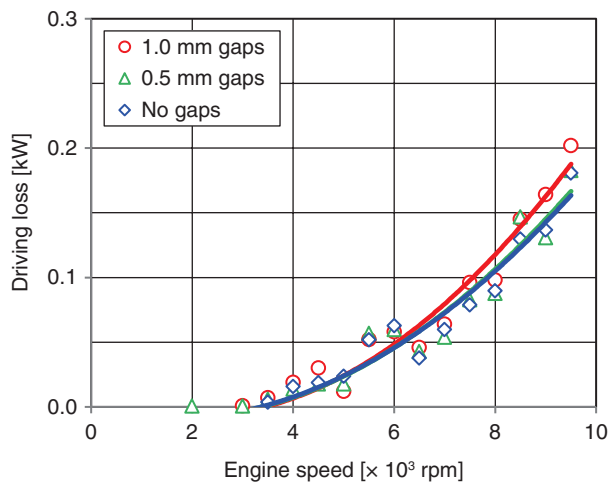


Fig. 15 Cooling fan driving loss at various slat clearances

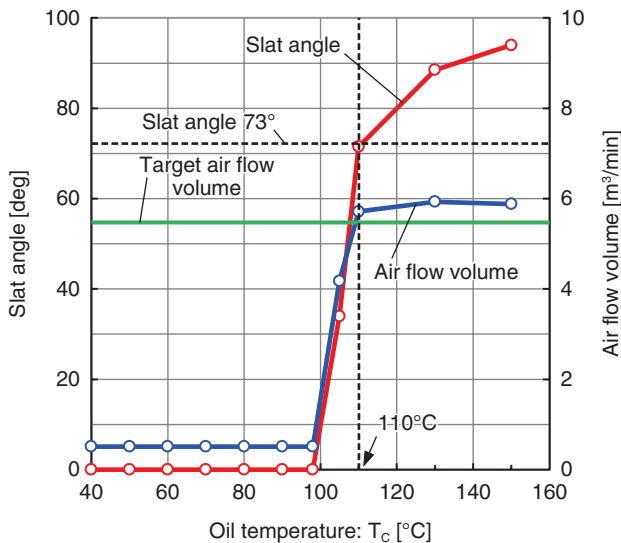


Fig. 16 Relationship among T_c , slat angles, and generated air flow volume at 7500 rpm

6. Verification of Fuel Economy Improvements for the Variable Cooling System

A vehicle equipped with the variable cooling system was driven in UDC to measure oil temperatures in the oil pan and fuel economy. The changes in oil temperature in the oil pan are as shown in Fig. 17. In the figure, the black line represents the base scooter, and the red line represents the scooter with the variable cooling system. The oil temperature of the scooter with the variable cooling system reached the same 79°C at completion of UDC driving as shown in Fig. 4. This confirms that the slat mechanism functions to shut off cooling air as intended.

The objective of this study – fuel economy improvement – was 2.1 km/L, or 3.3%. This result roughly matches with the previously presented estimates.

In addition, the fuel economy improvements of the variable cooling system when driving in WMTC (class 1) were also confirmed. The results were the same as in UDC: fuel economy improved by 2.1 km/L, or 3.4%. The changes in oil temperature when driving in WMTC are as shown in Fig. 18.

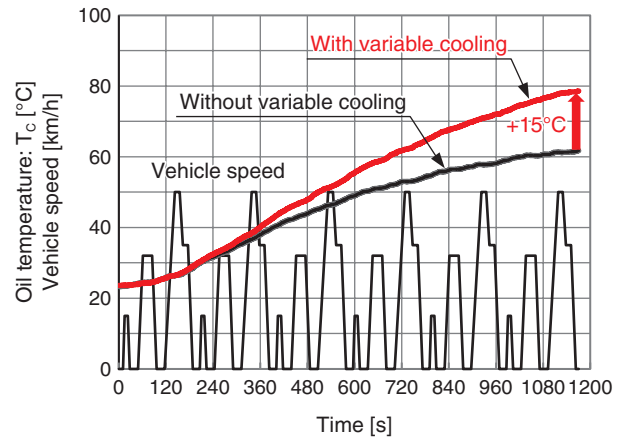


Fig. 17 Change in T_c with variable cooling system when driving in UDC

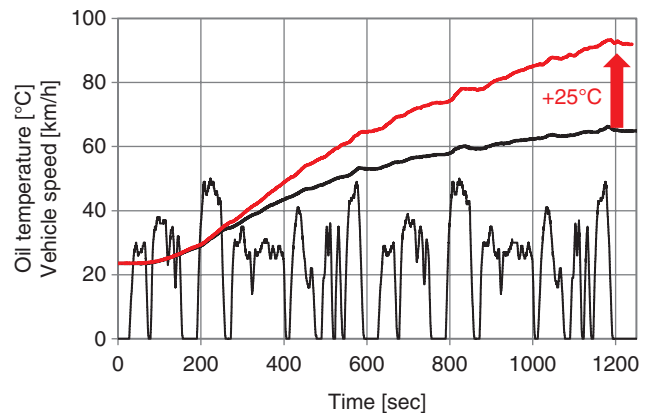


Fig. 18 Change in T_c with variable cooling system when driving in WMTC (class 1)

Table 4 Outline of in-house urban driving cycle

Distance [km/cycle]	1.0
Vehicle speed [km/h]	0-40
Engine speed [r/min]	1700-5500
Throttle opening [%]	0-50

In both UDC and WMTC, the variable cooling system louvers remained closed as engine oil temperatures did not reach the actuation temperature of the thermal actuator. With this, the vehicle was driven assuming urban conditions until the actuator was actuated, measuring fuel economy for each cycle. The driving cycle used for this test was an in-house driving cycle estimating urban driving in ASEAN countries and India (hereafter IUDC). An overview of IUDC is shown in Table 4. The tests room temperature was kept at $25\pm 5^\circ\text{C}$ during measurement.

The vehicle was driven with a cold engine for 30 cycles (30 km) of IUDC, measuring the changes in oil temperature and fuel economy over time for each cycle. The changes in oil temperature are as shown in Fig. 19, and the changes in fuel economy are as shown in Fig. 20.

After nine cycles, the louvers started to open and oil

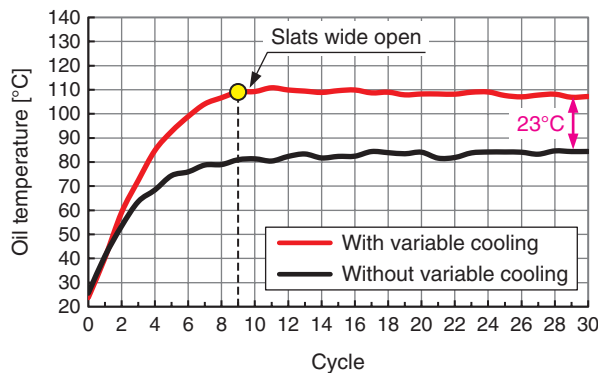


Fig. 19 Changes in oil temperature in oil pan in IUDC

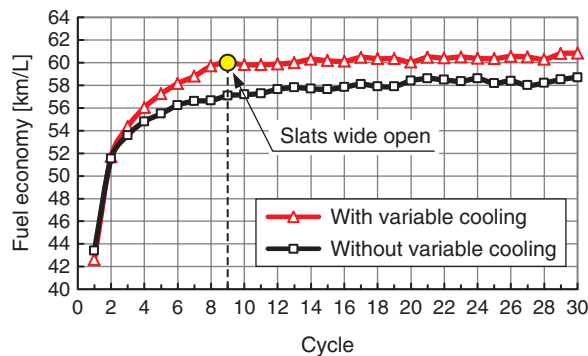


Fig. 20 Changes in fuel economy in IUDC

temperature started to drop. After driving 30 cycles with and without the variable cooling system, the oil temperature difference was 23°C . Thus, the fuel economy effects were maintained on the vehicle with the variable cooling system. Average fuel economy for the 30 cycles with and without the variable cooling system was 58.6 km/L and 56.7 km/L, respectively, giving the edge to the vehicle with the variable cooling system. Fuel economy improved by 1.9 km/L, or 3.4%. These results show that the variable cooling system has a great impact on fuel economy even in low load, low speed urban driving.

7. Conclusion

In this study, the authors quantitatively determined the loss generated by the cooling fan of forced air-cooled scooter engines. Based on the results, they proposed a variable cooling system that controls the cooling air volume based on engine oil temperature with the objective of improving fuel economy. Upon verifications on an actual vehicle, the proposed system achieved the intended results, functioning to shut off cooling air and improving fuel economy by 2.1 km/L (3.3%) in UDC and 2.1 km/L (3.4%) in WMTC (class 1).

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Vibration Reduction Technology with Mount Rubber for Outboard Motors BF4/5/6

Yasukata KOHASHI*

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ABSTRACT

When the BF5 outboard motor underwent a model change recently, a model was added with 20% more output, with faster engine speed and a higher compression ratio, even as it kept the same balancer-less engine and the same basic frame structure. The development discussed in this paper enhanced the customer appeal of the outboard motor by reducing handle vibration and yawing while idling. The mount rubber is a critical component for reducing vibration, as it transmits the thrust of the outboard motor and absorbs vibration. The specs of the mount rubber can also be changed. As such, the mount rubber became the focus of this study. Changing the characteristics of the mount rubber resulted in maintaining about the same level of handle vibration at the maximum speed, with only half as much yawing while idling, even though the new outboard motor had greater output.

1. Introduction

The five-horsepower BF5 outboard motor recently got its first model change in 30 years. Upon making this model change, Honda expanded the lineup into a series. Instead of a single model with five horsepower, there are now three models, offering four, five, and six horsepower. As a result, the BF6, which offers the most horsepower of the three models, offers 20% more output than the previous model, even as it keeps the same single-cylinder 127 cm³ engine and the same basic frame structure. Basic specifications of the engine are given in Table 1.

Major uses of outboard motors of this class include power for small fishing boats and tenders (small boats that move people and cargo between larger boats and shore), and kicker engines for large boats. Outboard motors are attached to the stern of the boat. The user controls the boat with a hand on the tiller handle, which is used to steer and adjust engine speed. Therefore, lowering handle vibration is desirable to make the outboard motor more appealing to customers. The previous model, BF5, was the only model in its output class, at Honda or any other manufacturer, to use mount rubber, and as a result offered the lowest handle vibration in its class, as noted in Fig. 1. The mount rubber, however, caused more visible swinging (below, yawing) of

Table 1 Engine specifications

	BF5 (previous)	BF6 (new)	BF4/5 (new)
Engine type	Single cylinder, 4-stroke		
Displacement (cm ³)	127		
Bore × Stroke (mm)	60 × 45		
Compression ratio	8.7:1	9.8:1	
Mass of reciprocating parts (g)	209.5	215.8	
Inertia force – 1st order (N)	646	958	805
Full throttle speed (r/min)	5000	6000	5500

the outboard motor while idling.

The recent model change included a newly designed mount rubber, the emblematic feature of the previous model. The new shape of the mount rubber changed its mounting characteristics and reduced handle vibration and yawing.

This paper introduces how the vibration was reduced and how the mount rubber can simultaneously provide its other function: supporting the outboard motor as it sustains thrust.

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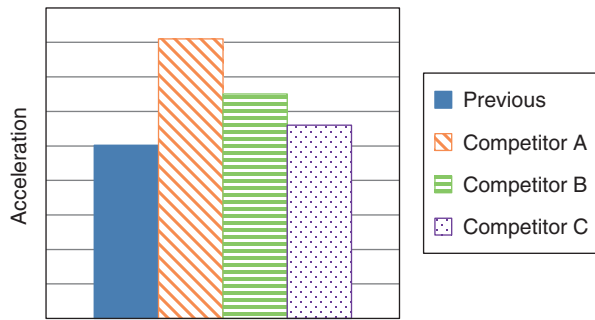


Fig. 1 Tiller handle grip vibration

2. Development Goals and Targets

The overall frame structure is shown in Fig. 2. The main frame connects the single-cylinder balancer-less longitudinal engine with the gear case, which moves the propeller. The mount rubber is positioned between the main frame and the outboard motor support parts (shown in blue in Fig. 2), which connect the main frame to the boat transom, in such a manner that no pressure is applied, and from there the mount rubber supports the main frame. The tiller handle is attached to the outboard motor support parts.

This research enhanced the characteristics of the five-part mount rubber, resulting in reduced handle vibration, reduced yawing, and more durable mount rubber.

When establishing the six-horsepower model as the top-of-the-line in terms of horsepower, Honda modified the compression ratio and changed the upper limit of engine speed (Table 1). Honda made other changes to counter the increase in cylinder pressure from the changed compression ratio, such as increasing the thickness of the main motor system components. As a result, the mass of the reciprocating parts of the main motor system increased. In addition, the upper limit of engine speed was increased by 1000 r/min over the previous model. This results in an increase of about 50% in exciting force by inertia. Vibration increases correspondingly, making it necessary to lower handle vibration.

The next issue to address was the fact that using mount rubber increases yawing while idling, as noted previously and as shown in Fig. 2. This results from fluctuation in the crank shaft driving torque. When the customer appeal of the motor is considered, it is desirable to have less yawing. Tests with actual equipment showed that cutting the amplitude of yawing in half compared to the previous model enhanced customer appeal, so one development target was to lower yawing.

Furthermore, greater output increased the amount of thrust generated by the propeller, raising maximum thrust 25%, from 560 N to 700 N. This thrust reaches the boat transom through the aforementioned mount rubber, becoming propulsive power for the boat. In other words,

there is more load on the mount rubber, which means that there is more displacement. Therefore, it is necessary to check for any decrease in mount rubber durability and verify the contact with structural members of the frame supported by the mount rubber.

In response to the above-mentioned exciting force increase, yawing while idling, and durability of mount rubber, the following were chosen as development targets for the new six-horsepower model.

- Keep handle vibration at 6000 r/min at the same level as 5000 r/min in the previous model.
- Reduce amplitude of yawing while idling by half compared to the previous model.
- In terms of mount durability, there should be no loss of function owing to damage or deformation even at 25% greater input load than that experienced by the previous model.

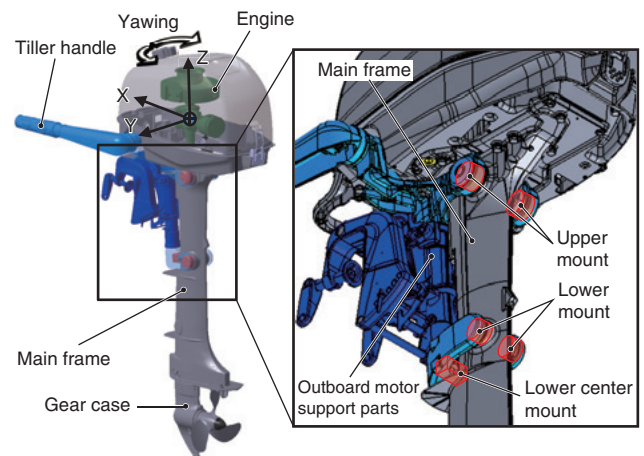


Fig. 2 Frame structure and mount rubber

3. Study of Mount Rubber

Since this development follows the basic structure of the previous model, the size and installation position of the mount rubber would remain the same. The study, therefore, would focus mainly on changing the shape of the mount rubber.

Figure 3 outlines the effects of changing the mount rubber spring rate. Low-rigidity rubber is preferable in respect to vibration, but high-rigidity rubber is preferable in respect to maximum displacement and durability. The new model would need to offer both these aspects. In the past, Honda's BF9.9 outboard motor achieved a more non-linear spring rate and lower vibration by adapting the shape of the mount rubber⁽¹⁾. This development sought likewise to achieve its vibration and durability targets with mount rubber having a non-linear spring rate. Figure 4 illustrates non-linear spring characteristics such as that rubber has low

rigidity under low load and high rigidity under high load. This paper describes the results of using CAE to forecast the effect of using such non-linear spring characteristics, and discusses the mount rubber shape that was finally chosen.

3.1. Requirements of Mount Rubber

To begin, the authors analyzed factors of handle vibration at high engine speeds. Figure 5 shows the results of vibration measurements at the tiller handle and close to the upper mount of the main frame. When the engine speed rose from 5000 r/min to 6000 r/min, the lateral acceleration of the main frame rose rapidly, leading longitudinal vibration of the tiller handle to increase. That is, lateral vibration of the main frame causes handle vibration to increase at high engine speeds. For that reason, lowering handle vibration requires damping lateral vibration.

Thus, the authors used CAE analysis to study the relationship between mount rubber spring rate and handle vibration⁽²⁾. Figure 6 is a conceptual diagram of the CAE analysis model. The outboard motor frame and tiller handle were modeled with 1D elements, with the upper and lower mount rubber expressed as spring elements. The various kinds of exciting force occurring at the engine's crank shaft were applied and the response of the tiller handle was evaluated.

To lower the lateral vibration with this model, the lateral spring rate was set lower than that of the mount rubber of

the previous model for the purposes of this study. The CAE analysis results are shown in Fig. 7. The results show that if the lateral spring rate is lowered 50% compared to the previous model, the new model operating at 6000 r/min will have even less handle vibration than the previous model had at 5000 r/min. This would meet the development target.

The authors next studied yawing while idling. The target was to cut such yawing in half compared to the previous model. Using the aforementioned CAE model, we confirmed the effect of changing the mount rubber's spring rate. The results are shown in Fig. 8. The previous model showed greater yawing at idling speed because of the mount rubber's resonance. First, based on the results of the study of handle vibration, the authors lowered the longitudinal and lateral spring rate by 50% compared to the previous

	Increase spring rate (increase resonance)	Decrease spring rate (decrease resonance)
Transfer function	Response Common use revolution Frequency	Response Common use revolution Frequency
Yawing	Good	Good
Tiller handle vibration	Poor	Good
Maximum displacement	Good	Poor
Durability	Good	Poor

Fig. 3 Effect of rubber from spring rate

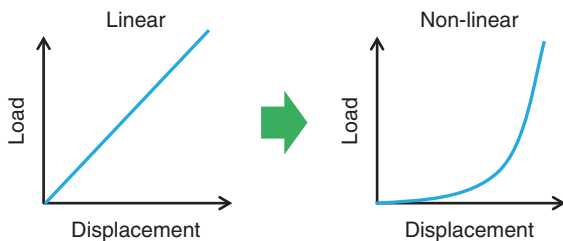


Fig. 4 Spring rate of mount rubber

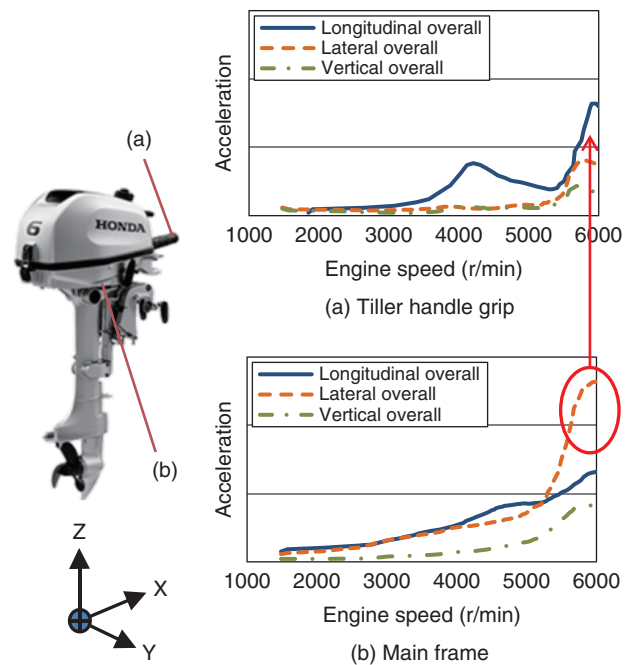


Fig. 5 Tiller handle and main frame vibrations

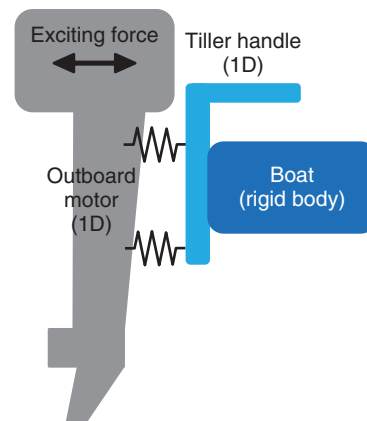


Fig. 6 CAE model

model and found that the results for yawing did not meet the target at engine speeds under 1500 r/min. When we further lowered the spring rate, to 33% that of the previous model, yawing declined by half across the entire idling speed zone, which meets the target.

Therefore, lowering the spring rate to just 33% or less that of the previous model became the requirement to achieving the handle vibration and yawing targets.

Next, this paper discusses permissible maximum displacement. Thrust from the propeller causes the mount rubber to deform. It is necessary to limit the amount of deformation in the mount rubber. This way, there will be no contact when there is narrow clearance with the main frame and outboard motor support parts, as illustrated in Fig. 9. The permissible maximum displacement for the mount rubber was determined based on the amount of clearance needed to help avoid contact between parts. Results of the

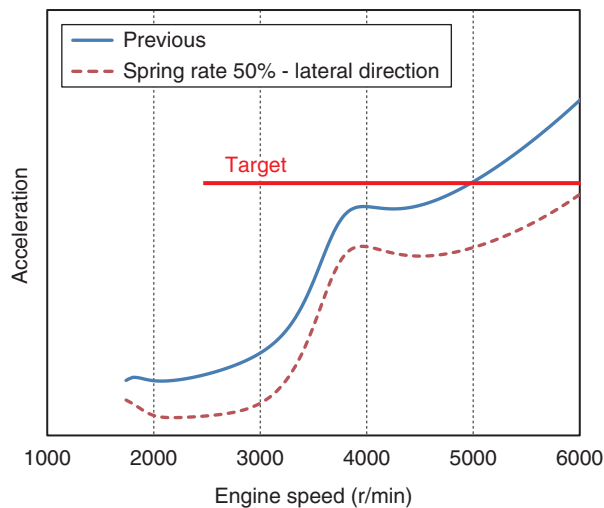


Fig. 7 Tiller handle vibration, by CAE

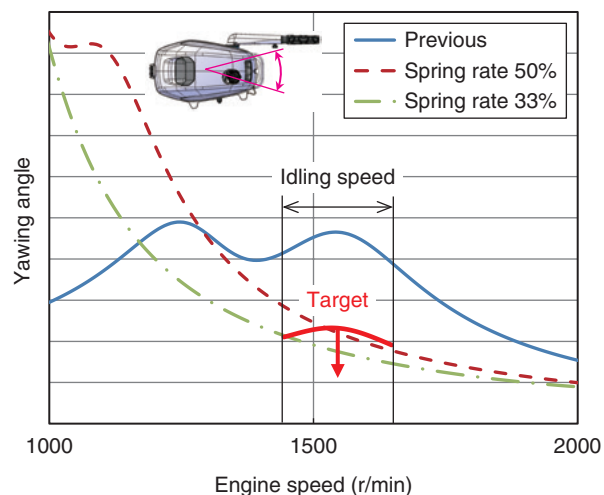


Fig. 8 Yawing while idling, by CAE

Table 2 Design targets for new mount rubber

Items	Direction	Upper	Lower
Spring rate at low load (comparison to previous)	Longitudinal	33% or under	
	Lateral		
Maximum displacement (mm)	Longitudinal	11.5 or under	4.5 or under
	Lateral	3.5 or under	2.0 or under
Strain	Longitudinal	Previous value or under	
	Lateral		

study are shown in Fig. 10. Making the displacement as great as possible is desirable for the purpose of lowering the mount rubber's spring rate, but the results show it is necessary to set longitudinal displacement no greater than 50% higher than that of the previous model at both the upper and lower mounts. Therefore, it is not possible to greatly increase longitudinal displacement.

Finally, the authors used CAE analysis to check the maximum strain value, which affects mount durability. A requirement was set to keep the maximum strain value within that experienced by the previous model.

Table 2 summarizes the requirements guiding design of the mount rubber so far.

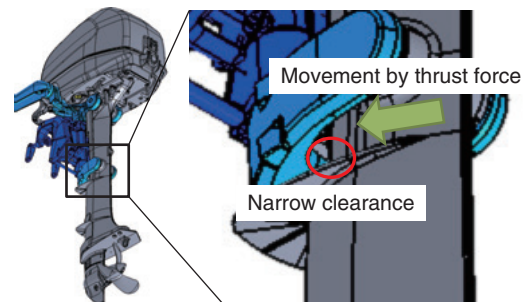


Fig. 9 Clearance between main frame and support parts

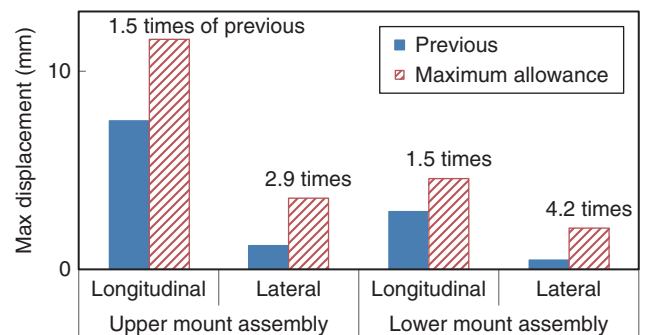


Fig. 10 Maximum displacement allowance to keep clearance

3.2. New-Shape Mount Rubber

Figure 11 compares the shape of the mount rubber in the previous and new models as studied here, taking the aforementioned requirements as preconditions.

Adding the protuberances shown as red circles greatly reduced rigidity in the longitudinal and lateral directions under low loads. In addition, the upper and lower mount rubbers were shaped to have plains along the circumference to give directionality in the longitudinal and vertical directions; this regulates rotation.

The spring characteristics of the mount rubber were confirmed by CAE. Figure 12 shows the upper mount assembly's spring characteristics in the longitudinal direction, while Fig. 13 shows the same in the lateral direction. The mount rubber's protuberances, shown within circles in the figure, are designed to make contact under low load. As the load increases, the protuberances are flattened so that the entire mount rubber bears the load. This structure helps enable the non-linear spring characteristics that the

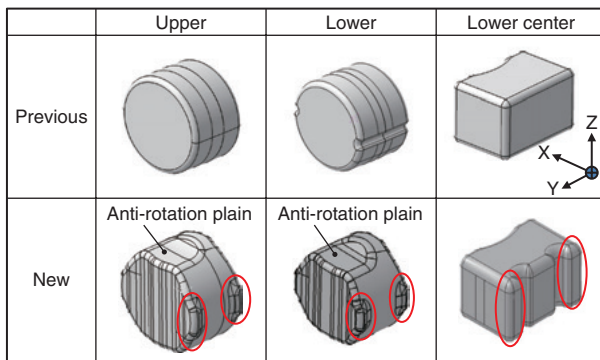


Fig. 11 Mount rubber shape

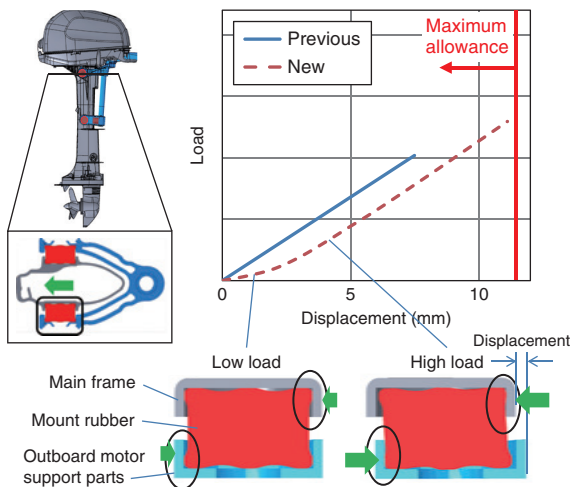


Fig. 12 Non-linear characteristic and deformation of new mount rubber (upper mount assembly, longitudinal)

research was targeting. In addition, permissible maximum displacement was within requirements even under the increased load of high output.

The spring characteristics of the lower mount assembly are shown in Figs. 14 and 15. Like the upper mount assembly, the rubber showed low rigidity under low load, while maximum displacement under high load also met requirements.

Additionally, CAE analysis was conducted on the mount rubber strain value in each direction of load to help the new mount rubber meet the durability target. The results are shown in Fig. 16. The strain value of the new-shape mount rubber remained as low as that of the previous model regardless of the higher maximum displacement.

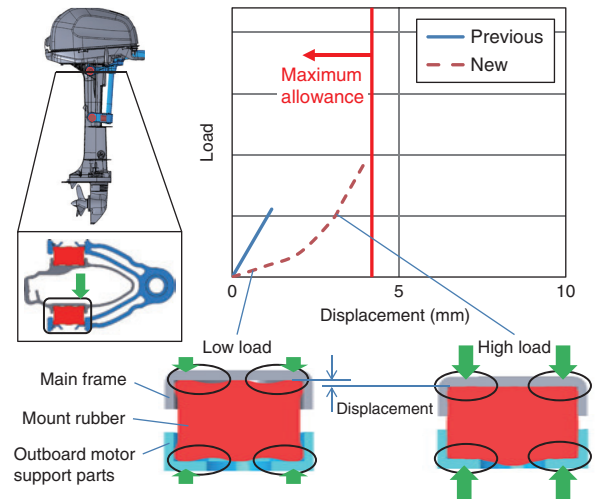


Fig. 13 Non-linear characteristic and deformation of new mount rubber (upper mount assembly, lateral)

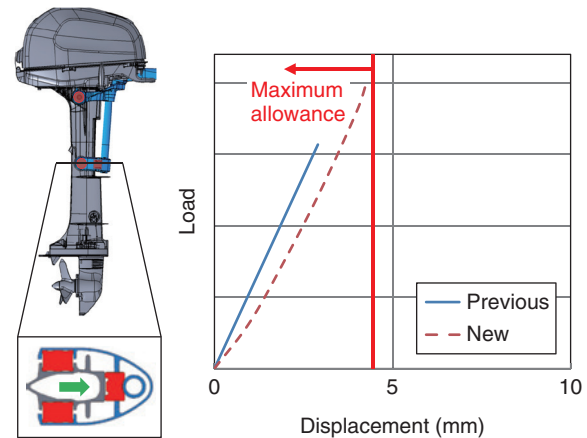


Fig. 14 Non-linear characteristic of new mount rubber (lower mount assembly, longitudinal)

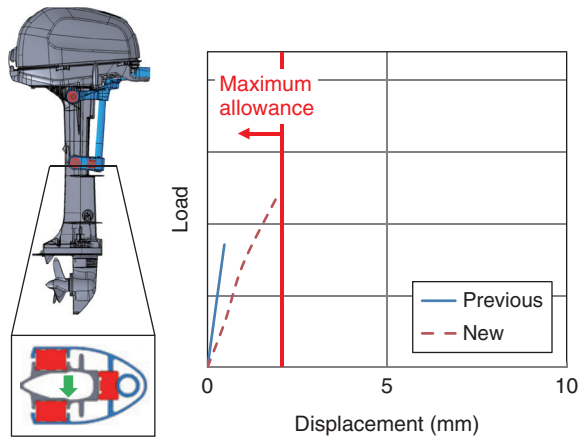


Fig. 15 Non-linear characteristic of new mount rubber (lower mount assembly, lateral)

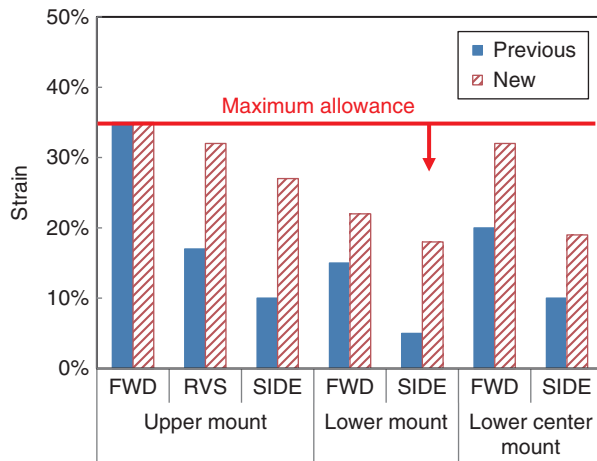


Fig. 16 Strain value, by CAE (each part and load direction)

4. Test Results

Vibration tests were conducted on actual equipment incorporating the new-shape mount rubber illustrated in Fig. 11.

Handle vibration test results are given in Fig. 17. Acceleration at 6000 r/min in the new model was about the same as that at 5000 r/min in the previous model, which was one of the development targets. In addition, tiller handle vibration was greatly reduced over the entire range from low speeds to high. Acceleration decreased by up to 50% when the two models were compared at the same speed.

Next, test results for yawing during idling are given in Fig. 18. The new model caused up to 75% less yawing than the previous model, thus achieving the target.

Finally, the paper discusses the results of the durability check. The mount rubber did not suffer damage or cracking in the various durability and strength tests conducted

during development. Even with protuberances added to the mount rubber to lower rigidity, the mount rubber satisfied the durability target by keeping the maximum strain value within requirements.

The above results indicate the effect of giving the mount rubber non-linear properties so that it has low rigidity at low loads and high rigidity at high loads.

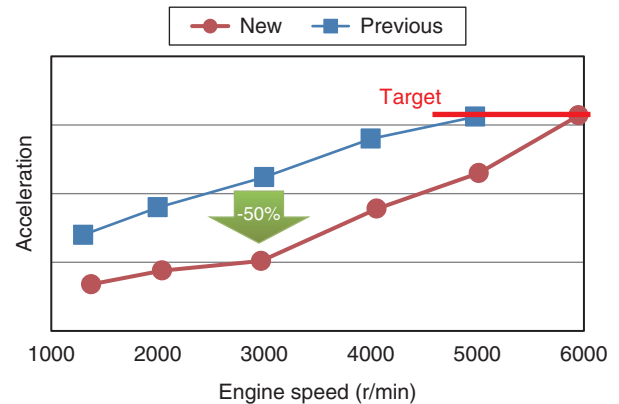


Fig. 17 Tiller handle vibration (experiment)

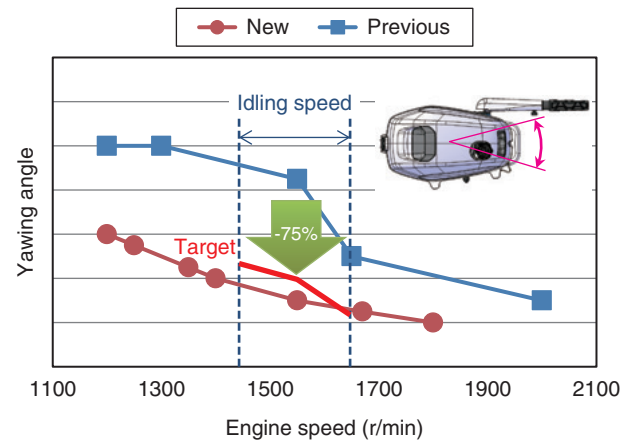


Fig. 18 Yawing (experiment)

5. Conclusion

Tests and CAE analysis were used to clarify the performance required of mount rubber in and of itself in order to satisfy the target vibration performance of an outboard motor. To embody such performance, the shape of the mount rubber was newly designed to make it highly non-linear. In other words, the mount rubber has two opposing characteristics: it has low rigidity in respect to vibration and high rigidity in respect to load.

The results indicate the target vibration performance was achieved even with the new model's high output and speed.

Specifically, handle vibration is reduced by up to 50% at the same speed, and even at its maximum speed, the new model has about as much handle vibration as the previous model at its own maximum speed. Additionally, the amplitude of yawing during idling is reduced by up to 75% compared to the previous model, greatly contributing to customer appeal.

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Development of Rear Bumper Beam Using Thermoplastic Glass Fiber-reinforced Plastic

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ABSTRACT

Parts design technology that uses thermoplastic glass fiber-reinforced plastic with high-impact strength was developed to reduce the rear bumper beam weight. Both continuous fiber that provides good impact resistance and chopped fiber that is advantageous for molding complex shapes were applied to create the ideal impact-resistant design for the rear bumper beam. Short process molding technology was also developed that can simultaneously mold three types of materials with different fiber formats in the same mold in order to reduce parts weight and cost. In addition, the influence of the rib shape on product performance in this molding process was clarified, and design technology that reduces that influence was concurrently developed.

The developed technology was applied to the rear bumper beam that is part of the frame of a mass-production vehicle, and enabled a reduction of the weight by 46% and the number of parts, except for fastening parts, to 1/9 that of the previous model.

1. Introduction

Regulation of CO₂ emissions produced during vehicle operation is increasing in stringency worldwide as a means of addressing the issue of global warming. As a result, it is not enough to simply increase the fuel economy of powertrains, and reduction of the overall operating energy of vehicles is an urgent task. One means for achieving this is to reduce the body weight.

In particular, the bumper beams used in the front and rear of vehicles are heavy parts consisting of a beam that absorbs impacts by bending with torsional deformation and crush boxes that absorb impacts by axial collapsing. In addition, bumper beams are positioned at the front and rear of vehicles, so they have a large influence on not just fuel economy performance, but also handling stability. Automotive manufacturers are conducting R&D to reduce weights and cost⁽¹⁾, but there are limits to the weight reduction that can be achieved assuming the use of metallic materials such as steel plate (SP) and aluminum (AL).

There are cases of using fiber-reinforced plastic (FRP) material to reduce weight, but the applicable models are limited in terms of productivity and cost. Thermoplastic FRP that uses thermoplastic resin as the base material has better productivity and recyclability compared to conventional thermoset FRP, and extensive research is being performed on these materials⁽²⁾.

Thermoplastic FRP has a higher material cost than metallic materials such as SP and AL, or fiber-reinforced

pellets for injection molding. In addition, compression molding of continuous fiber-reinforced materials can form only simple shapes on the same level as SP pressed material, so it is necessary to assemble multiple parts. Furthermore, molding systems used to mold thermoplastic FRP entail great investment and need more dies to mold the same part configurations compared to SP. These factors all increase the cost.

Therefore, the authors investigated a combination of base material and reinforcing fiber from the viewpoint of cost relative to the bumper beam performance requirements in order to reduce material costs, and developed both a large integrated structure that enables a reduction in the number of parts and molding technology for manufacturing that structure. The thermoplastic FRP bumper beam developed using these technologies was used in CLARITY FUEL CELL (FCV).

2. Material Selection

Table 1 shows the results of axial collapse tests using various materials. This table shows that FRP has better specific strength and impact energy characteristics than SP and AL. Carbon fiber-reinforced plastic (CFRP) in particular exhibits a high performance but is also high cost. In comparison, glass fiber-reinforced plastic (GFRP) offers better cost effectiveness. Therefore, this development selected thermoplastic GFRP.

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Table 1 Performances and costs of various materials

Material	Molding method	Specific stiffness	Specific tensile strength	Specific energy absorption	Cost
		GPa/ ρ	MPa/ ρ	J/g	
SP (JSC270C)	Press	26	35	6	1
AL (A6063 T7)	Extrusion	26	89	17	3
GF/PA6 continuous FRP	Press	12	224	45	5
CF/PA6 continuous FRP	Press	38	560	61	30

ρ : specific gravity PA: polyamide

3. Structure and Manufacturing Method

3.1. Structural Concept

FRP that uses thermoplastic resin as the base material exhibits a different material performance according to the reinforcing fiber format. FRP fiber formats include continuous fiber material that has high strength and stiffness, and chopped fiber material that increases the degree of molding freedom by chopping the fibers, making it suitable for complex shapes. Figure 1 shows the relationship between the thermoplastic FRP fiber length and various performances (modulus of elasticity, static strength, impact strength)⁽³⁾. The fiber length is strongly related to static strength and impact strength. However, the degree of molding freedom decreases as the fiber length increases, which calls for a selection of materials suited to the application.

Continuous fiber-reinforced material was used in the main bumper beam member that needs both strength and stiffness in consideration of the property requirements. In addition, chopped fiber-reinforced material with a fiber length of 30 mm or more that can be used for compression molding was used in reinforcing shape locations with complex shapes, such as ribs, that need stiffness more than

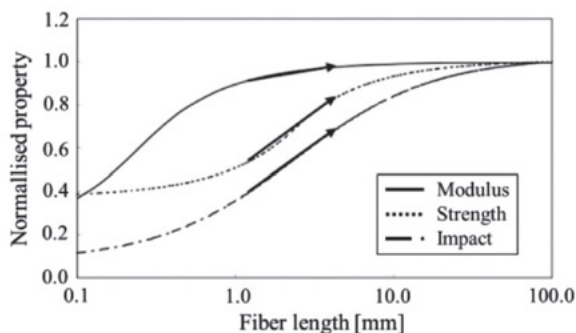


Fig. 1 Influence of fiber length on mechanical properties

strength. It was thought that this structural concept could satisfy the property requirements of each member. Open sections have lower stiffness and strength with regards to member bending deformation, so it was thought that the two-part configuration with a normally closed section could be integrated into a single part. Figure 2 shows an image of this concept.

3.2. Molding Concept

Integrated molding of parts, including the ribs, was achieved by simultaneously compression molding continuous fiber-reinforced material and chopped long fiber-reinforced material, with a fiber length of 30 mm to 50 mm, as the molding process for realizing the structural concept (Fig. 3). After compression molding, injection molding is performed to the parts periphery to add supplemental shapes that tolerate an elongation of portions that cannot be molded using continuous fiber-reinforced material, and to reduce secondary processing such as deburring of the parts periphery.

In addition, when molding 3-dimensional structures using the conventional method, it is necessary to set preformed reinforced-plastic material in the rib areas inside the die and perform re-molding. However, the developed method realizes one-shot molding after setting the necessary materials. This shortens the series of molding processes and helps eliminate incidental preforming dies, which also reduces costs.

3.3. Performance Requirements and Issues for Integrated Molding

3.3.1. Change in physical properties after compression molding of chopped fiber materials

To achieve the molding concept described above, it is necessary to understand the flow of chopped long fiber-reinforced material during compression molding and apply this to design. Therefore, a compression molding test was performed using chopped long fiber-reinforced material. Test pieces were cut from the rib molding test piece at different heights as shown by the red frames in Fig. 4, and tensile tests were performed. Comparison of the top and bottom areas of the rib showed that while there was little difference in the tensile test piece density, the tensile

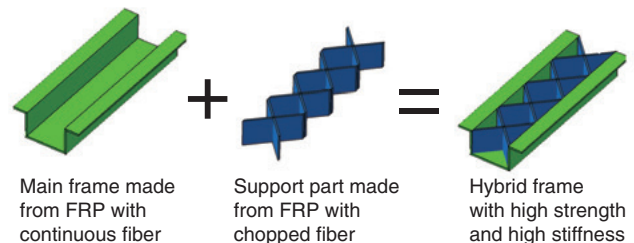


Fig. 2 Material composition concept

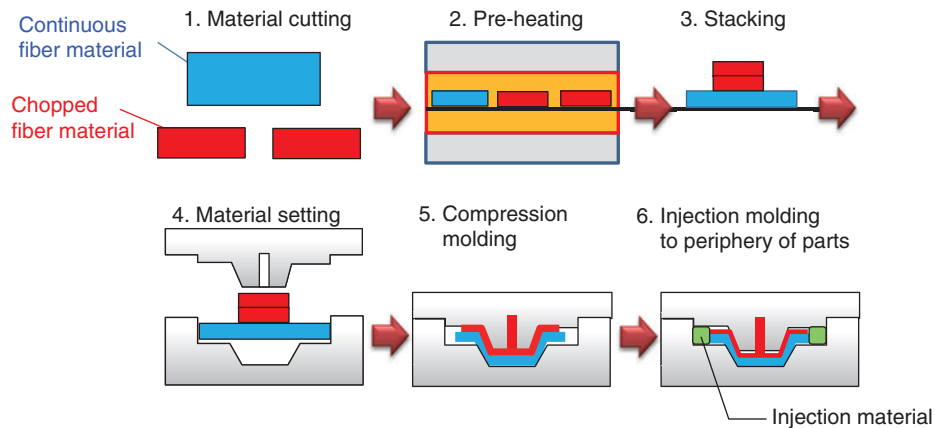


Fig. 3 Molding process

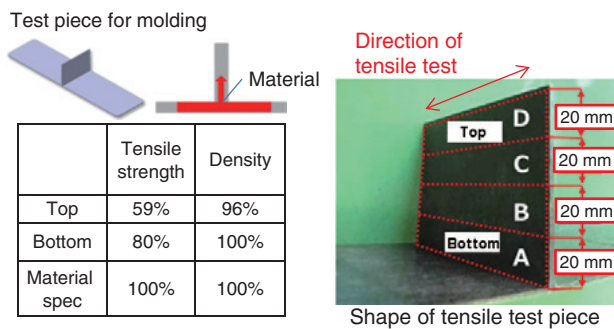


Fig. 4 Test of rib shape molded by compression molding

material flows due to compression molding, and performed molding tests. Figure 7 shows the compression molding test piece and the method of cutting out the tensile test pieces. In addition, Table 2 shows the relationship between two different rib shapes and the tensile strength. Figure 8 shows these two different rib shapes and the rupture start points. The test results showed that increasing the draft angle and the fillet R size, such as in Case 2, helps the plastic to flow more easily and reduces continuous fiber meandering, effectively increasing the strength. In this manner, both the fluid and mechanical properties were investigated when determining the product shape, and the results were reflected in the bumper beam shape design.

strength was lower at the top of the rib. Figure 5 shows the condition of the remaining fibers after heating the test piece to bake the resin. Long fibers remain at the bottom of the rib, but many shorter fibers can be seen at the top of the rib. Figure 6 shows the results of investigating the fiber length distribution at different heights of the above-mentioned rib molding test piece. This shows that fibers with a fiber length of 10 mm or less increase from the bottom towards the top of the rib. These test results revealed the rib height that can provide the needed base material performance, which enabled optimization of the shape.

3.3.2. Drop in strength when continuous fiber and chopped fiber materials are simultaneously molded

The developed manufacturing method simultaneously compression molds continuous fiber-reinforced material and chopped fiber-reinforced material. However, when the chopped fiber plastic flows due to the compression, the continuous fiber sometimes meanders according to the flow of the plastic. This phenomenon may result in a loss of continuous fiber-material linearity, leading to a drop in part stiffness and strength. The authors focused on the shear resistance generated when chopped fiber-reinforced

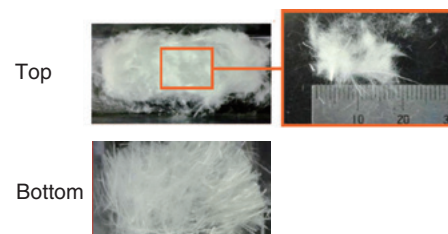


Fig. 5 Fiber distribution in rib after baking base resin

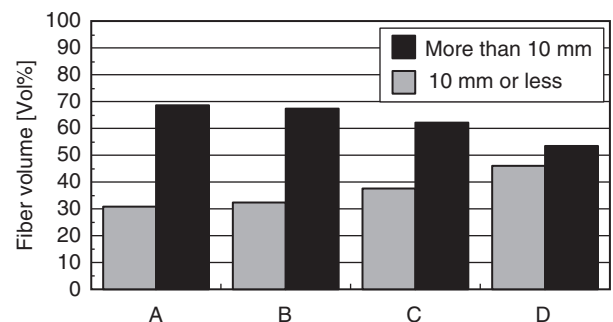


Fig. 6 Distribution of fiber contents in rib shape by compression molding

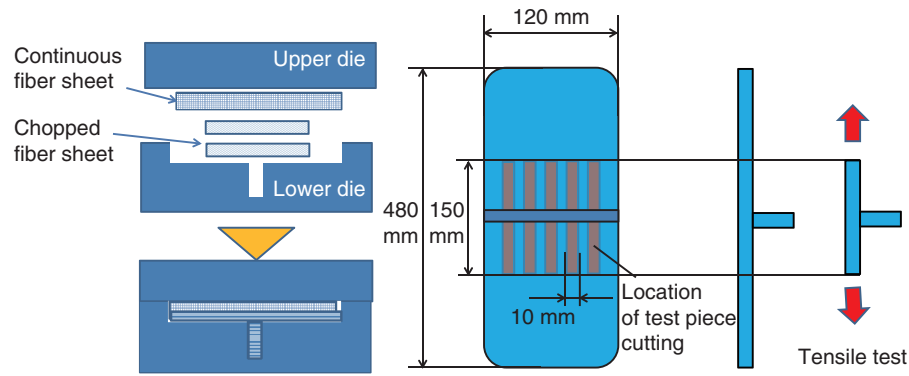


Fig. 7 Test piece molding method

Table 2 Relationship between fillet R at bottom of rib and tensile strength

	No rib	Case 1	Case 2
t : thickness [mm]	-	2.5	2.5
θ : draft angle [°]	-	0.5	1.5
R : fillet R [mm]	-	0.5	2
Strength index	1.0	0.41	1.06

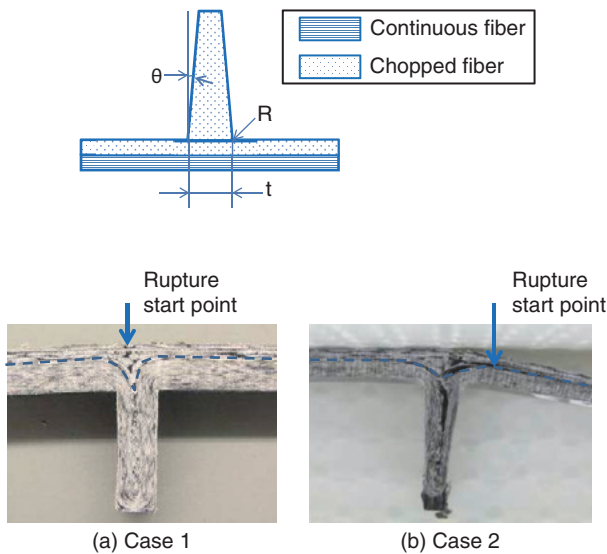


Fig. 8 Shape of rib test piece and location of rupture start in tensile test

4. Application to Rear Bumper Beam

Figure 9 shows the thermoplastic GFRP rear bumper beam, with the structure designed using the developed technology, and its location in CLARITY FUEL CELL. Figure 10 shows the structure and the material composition.

Figure 11 shows the relative positions of the bumper beam and the test jig in the Part 581 test of the U.S. Federal Motor Vehicle Safety Standards (FMVSS) for low-speed crashes. The structure positions hybrid structures consisting of high-strength continuous fiber-reinforced plastic and chopped fiber-reinforced plastic with a long fiber length at locations where a bending moment is generated. The test mode that applies a load from outside the vehicle can be addressed by the compression performance of the member instead of the moment. Therefore, supplementing the shape



Fig. 9 Thermoplastic GFRP rear bumper beam and location in CLARITY FUEL CELL

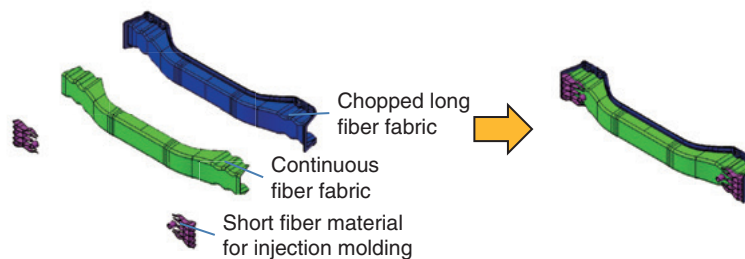


Fig. 10 Material composition of rear bumper beam

with injection molding materials that include low-strength glass-fiber filler can enhance the continuous fiber material yield, which helps to reduce the cost.

As a result of parts integration, the basic section of the bumper beam has a hat shape with an open section. When a beam with an open section receives a bending moment, the section opens further according to the input load, which lowers the stiffness and strength. This was addressed by positioning chopped fiber materials on the rear side of the beam and setting ribs as shown in Fig. 10. Figure 12 shows the test condition of the static load test, and Fig. 13 shows the rupture location at the peak load. The shape was optimized based on the rib investigation results in Section 3.3, and it was confirmed that there was no occurrence of final rupture resulting from a drop in strength at the bottom of the rib.

Figure 14 shows the Part 581 test in an actual vehicle, and Figs. 15 and 16 show the CAE results and the test

results. These graphs show that the needed crash energy absorption amount can be obtained at the target deformation distance or less, which confirmed that the developed method provides the same level of performance as that of the previous part.

Figure 17 compares the number of parts with that of the previous rear bumper beam. The developed thermoplastic GFRP rear bumper beam has 1/9 the number of parts and achieved a weight reduction of 46% compared to the previous structure.

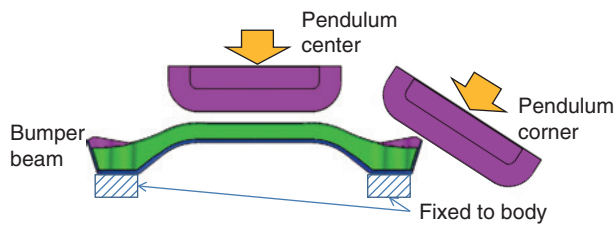


Fig. 11 Position of bumper beam and Part 581 pendulum test

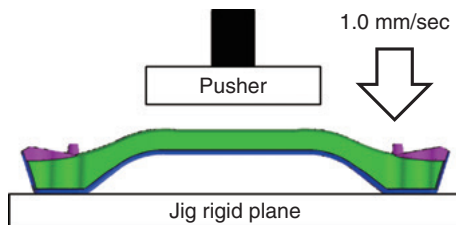


Fig. 12 Test condition of static load test

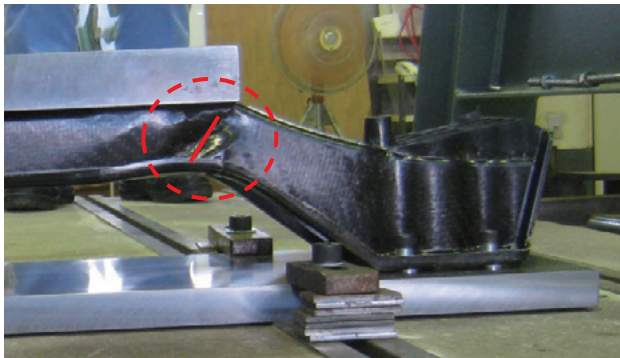


Fig. 13 Location of rupture at the peak load

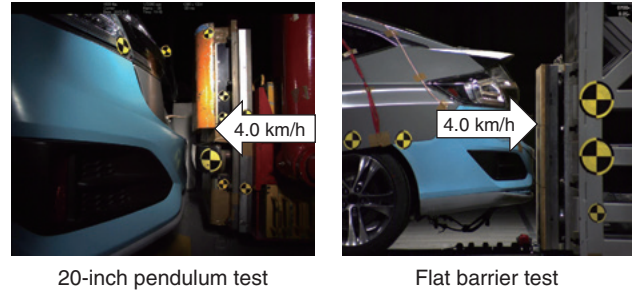


Fig. 14 Part 581 test

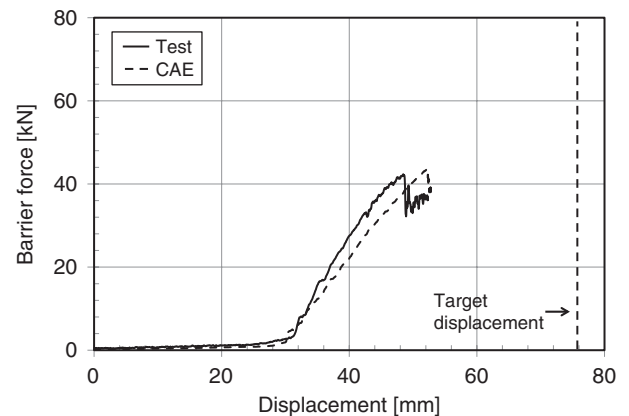


Fig. 15 Comparison of actual test and CAE simulation in Part 581 20-inch pendulum test

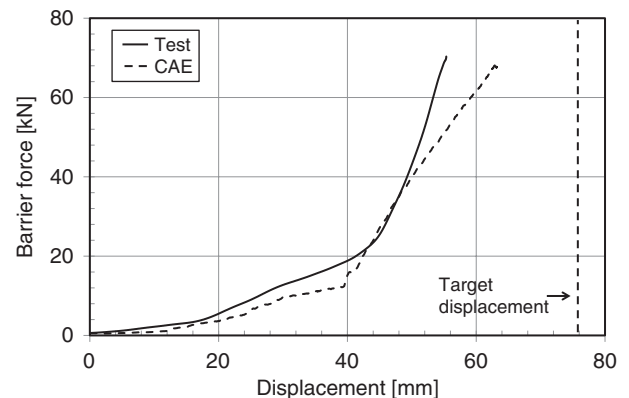


Fig. 16 Comparison of actual test and CAE simulation in Part 581 flat barrier test

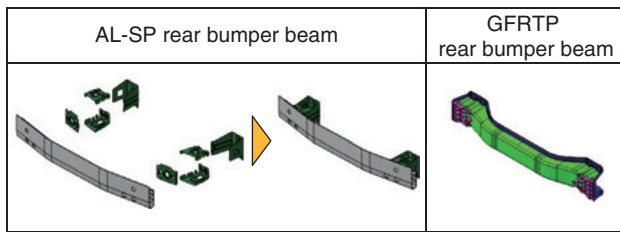


Fig. 17 Comparison of GF RTP rear bumper beam and AL-SP rear bumper beam

5. Conclusion

Parts design technology that uses thermoplastic glass fiber-reinforced plastic was developed to reduce the rear bumper beam weight, and the following findings were obtained.

- (1) A new hybrid molding method was developed that simultaneously compression molds continuous fiber-reinforced material and chopped long fiber-reinforced material, and flows chopped long fiber-reinforced material to the rib areas. This method realizes one-shot molding after setting the necessary materials, which shortens the series of molding processes and helps eliminate incidental preforming dies, which reduces costs.
- (2) Compression molding tests of chopped fiber-reinforced material were performed, and the results clarified the relationship between the rib height and the contained fiber length, which helped to optimize the shape.
- (3) It was found that when continuous fiber-reinforced material and chopped fiber-reinforced material are simultaneously compression molded, the resin flow may result in a loss of continuous fiber-material linearity, leading to a drop in part stiffness and strength. Therefore, the bottom of the rib was changed to a shape that helps the plastic to flow more easily, which reduced the drop in performance.
- (4) Parts integration was achieved by arranging three types of materials with different fiber formats in the appropriate locations and by making use of the degree of molding freedom inherent to plastic. This enabled weight to be reduced by 46% and the number of parts to 1/9 compared to the previous rear bumper beam, while still satisfying the U.S. low speed crash standards.

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Crosswind Stability Simulation Technology for Performance Design in Model Base Development of Mass-production Vehicles

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ABSTRACT

A simulation technology was developed that can be used in performance design with respect to crosswind stability for various vehicle types. This involves computation that takes the vehicle model used in the model base development of mass-production vehicles, and combines it with the model of driving conditions used to define actual vehicle tests for evaluation of crosswind stability. For the modeling of driving conditions, in particular, the time when the vehicle is entering the crosswind section and the time when the vehicle is exiting the crosswind section are treated separately, so both a continuous crosswind model, for a crosswind with continuously changing influence on the vehicle, and a discontinuous crosswind model, for discontinuously changing influence, were developed respectively. Combining these to define a half-continuous crosswind model enabled computation time to be shortened while still maintaining the necessary accuracy in calculations for performance evaluation of crosswind stability. The validity of this conceptual approach was verified using a 2014 model year FIT, and this simulation technology has enabled the study of specifications by means of crosswind stability simulation, for the development of other mass-production vehicles as well. The effectiveness of the technology was verified in development of the 2018 model year N-BOX.

1. Introduction

The development of automobiles has been growing increasingly complicated, and model base development (MBD) is an effective technique for efficiently advancing this kind of development. Figure 1 shows graphic representation of MBD as a V-model, where the central area enclosed by a red border shows the phases of performance design and performance verification (measurement). Performance design in MBD assumes that active use will be made of simulation. This necessitates a simulation environment that is capable of outputting computation results for a variety of performance design items within the limited time available in the development schedule. Therefore a simulation environment was developed with the capability of outputting results in a short enough time to enable actual use in chassis performance design for MBD of mass-production vehicles⁽¹⁾. The application of this simulation technology further enabled the examination of a number of performance design items that had not been

readily subject to examination in performance design for mass-production vehicle development up to that point. This technology can therefore be used for mass-production vehicle development. Simulation that predicts lap times⁽²⁾ is a typical example of such technology. In this paper, a

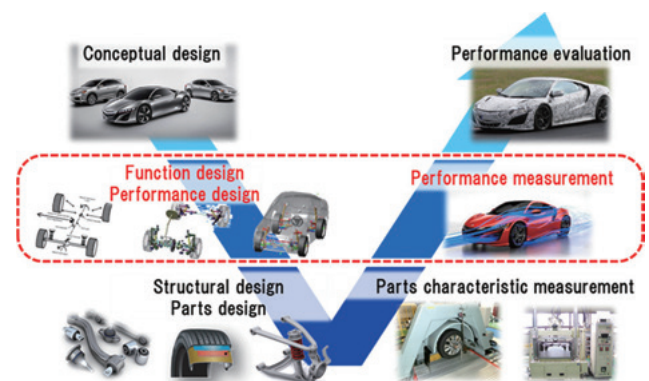


Fig. 1 V-Model

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technique for simulation that predicts crosswind stability (hereafter referred to as crosswind stability simulation) will be described.

2. Evaluation of Crosswind Stability

Methods for testing crosswind stability in actual vehicles are prescribed in ISO 12021-1⁽³⁾. In conformance with that, JASO Z108⁽⁴⁾ also defines a test procedure for evaluating crosswind stability, and this testing method (hereafter referred to as the crosswind stability test) has shown results in performance evaluation during vehicle development. Mini-compact cars, tall minivans, and other such light-weight vehicles tend to be more influenced by crosswinds⁽⁵⁾, so it is particularly important to evaluate their performance using crosswind stability testing.

Figure 2 shows an overview of the crosswind stability test. For crosswind stability testing, first of all a crosswind blower is placed beside the test course to generate a crosswind on the course, creating a zone where a crosswind blows (hereafter referred to as the crosswind section). An actual vehicle is then driven through that crosswind section so that it moves across the crosswind at a specified speed, and the amount by which the line of the vehicle's path diverges laterally from a straight line due to the influence of the crosswind (hereafter referred to as the lateral displacement) is measured. The amounts of such lateral displacement are compared to evaluate crosswind stability. Figure 3 shows the yaw rate as an example of measurement data obtained from the crosswind stability test. Crosswind stability is evaluated using the lateral displacement determined from this kind of measurement data in combination with yaw rate peak values and changes in the yaw rate.

A crosswind stability test is a more elaborate procedure than other driving tests, so it requires more man-hours to carry out. It has been reasoned, therefore, that if a simulation could substitute for the crosswind stability test, then the examination of specifications could be performed

more efficiently, and various research efforts have been made up to now on simulation technology that predicts crosswind stability^{(6), (7)}. Most simulation technology developed to date, however, has been focused mainly on highly precise computation using complex models that attempt to accurately represent fine details of the vehicle shape as well as details of wind flow around such areas. Figure 4 shows a conceptual image of the computational model found in that type of simulation. That kind of simulation requires large amounts of data, in addition to which the model is complex. Consequently, it takes a long time to output the results, and such methods could not readily be applied to the development of mass-production

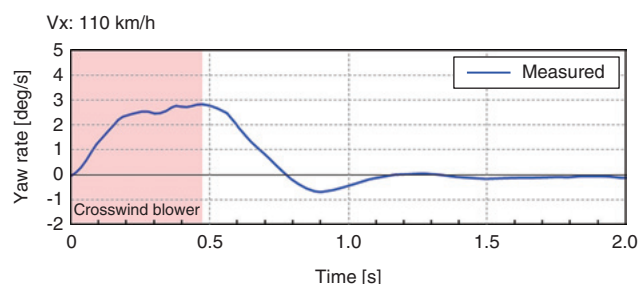


Fig. 3 Yaw rate in time series



Fig. 4 Crosswind simulation image

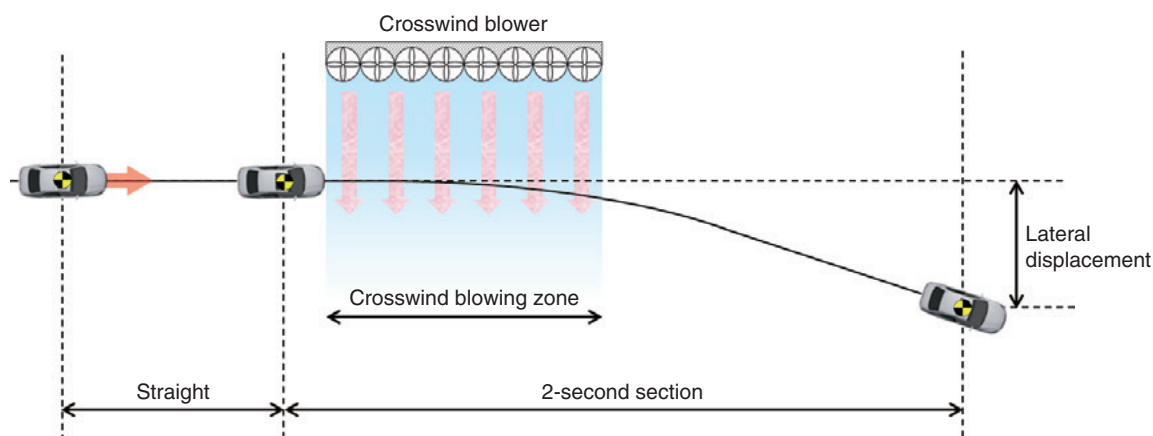


Fig. 2 Scheme of crosswind test

vehicles^{(8), (9)}.

If the simulation of crosswind stability could be performed using less data and a simpler model, then it could readily be included as an item for examination in all MBD performance design. Simulation that allows for computation using only the data acquired in the initial stages of development is particularly effective. Therefore it was decided to apply the vehicle model that had been created for the purpose of conducting MBD of mass-production vehicles.

3. Aims for the Developed Technology

The following three items were defined as the objectives for this technology, with the aim of developing a crosswind stability simulation method that would have sufficient accuracy to be effective in furthering performance design for MBD of mass-production vehicles.

- (1) Provides the ability to create a vehicle model using data that can be acquired in the initial stage of mass-production vehicle MBD.
- (2) Provides the capability to examine yaw rates and yaw rate peak values in addition to lateral displacement.
- (3) Provides the accuracy necessary for performance design in comparison with crosswind stability testing, and yields results within a time that allows for application to the development of mass-production vehicles.

4. Evaluation Indices

4.1. Crosswind Stability Test

The ISO and JASO standards for crosswind stability testing specify that the test vehicle should be driven at a speed of 100 km/h or 110 km/h. When developing mass-production vehicles, however, it is common to test across a broader range of vehicle speed conditions, starting at lower speeds and extending into higher speeds. Therefore the simulation should also be capable of a broader range of vehicle speeds.

The test specifications further call for crosswind at a velocity of 20 ± 3 m/s at the observation points in the crosswind section, for testing to be conducted in an environment with natural winds of 1 m/s or less, and so on^{(3), (4)}. The determination of crosswind stability is made from the lateral displacement of the center of gravity two seconds after the front end of the vehicle begins to enter the crosswind section. In mass-production vehicle development using actual vehicles, time series changes in the yaw rate, as observed in a two-second section and yaw rate peak values, are also referred to as evaluation indices.

The driving state of the vehicle when it enters the crosswind section greatly influences the accuracy of lateral displacement as an evaluation index for crosswind stability testing. This means that lateral displacement cannot readily be measured directly. Therefore, crosswind stability tests normally calculate lateral displacement from the yaw rates

generated in the two-second section, and use that calculated value as an evaluation index instead of direct measurement of lateral displacement. The JASO standard also takes the same conceptual approach to measurement of lateral displacement.

4.2. Method for Determining Lateral Displacement

Figure 5 shows the relationship of vehicle movement to a fixed X-Y coordinate system overlaid on the crosswind stability test course. The direction of straight ahead advancement that is the objective on entering the crosswind section is represented by the X-axis, and the direction of the wind that is blown onto the crosswind section is represented by the Y-axis. The X and Y axes are at right angles. The velocity of the vehicle is represented as V , with the velocity in the X-axis direction as V_x and the velocity of lateral displacement as V_y . The distance that the center of vehicle gravity moves in the direction of the Y-axis, two seconds after beginning to enter the crosswind section, is the lateral displacement that is the object of evaluation. The lateral displacement is determined by the value calculated using the measured yaw rate value r . If the yaw angle is θ , then θ is expressed by Eq. (1).

$$\theta = \int r \cdot dt \quad (1)$$

If the lateral acceleration is a_y and the body slip angle of the center of gravity is β , then β is expressed by Eq. (2).

$$\beta = \int \left(\frac{a_y}{V} - r \right) \cdot dt \quad (2)$$

From this, the displacement Y_i in the Y direction on the coordinate system that is fixed on the ground can be determined using Eq. (3).

$$Y_i = V \int [\sin(\theta + \beta)] dt \quad (3)$$

However, the value of β is normally lesser than θ , enough so that if the yaw rate can be correctly determined in the two-second section, then the lateral displacement can also be determined with sufficient accuracy.

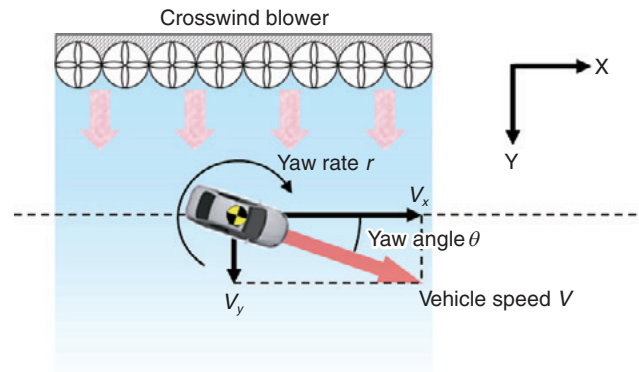


Fig. 5 Crosswind simulation

5. Simulation Model

5.1. Computational Model of Vehicle Conditions

The vehicle conditions dealt with here are the vehicle dimension specifications, component characteristics, and other such elements related to the dynamic performance of the vehicle. Specifically, these are the vehicle mass, the moment of inertia, the wheelbase, the center of gravity, the front and rear tire characteristics, the front and rear suspension characteristics, and the aerodynamic characteristics of the vehicle. The vehicle data used in MBD of mass-production vehicles can be used for these items of data on characteristics. The vehicle data used in MBD of mass-production vehicles has been described in a previous report⁽¹⁾.

5.2. Computational Model of Driving Conditions

There is a method that allows convenient computation of the influence of a crosswind by supposing that the force applied to the vehicle when passing through the crosswind section is a constant force that is generated as a rectangular wave for a set period of time. Here the computational model for this method is referred to as the discontinuous crosswind model. Figure 6 shows an overview of the discontinuous crosswind model. Some characteristics of the discontinuous crosswind model are that the vehicle mass is represented by mass points and that transient changes in aerodynamic characteristics that occur during entry and exit are not taken into consideration. As the result of a constant crosswind being applied to the aerodynamic center of a vehicle with a specific aspect, a yaw moment is generated around the center of gravity, with the distance from the aerodynamic center to the center of gravity of the vehicle as the moment arm length. A yaw moment is generated from the change in yaw angle that occurs between the instant when the leading edge of the vehicle enters the crosswind section and the instant when the leading edge of the vehicle exits the crosswind section. The magnitude of the yaw moment is largely determined by the force of the crosswind working

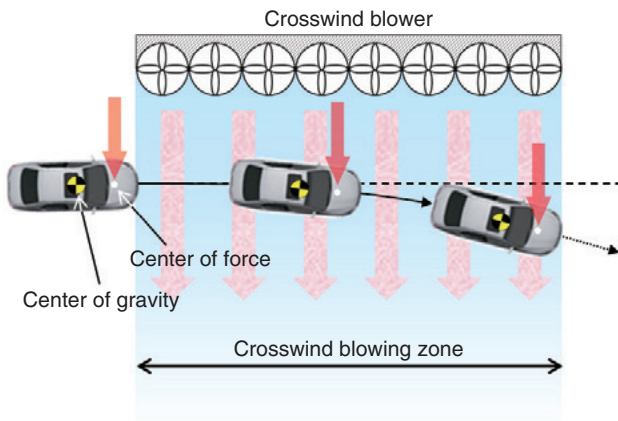


Fig. 6 Discontinuous crosswind model

Table 1 Specification list (FIT)

	FIT
Length × Width × Height [m]	3.990 × 1.695 × 1.525
Wheelbase [m]	2.530
Track Front/Rear [m]	1.480/1.470
Weight [kg]	1080

on the vehicle body according to the yaw angle change and the distance from the aerodynamic center to the center of gravity of the vehicle. Figure 7 shows a graph depicting the change in yaw moment generated in the vehicle body during passage through the crosswind section. In the discontinuous crosswind model, there is discontinuity between the yaw moments while driving through the crosswind section and while driving outside the crosswind section. Since this computational model is simple, it does not need large amounts of data to create a model. This also has the advantage that the computational burden is smaller, so that results can be output in a shorter time.

Regarding the 2014 model year FIT (hereafter FIT), Fig. 8 shows a graph that compares the computation results for yaw rate using the discontinuous crosswind model with the yaw rate measured in an actual crosswind stability test. The main specifications of the FIT are as shown in Table 1.

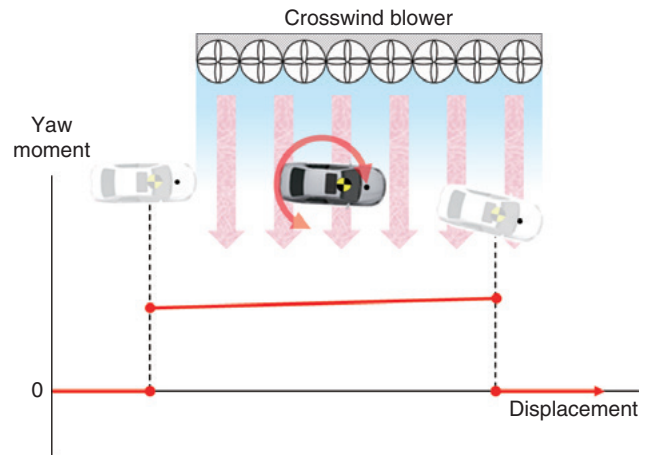


Fig. 7 Yaw moment of discontinuous crosswind model

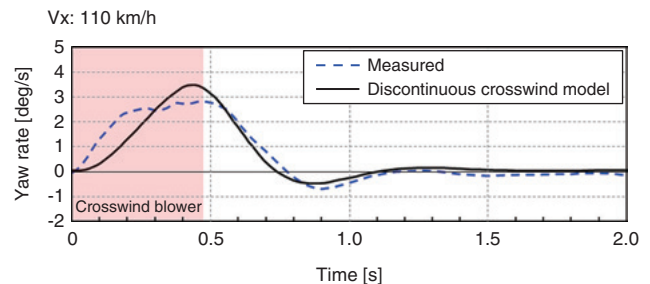


Fig. 8 Comparison of yaw rate in time series

The horizontal axis in Fig. 8 is the time, with the instant of entry into the crosswind section as zero seconds. The computation and measurement condition for both is 110 km/h. It can be confirmed from this graph that a peak occurs in the computation results for crosswind stability simulation after around 0.4 to 0.5 seconds, and that the results converge after around 1.5 seconds. By contrast, the results of the crosswind stability test using an actual vehicle show the yaw rate starting to rise at an earlier stage, with the first peak appearing after about 0.2 seconds, and the last peak occurring after about 0.5 seconds, and the results converging after around 1.5 seconds. The computation results from the discontinuous crosswind model and the measurement results from the crosswind stability test differ in how the yaw rate manifests, in the location of the yaw rate peaks, and so on, so that the computation results for lateral displacement produced from the simulation differ from those from the test results.

The continuous crosswind model sought a means for computing the rise in the yaw rate immediately after entry into the crosswind section and the first peak that occurs in the yaw rate by considering to make continuous changes in the yaw moment in accordance with the total length of the vehicle before and after entering the crosswind section, and before and after exiting the crosswind section. Figure 9 shows an overview of this approach. In the continuous crosswind model, the yaw moment is defined by dividing the passage through the crosswind section into three phases: (a) the phase of entry to the crosswind section, (b) the phase of passage through the crosswind section, and (c) the phase of exit from the crosswind section.

Figure 10 depicts the magnitude of the yaw moment generated in the vehicle body as computed by the continuous crosswind model. In the continuous crosswind model, the vehicle body is subjected to the crosswind while passing through the crosswind section, and the yaw moment that is thereby generated is continuous with the yaw moment (which is zero) generated while driving outside the crosswind section. This yaw moment changes transiently with the passage section, which corresponds to

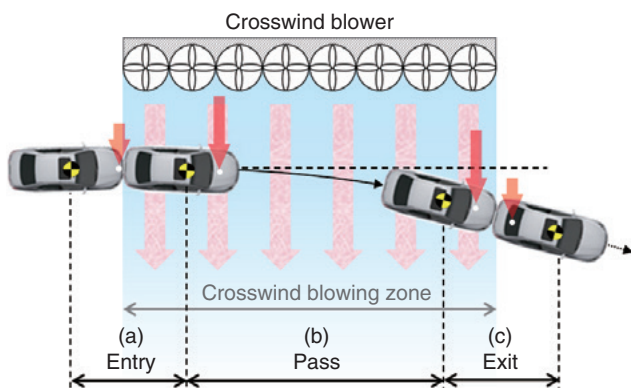


Fig. 9 Continuous crosswind model

the total length of the vehicle. Figure 11 shows the yaw rate computation results from the continuous crosswind model plotted onto the graph in Fig. 8. It is apparent from this graph that the results from the crosswind stability test and the computation results from the discontinuous model yield yaw rates that match closely from entry into the crosswind section to around 0.5 seconds after entry. However, it is also apparent that the calculated value and measured value diverge to a large extent from 0.5 seconds after exit from the crosswind section to around 1.0 second after exit.

Therefore a new model was devised in which the continuous model is used for the first half of passage through the crosswind section, where the yaw moment changes transiently, and the discontinuous model is used for the yaw moment in the last half. This has been designated the half-continuous crosswind model. In the half-continuous crosswind model, the yaw moment is taken to become zero when the vehicle reaches the exit of the crosswind section.

Figure 12 depicts the magnitude of the yaw moment that is generated in the vehicle body computed by the half-continuous crosswind model. Figure 13 shows a graph with the computation results from the half-continuous crosswind model plotted onto Fig. 11. It can be confirmed from this graph that the computation results from the half-continuous crosswind model match closely with the measurement results from the crosswind stability test. Of the three, the

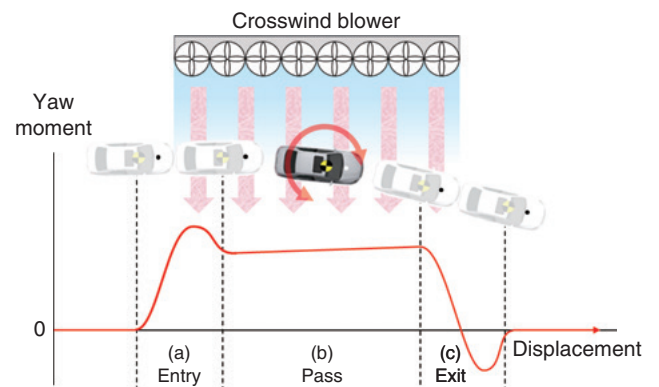


Fig. 10 Yaw moment of continuous crosswind model

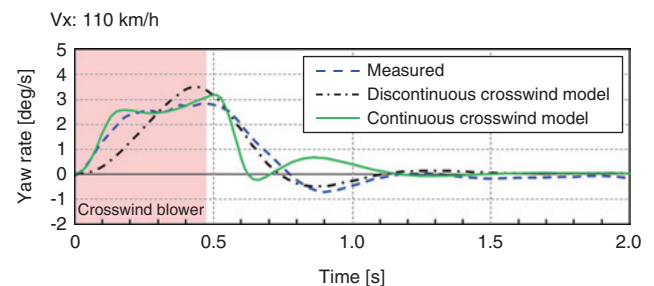


Fig. 11 Comparison of yaw rate in time series

half-continuous crosswind model tends to produce the closest results to the crosswind stability test. Figure 14 shows a bar graph presenting the measurement results for lateral displacement, which is the evaluation index for the

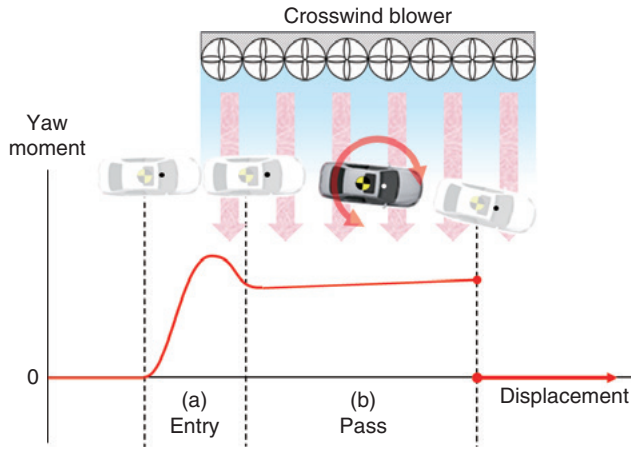


Fig. 12 Yaw moment of half-continuous crosswind model

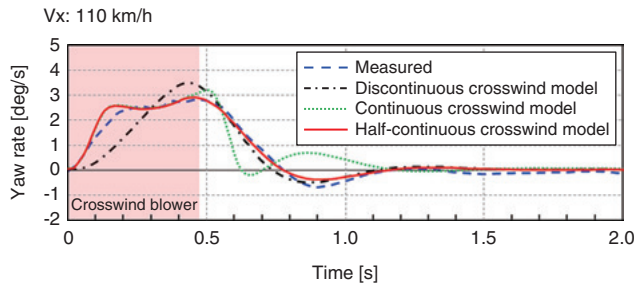


Fig. 13 Comparison of yaw rate in time series at 110 km/h

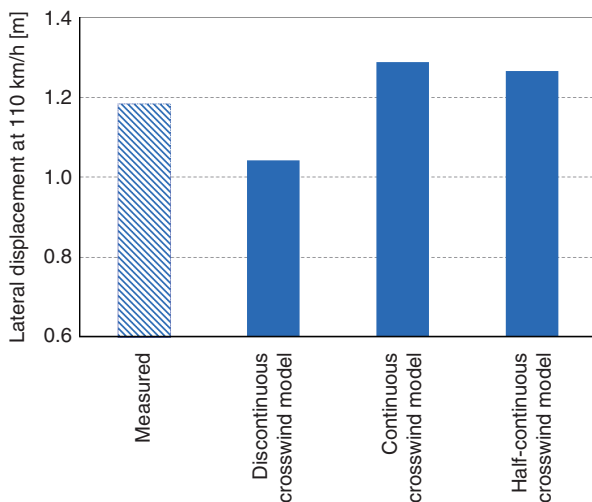


Fig. 14 Comparison of lateral displacement at 110 km/h

crosswind stability test, compared with the computation results for lateral displacement determined from the discontinuous crosswind model, the continuous crosswind model, and the half-continuous crosswind model. These computation results show that use of the half-continuous crosswind model yields simulation results for crosswind stability with an accuracy that makes this model effective for performance design.

5.3. Verification of the Half-continuous Crosswind Model

A graph that compares the computation results from the discontinuous crosswind model, the continuous crosswind model, and the half-continuous crosswind model with the measurement results from crosswind stability testing, where the vehicle speed condition has been changed to 140 km/h, is shown in Fig. 15. A similar graph that compares lateral displacement is shown in Fig. 16. It is apparent from these computation results that even when the speed condition is changed, the half-continuous crosswind model yields results that match closely with those from the crosswind

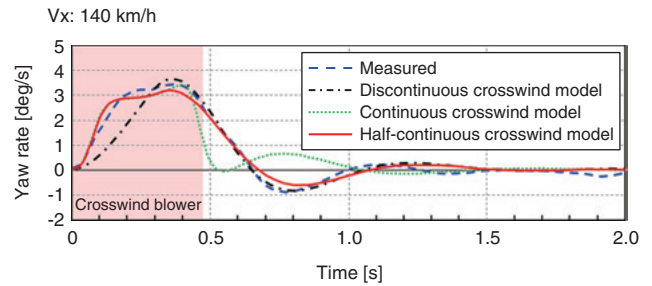


Fig. 15 Comparison of yaw rate in time series at 140 km/h

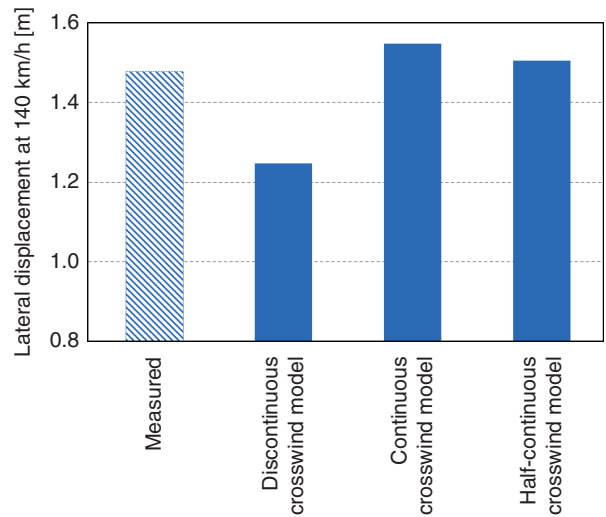


Fig. 16 Comparison of lateral displacement at 140 km/h

stability test.

As for the crosswind stability test, there have been reports to date on research regarding the conceptual approach to the entry portion of the crosswind section^{(10), (11)}. There were few examples, however, that discussed the conceptual approach to the exit portion of the crosswind section. There have been only a few examples in the past of simulation models that are like the half-continuous crosswind model devised in the current research in grasping the whole, made up of the entry portion to the crosswind section together with the exit portion from the crosswind section. The half-continuous crosswind model is a new simulation model that has been proposed in order to achieve a balance between accuracy in computation of crosswind stability and computation time.

6. Cases of Application of Simulations

The previous chapter discussed the crosswind stability simulation technology that was created through development of the FIT. Next, the effectiveness of this approach in similar application to the development of other mass-production vehicles was confirmed. The following is a case of application of the developed simulation technology to development of the 2018 model year N-BOX (hereafter referred to as the new N-BOX).

Table 2 shows the main specifications for the new N-BOX. Since the N-BOX had a body shape that made it susceptible to the influence of crosswinds, there was a need to examine specifications that would also realize other aspects of performance without degrading crosswind stability. It is particularly important in this case to seek as high a level of crosswind stability as could be managed from the initial stages of development. Given this context, the developed simulation technology was utilized for the new N-BOX as it had been for the FIT.

Figure 17 shows the study results from examination conducted during development of the new N-BOX. These results can be used in confirming the effectiveness of measures taken with regard to lateral displacement and yaw rate peak value. This kind of study enables simultaneous consideration of other performance elements as well as the discovery of effective measures to implement for them.

Figure 18 presents a graph showing the effectiveness of measures actually taken in various chassis components during development of the new N-BOX. This approach is effective for system design that advances the examination of specifications while taking into account the influence of the various chassis components on crosswind stability, and that ultimately finds the specifications that are able to achieve the objectives. In the present case of the new N-BOX, the objectives were achieved in terms of reduction in weight and design constraints by weight distribution, tire characteristics, suspension characteristics, aerodynamic characteristics, and other such factors. This indicated that

Table 2 Specification list (N-BOX)

	N-BOX
Length × Width × Height [m]	3.395 × 1.475 × 1.790
Wheelbase [m]	2.520
Track Front/Rear [m]	1.305/1.305
Weight [kg]	890

the developed simulation technology is able to allocate crosswind stability performance to each of the components at the stage of performance design for MBD of mass-production vehicles.

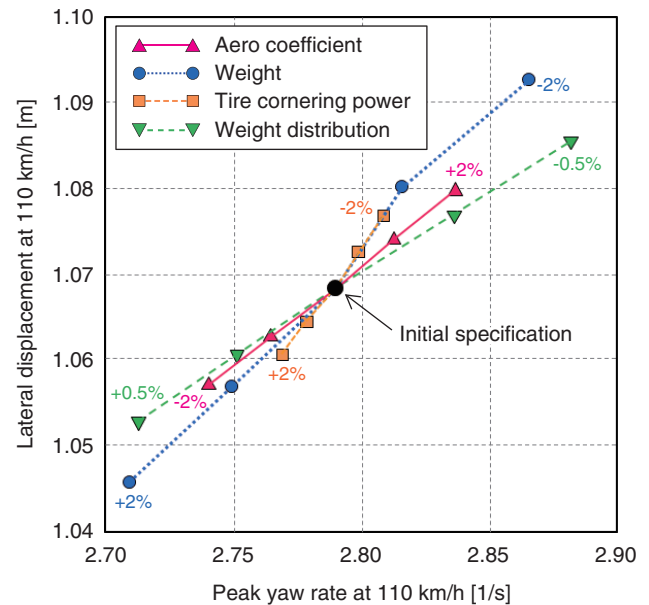


Fig. 17 Peak yaw rate and lateral displacement

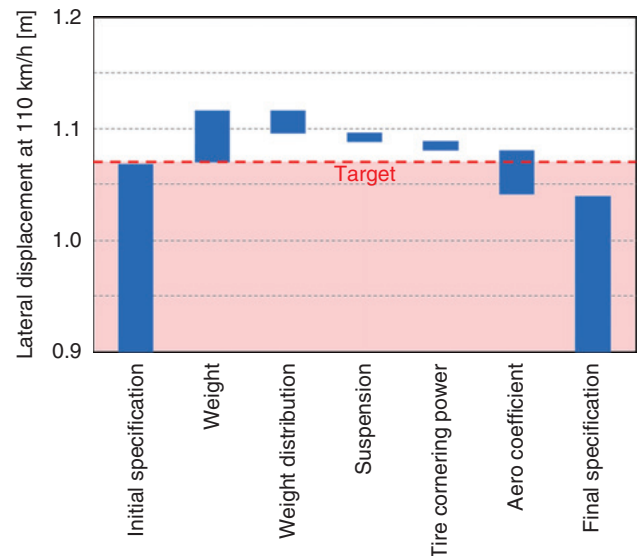


Fig. 18 Lateral displacement (N-BOX)

Figure 19 is a graph showing the extent to which the final specifications are dependent on vehicle speed where crosswind stability is concerned, as verified with an actual vehicle. Values below the criteria prescribed in standards were achieved in the interval between the two points of 80 km/h and 110 km/h, and the specifications for crosswind stability were determined accordingly. It was apparent that the developed simulation technology was useful in the development of a mass-production vehicle.

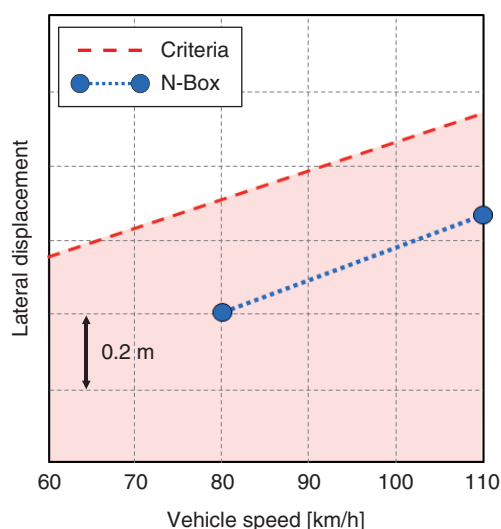


Fig. 19 Lateral displacement (N-BOX)

7. Conclusion

The developed simulation technology has enabled examination of specifications that include crosswind stability for performance design in MBD of mass-production vehicles.

- (1) A simulation technology was developed that can compute predicted crosswind stability utilizing the vehicle data used in MBD of mass-production vehicles.
- (2) The developed simulation method can yield computation results that are close to measurement values not only for lateral displacement, but also for yaw rate and yaw rate peaks.
- (3) It was verified that use of the half-continuous crosswind model could also enable the application of performance design for crosswind stability to the development of mass-production vehicles, in terms of computation time and computation accuracy.

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Degradation of Structure Strength by Welding Heat Effect for Hot-stamped Material

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ABSTRACT

The phenomenon where welding heat reduces the structure strength performance of hot-stamped materials used in automobile bodies was clarified. Tests using test pieces demonstrated that continuous welding methods, such as laser welding, that transmit heat over a wide range may reduce the structure strength performance compared to resistance spot welding. CAE analysis was performed to clarify the mechanism of this phenomenon. The material strength properties were obtained using micro tensile test specimens and applied to CAE models to reproduce the phenomenon where welding heat softens the area around the weld. The calculation results closely matched the test results, which showed that the drop in structure strength performance is due to material softening. In addition, the relationship between the material softening range and structure strength performance was investigated, and showed that softening of the welding flange area has a small effect, and softening of the hinge line areas has a large effect. This is because the hinge line areas bear a large share of the structural stress, and softening occurred in these areas. These results provided useful knowledge for future investigation of body structures and welding methods.

1. Introduction

High-tensile steel is increasingly used in automobile bodies to help secure strength for better crash safety performance and to reduce weight for better fuel efficiency performance. In particular, use of hot-stamped steel sheet materials with high tensile strength continues to expand rapidly^{(1), (2)}. The hot stamping method heats special steel sheets to approximately 900°C and then presses the sheets while at the same time rapidly cooling them with the die to achieve a tensile strength of 1500 MPa or more. Parts made by this method are used in many body frame members such as the front pillar, center pillar, and side sill to reduce cabin deformation and protect passengers in the event of a crash (Fig. 1)⁽¹⁾.

Meanwhile, there are reports that for high-tensile steel with strength in excess of around 780 MPa, welding heat softens the materials around the weld, reducing the weld strength⁽³⁾⁻⁽⁵⁾. Continuous welding, such as laser welding, is increasingly used to enhance body stiffness and crash safety performance⁽⁶⁾. Continuous welding transmits heat over a wide range, so it is thought that heat-induced softening will occur over a wider range when compared to resistance spot welding (RSW), which is

widely used in vehicle bodies. However, there are no reports known to date of this heat reducing the structure strength performance. Body structure strength is a key factor for body performance, so it is necessary to clarify this phenomenon and apply the knowledge to future development.

This study manufactured test pieces using hot-stamped materials welded by RSW, laser welding, and other methods, and then performed bending tests to clarify the

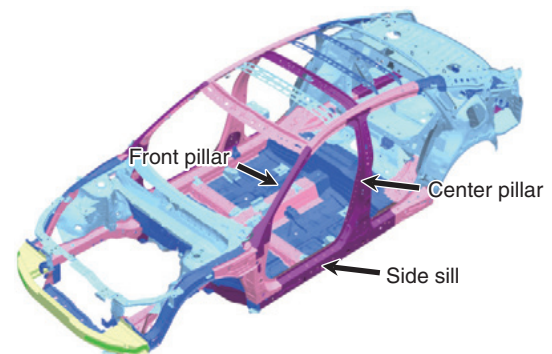


Fig. 1 Applicable parts made of hot-stamped material

* Automobile R&D Center

effects on strength performance. CAE was also used to model the micro strength properties of softening locations near welds to investigate factors reducing the strength. In addition, the relationship between the softening range and structure strength performance was clarified, locations exhibiting large drops in performance were identified, and these results were verified by tests using actual parts.

2. Clarification of Softening and Effect on Structure Strength Performance

Tests were performed using test pieces that simulate the frame to clarify the effect of welding heat on body strength performance. Parts that use hot-stamped materials are often used in body locations where bending deformation occurs in crashes. For this reason, evaluation was performed by bending tests.

2.1. Test Method

The test piece shape used a structure with two hat shapes stacked and welded together (hereafter, hat part) to simulate a typical center pillar section (Fig. 2). The materials were aluminum-plated steel for hot stamping, and Table 1 shows the mechanical properties after hot stamping. The thickness was 1.6 mm and the length was 1,000 mm. The flat part of the welding flange had a width of 16 mm.

Figure 3 shows each welding method. The three typical continuous welding methods of laser welding, arc welding, and seam welding were used. Comparison was performed using the commonly used 30 mm pitch RSW (hereafter, standard RSW) as the standard. In addition, comparison was also performed with 15 mm pitch RSW (hereafter, short pitch RSW), which is reported to have a high level of stiffness and strength⁽⁷⁾⁻⁽⁹⁾.

Figure 4 shows the bending test method. The entire circumference of the plate was welded to reduce hat part edge deformation during the bending test. The test conditions were three-point bending, indenter contact surface = R50, support jig contact surface = R30, and distance between supports = 700 mm. The indenter push-in amount was 200 mm, and the test speed was 10 mm/min.

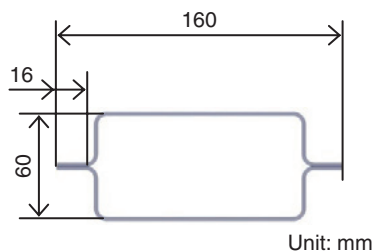


Fig. 2 Hat part section view

Table 1 Mechanical properties

	Measured value
Hardness (Hv)	494.3
Tensile strength (MPa)	1505.3
Yield strength (MPa)	1050.5
Elongation (%)	9.8

2.2. Test Results and Discussion

Figure 5 shows the test results. It was confirmed that weld fracturing did not occur for any test piece. Figure 6 shows the maximum reactive force and the absorbed energy. Compared to standard RSW, the absorbed energy was 1.5% higher for short pitch RSW, but was confirmed to be 5.5% lower for laser welding, 13.4% lower for arc

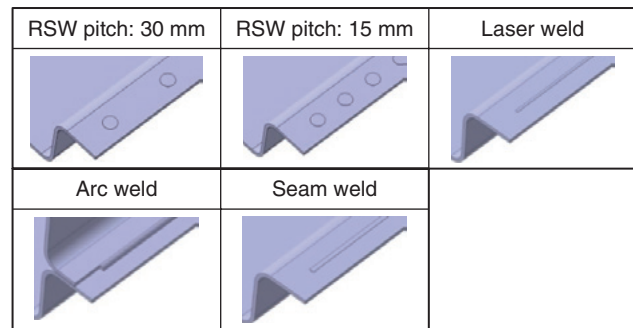


Fig. 3 Welding methods

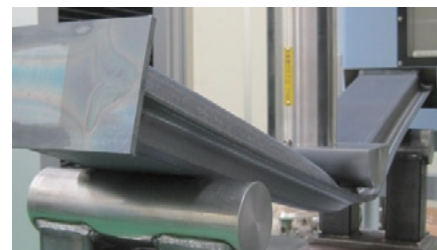
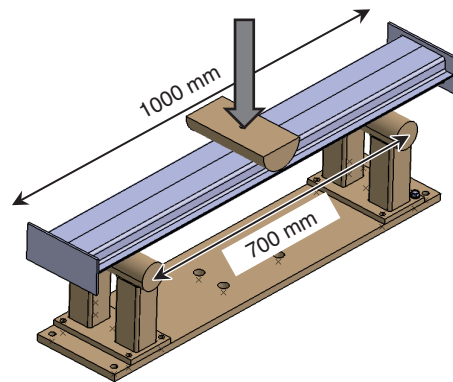


Fig. 4 Bending test specification

welding, and 7.0% lower for seam welding. This shows that the absorbed energy for continuous welding was lower than that for standard RSW in all cases.

The lower absorbed energy performance is presumed to be due to material softening as a result of the continuous welding heat. In addition, arc welding resulted in the lowest performance, which is thought to be because in addition to the heat effect, the joint is a lap fillet and the side to be welded has a short flange.

Hardness tests were performed in and around the areas melted by welding heat and then solidified by cooling to verify the material softening state. Figure 7 shows the results. The hardness of the base material before welding was approximately 500 Hv, and softening was confirmed to occur with each welding method. Standard RSW has a narrow softening range, and softening was confirmed over a wide range from the end of the flange, and including the hinge line areas for the continuous welding methods.

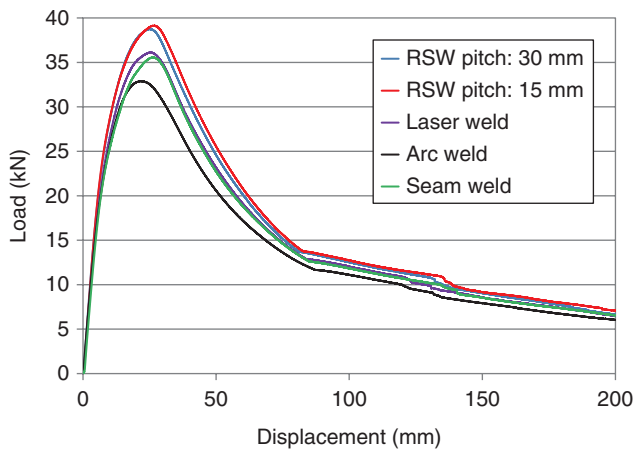


Fig. 5 Results of bending test

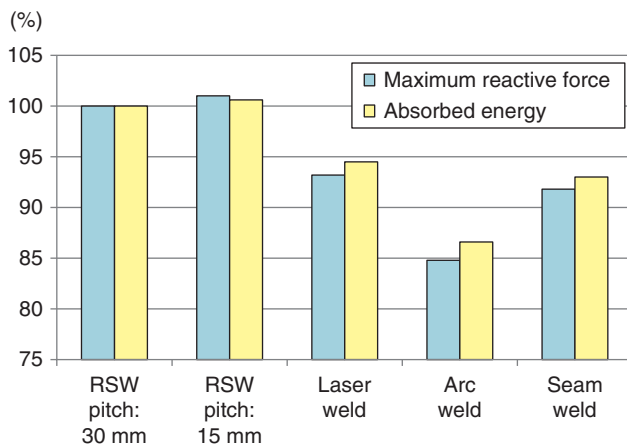


Fig. 6 Results of maximum reactive force and absorbed energy (compared to RSW pitch: 30 mm)

Therefore, specimens were cut from around the test piece welds and micro tensile tests were performed to clarify the tensile strength properties in the softening range. Figure 8 shows the specimen shape. Figure 9 shows the positions where the specimens were cut from the laser welded test piece, and Fig. 10 shows the test results. Reduced material strength compared to the base material was confirmed around the melt-solidified area and in the heat-affected zone.

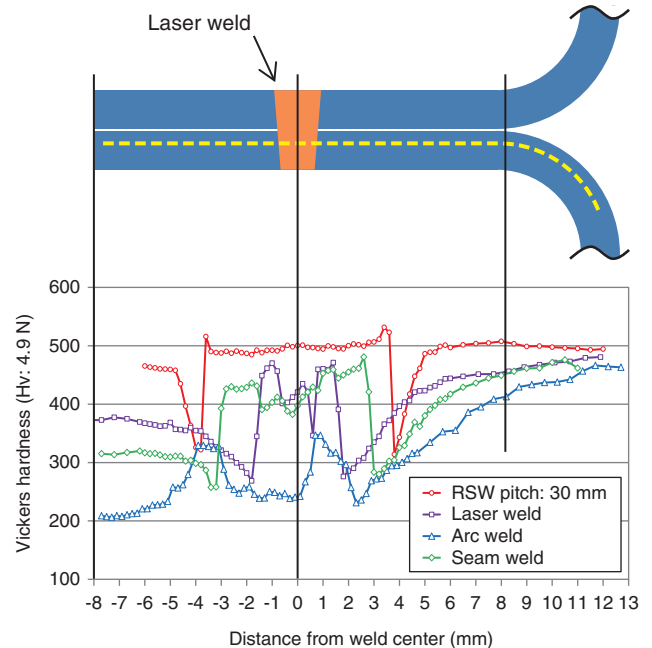


Fig. 7 Hardness test results

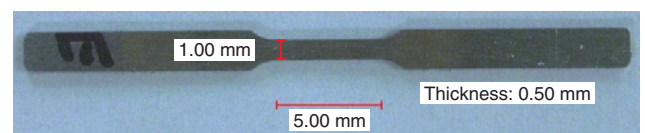


Fig. 8 Dimensions of micro specimen

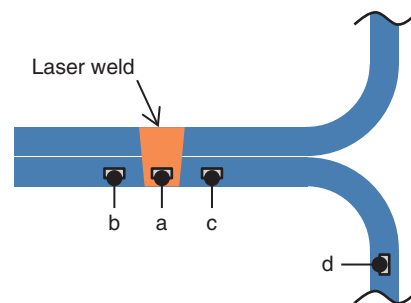


Fig. 9 Locations of micro specimens

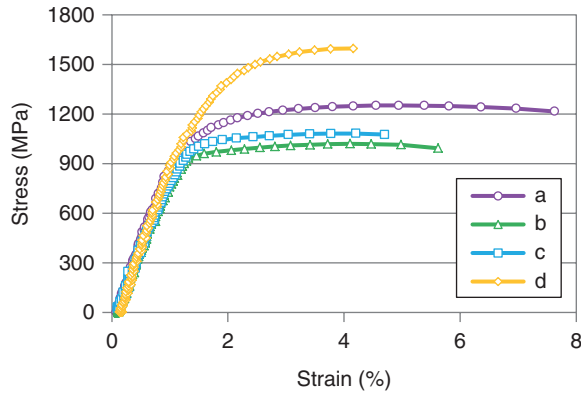


Fig. 10 Micro tensile test results (stress-strain curves)

3. Clarification of Mechanism Using CAE

The structure three-point bending test was modeled using structural analysis CAE to clarify the mechanism of reduced structure strength performance due to material softening by welding heat effect. Models were created for each of the five welding methods used to manufacture the test pieces, and verification was performed.

3.1. Analysis Model

First, the stress-strain curves of the plastic regions were modeled so that the micro tensile test results (Fig. 10) of the specimens cut from the test pieces could be used in structural analysis CAE. The yield stress was determined using 0.2% proof stress. A Young's modulus of 205.8 GPa and a Poisson's ratio of 0.3 were used.

Figure 11 shows the analysis model. This model expresses the hat part as a solid and the jigs as completely stiff surfaces. The boundary conditions all used a friction coefficient of zero. The structure was expressed using a square mesh with the sizes shown in Table 2. The mesh size is reduced in the 30 mm range, greatly deformed by contact with the indenter and the surrounding 75 mm range (Fig. 12).

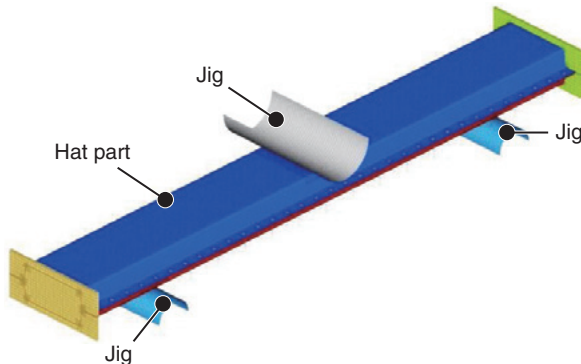


Fig. 11 CAE model

Table 2 Mesh size

Unit: mm

		Longitudinal direction	Lateral direction
Substrate	Low strain	3.75	5.12
	High strain	1.87	2.56
	Super-high strain	1.25	2.56
Joining area	Spot weld	3.00	
	Laser weld	3.75	0.50
	Arc weld	3.75	0.80
	Seam weld	3.75	0.80

Figure 13 shows the models of the structures made by using each welding method. Welding was reproduced by setting a 0.1 mm gap between the upper and lower hat part pieces and joining the welded areas across the gap.

Figure 14 shows the ranges where material softening was applied to the models for each welding method (hereafter, softening models). Modeling was performed with the softening range set based on the hardness test results (Fig. 7). The tensile strength values in each location used the values obtained from the micro tensile tests. For comparison of calculations, analysis was also performed using the same models without any softening locations (hereafter, non-softening models).

The ABAQUS explicit method was used as the solver.

3.2. CAE Analysis Results and Discussion

Figure 15 compares the results for the standard RSW test and the CAE model analysis. The results from load rise until the maximum reactive force is reached and the decreasing trend thereafter match closely, with a difference in absorbed energy of 1.6% or less.

Evaluation was performed using the absorbed energy for each welding method model to verify the softening model results. Figure 16 compares the results of tests using test pieces with the CAE results. The softening models

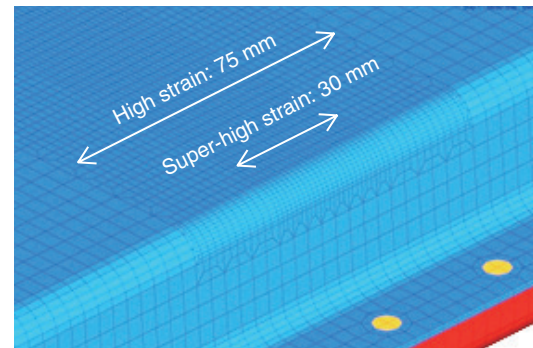


Fig. 12 CAE model detail

were confirmed to produce values close to the test values. In case of laser welding, the absorbed energy of the non-softening model was 7.7% higher than the test value, but the difference for the softening model was just 2.7%. In

	Joint shape	Joint width	Image
RSW pitch: 30 mm	Circular	ϕ 6 mm	
RSW pitch: 15 mm	Circular	ϕ 6 mm	
Laser weld	Rectangular	1.6 mm	
Arc weld	Quarter cylindrical	1.7 mm	
Seam weld	Rectangular	1.0 mm	

Fig. 13 Joint CAE models

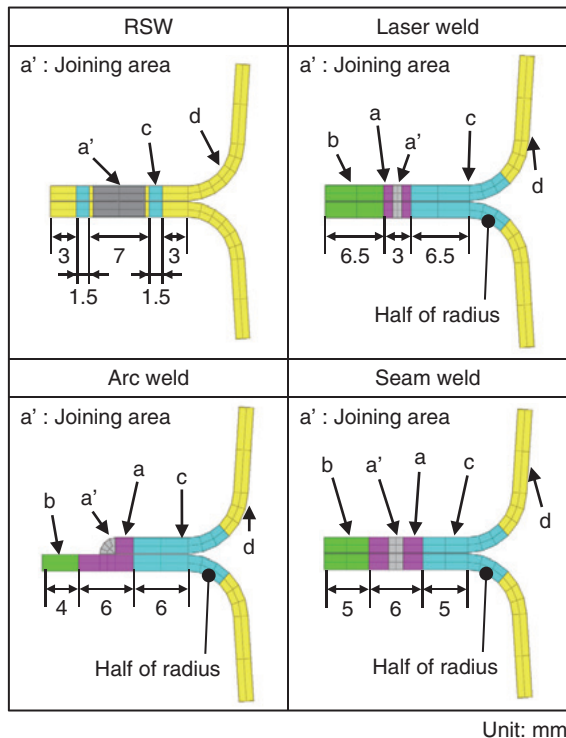


Fig. 14 CAE softening models

addition, the absorbed energy for short pitch RSW was higher than that for standard RSW, but was confirmed to correlate with the test values.

Figure 17 shows the stress distribution for a 100 mm stroke. The non-softening model in Fig. 17(a) exhibits high amounts of stress distributed widely around the welding flange. In contrast, the softening model in Fig. 17(b)

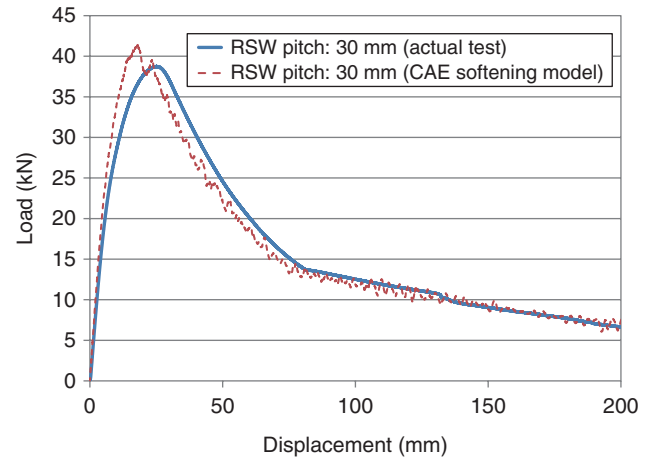


Fig. 15 Results of actual test and CAE softening model

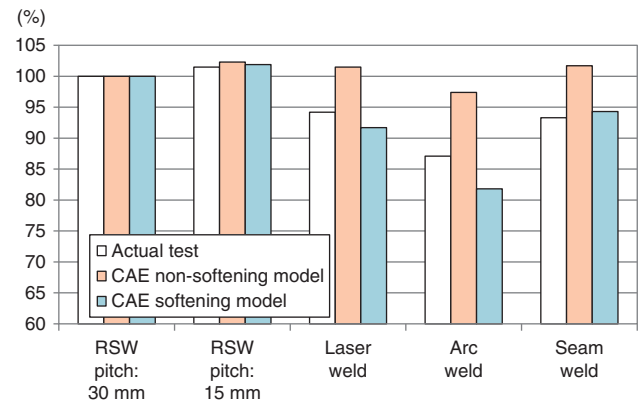


Fig. 16 Results of absorbed energy (compared to RSW pitch: 30 mm)

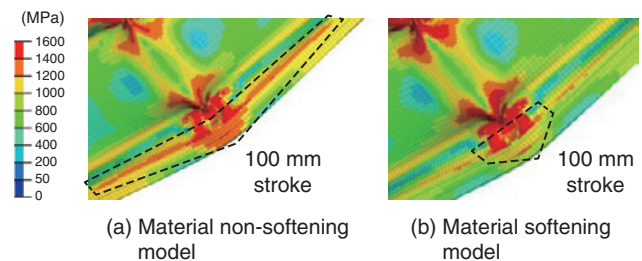


Fig. 17 Stress distribution

exhibits lower amounts of stress concentrated narrowly around the welding flange. This is because the plastic deformation around the welding flange proceeded under low stress. In this manner, stress concentrated around the indenter contact area in the condition with low stress around the welding flange, which resulted in lower absorbed energy.

These results clarified the mechanism of material softening by welding heat, resulting in lower reactive force and lower absorbed energy. In addition, this showed that structure strength performance can be predicted by modeling the strength properties for each heat-affected zone.

3.3. Clarification of Relationship between Softening Range and Structure Strength

Next, the effect of the softening range on the reduction of absorbed energy was investigated. The bending input does not produce a uniform stress distribution in the flange (welding location) and surrounding area as shown in Fig. 17. Therefore, the relationship between the material softening range and structure strength performance was investigated to identify the range over which heat-softening has a large strength performance reduction effect. The laser welding analysis model was used to create five different structure softening ranges for analysis, as shown in Fig. 18.

Model A is the non-softening model, and model B has softening in the outer half of the flange softened. Models C, D, and E have gradually wider softening areas as compared to model B.

Figure 19 shows the relationship between the softening area and the absorbed energy. The absorbed energy for condition C was just 2.4% less than that for the non-softening model A. However, when the hinge line area also softens such as in conditions D and E, the absorbed energy drops rapidly, and results were 9.4% lower for condition D, and 10.2% lower for condition E. The absorbed energy is almost the same for conditions D

and E, so it is thought that of the hinge line areas, much of the energy was absorbed by the flange corner part. Figure 20 shows the stress distributions for 50 mm and 100 mm strokes in condition A. At a stroke of 50 mm, the stress is widely distributed on the hinge lines around the indenter, and there is little stress on the flange part. At a stroke of 100 mm, the stress distribution is even wider in the hinge line areas, but there is little change in the flange area stress.

These results are thought to indicate that a softening of the hinge line areas that bear a large share of the stress had a large effect on the drop in absorbed energy. Therefore, it is thought that the drop in the energy absorbed by a structure can be reduced by suppressing softening of the hinge line areas.

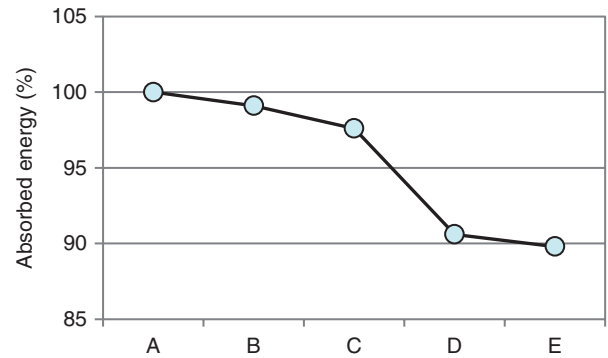


Fig. 19 Relationship between softening area and absorbed energy

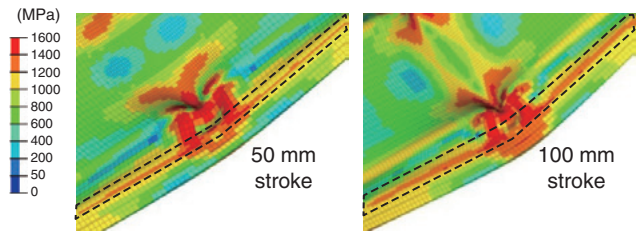


Fig. 20 Stress distribution at weld for condition A

Condition	A	B	C	D	E
Flange softening area	0%	50%	100%	100%	100%
Hinge line softening area	0%	0%	0%	50%	100%
CAE model					

Fig. 18 CAE softening model conditions

4. Development of Method for Suppressing Drop in Absorbed Energy

Tests using test pieces were performed to investigate the welding conditions in order to suppress heat softening of the hinge line areas. Faster welding speeds generally reduce the temperature rise around the weld. Therefore, increasing the laser welding speed was investigated. Simply increasing the speed lowers the welding quality, so the laser power was adjusted to achieve the same melting width. Table 3 shows the welding conditions. Condition 1 is the same condition

Table 3 Laser welding conditions

Condition	1	2	3
Welding speed (m/min)	1.0	2.5	8.0
Laser power (kW)	3	6	10

as in the previously investigated tests, and conditions 2 and 3 have faster welding speeds.

Figure 21 shows the bending test results. The absorbed energy was confirmed to rise for conditions 2 and 3, which have faster laser-welding speeds.

The surface temperatures of the hinge line areas were measured during welding to understand the heat transmission. Figure 22 shows the measuring point, and Fig. 23 shows the results. Compared to condition 1, the hinge line area was confirmed to have a lower temperature for conditions 2 and 3 with faster welding speeds. In addition, Fig. 24 shows the hardness test results around the weld location. This confirmed that the drop in hardness decreased and the range over which the hardness dropped was also narrower at lower temperatures.

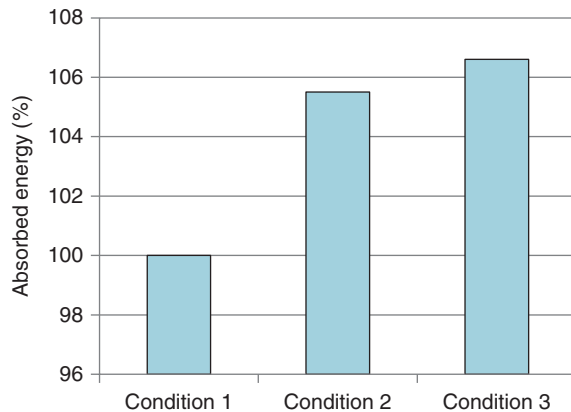


Fig. 21 Absorbed energy

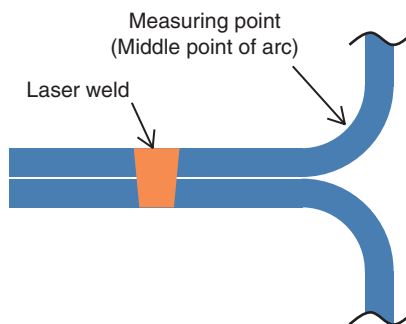


Fig. 22 Temperature measuring point

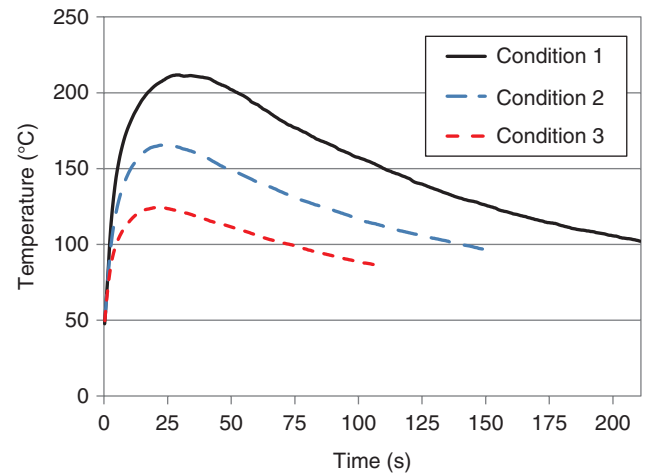


Fig. 23 Temperature history at middle point of arc

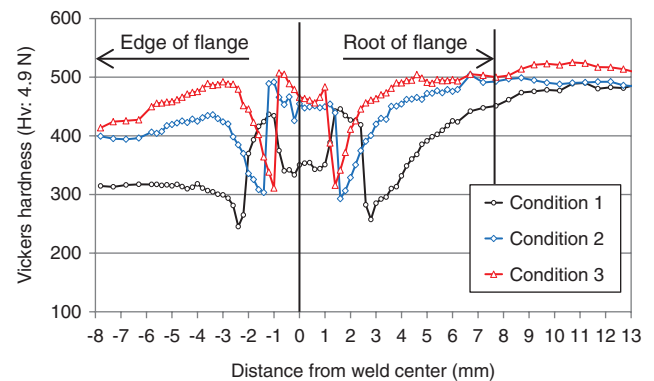


Fig. 24 Hardness test results of laser weld

5. Conclusion

The factors reducing strength due to welding heat in structures using hot-stamped materials was clarified, and the following conclusions were reached.

- (1) The mechanism of welding heat softening hot-stamped materials and resulting in lower absorbed energy was clarified.
- (2) CAE analysis was used to apply strengthening properties when material softening occurs to CAE models, which enabled prediction of structure strength performance.
- (3) Softening of the hinge line areas that bear a large share of the structural stress has a large reduction effect on structure strength performance.

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Development of New US Evaluation Course in Takasu Proving Ground

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ABSTRACT

An evaluation course was newly developed at the Takasu Proving Ground in Hokkaido to verify the compatibility of new type vehicles for the North American market with local road conditions. The driving states and ratio of occurrence on the evaluation route in the US were analyzed, and a course layout that aggregates sections with similar characteristics was created. The new course reduced the driving distance from 35 km to 16 km while maintaining the same driving feel. This shortened the driving time, from approximately 60 minutes for the evaluation route in the US, to 15 minutes. In addition, a paving method that uses a special jig to create surface undulation was devised, designing and constructing the undulating road surface with small amplitude as well as short wavelength needed to reproduce the ride comfort. This enabled to reproduce the body vibration that is an issue when driving in the US. These results realized a US evaluation course in the Takasu Proving Ground that enables verification of the driving feel unique to US road conditions in a short time.

1. Introduction

Honda opened its first test course in 1958, and then established the Tochigi Proving Ground (Tochigi PG) in 1979 to handle an increasing amount of function tests. In addition, the Takasu Proving Ground (Takasu PG) established in Hokkaido in 1990 gathered together the previously scattered cold weather test sites and expanded the range of vehicle safety and functionality that can be verified in a safe testing environment (Fig. 1).

The Tochigi PG contains courses such as an oval course for verifying the safety of vehicles driving at high speeds and a winding course for verifying handling performance under various conditions, from racing circuits to winding mountain roads. These courses help forge the structure of Honda vehicles and contribute to the development of Honda vehicles.

The Takasu PG contains courses that help meet the increasing demand for function tests at the Tochigi PG, and a high-speed oval course was established in 1995 to help safely confirm vehicle functionality during high-speed driving, such as on the German Autobahn. In addition, various test environments, such as an EU suburb course that simulates ordinary European suburban roads, have

been constructed since 2000 enabling evaluation of safety, functionality, and also vehicle performance in customer operating environments. These courses have been utilized to test Honda vehicles since the first-generation Fit.

Ongoing vehicle development has seen the development of simulation technology that aims to shorten development periods in the initial stages^{(1), (2)}. This has increased prediction accuracy for basic performances related to safety, stability, and comfort, which has reduced demands for additional courses.

However, demands are increasing for courses that enable evaluation of combined powertrain and handling performance, such as a cornering course that includes the ups and downs found on ordinary roads. In addition, control devices that enhance vehicle characteristics such as stability, responsiveness, and ride comfort, Advanced Driver Assistance Systems (ADAS), and devices for realizing autonomous drive are also being implemented in vehicles, so expectations are increasing for courses needed for verification of control systems.

When evaluating combined performances and vehicles that implement multiple advanced devices, the integrity of the completed vehicle and the passenger feel are key items. However, it is a challenge to perform all verifications using

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only the courses constructed so far.

In addition, there are many development models for North America and a high degree of maturation is demanded for each model, so verification on local roads takes much time.

Therefore, a new course was created in the Takasu PG that helps enable local testing of development models for North America to be performed in Japan. This report introduces this newly developed US evaluation course.

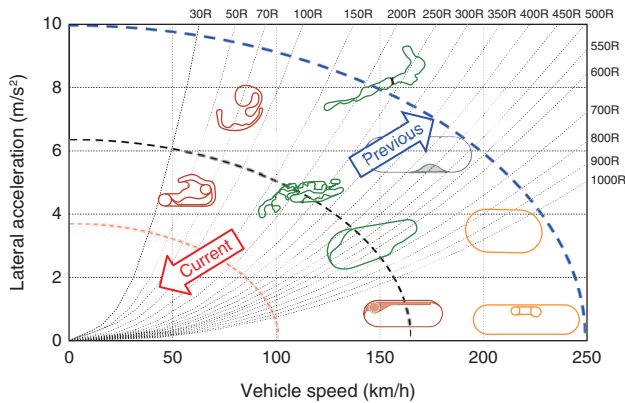


Fig. 1 Demand for test course development

2. Goals

A US evaluation course that achieves the following goals was newly established in the Takasu PG as a substitute for local tests of North American models.

- (1) A course layout that can be constructed within the PG site while reproducing the characteristics of the evaluation route in the US
- (2) A course that enables evaluation of combined performance and ride comfort, which are issues when driving in the US

3. Characteristics of Evaluation Route in US

Local verification of mass production models for the North American market is performed using a route starting from the Honda R&D Americas, Inc. in Los Angeles that is approximately 35 km long and takes around 60 minutes to drive. This route can be classified into four areas, City, Hill, Suburb, and Freeway, each with greatly differing characteristics.

The City area consists of a succession of straight road sections, except for intersections, and the vehicle speed is slow but frequent acceleration and deceleration are needed. The Hill area has curves with ups and downs and a small turning radius that needs to be driven at a faster speed than that in the City area. The Suburb area consists of straight road sections with many ups and downs that need to be

driven at a constant speed equal to that in the Hill area. The Freeway area has straight road sections and curves with no ups and downs, and a large turning radius that need to be driven at high speed.

Figure 2 shows typical views of these four areas.

Figure 3 shows an example of the change in vehicle speed when driving in the actual traffic flow.

Next, Fig. 4 shows the results of further dividing these classification areas into sections with similar characteristics and comparing the relationship between the turning radius and the road longitudinal slope in each section. In this figure, the circle size represents the distance of sections with the same characteristics, and the inverse of the turning radius is used so that straight road sections are zero. This figure quantitatively expresses the characteristics of the four areas described above, and the slope and turning radius were confirmed to vary greater in the Hill area compared



Fig. 2 Specific views of evaluation route in US

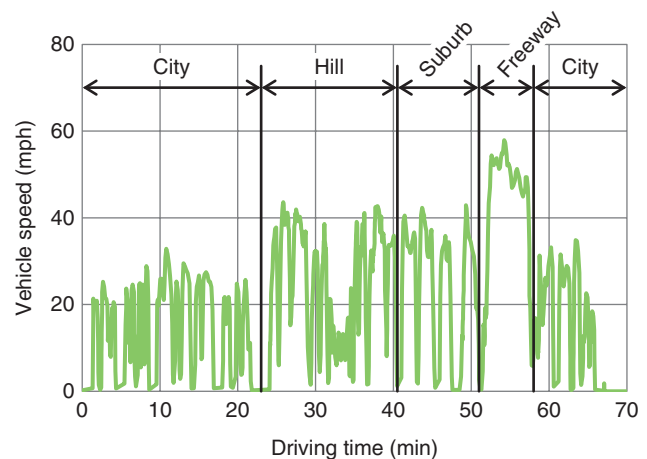


Fig. 3 Vehicle speed during evaluation route driving

to the City, Suburb, and Freeway area. This showed that it is necessary to reproduce a turning course with ups and downs to evaluate combined power train and handling performance.

Next, Fig. 5 shows an example of seat vibration, which is an issue for ride comfort, while driving the suburb area in the US.

Comparison of comments by development experts and measurement results revealed that reproduction of the vibration level in the frequency range from 10 Hz to 20 Hz is considered necessary to reproduce the ride comfort feel during the drive in suburb area.

Road surface undulation that affects ride comfort performance can generally be expressed by the wavelength in the direction of travel and the amplitude in the height direction as shown in Fig. 6.

The input frequency from the road surface to the tires varies depending on the vehicle speed. This makes it necessary to understand the vehicle speed and the body vibration level when determining the course road profile in order to reproduce the ride comfort vibration of the evaluation route in the US.

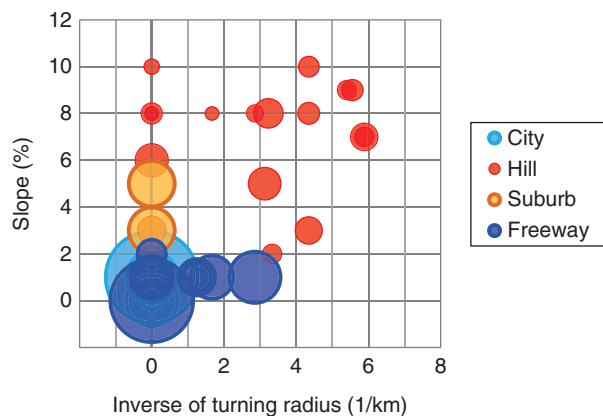


Fig. 4 Characteristics of each divided section of evaluation route in US

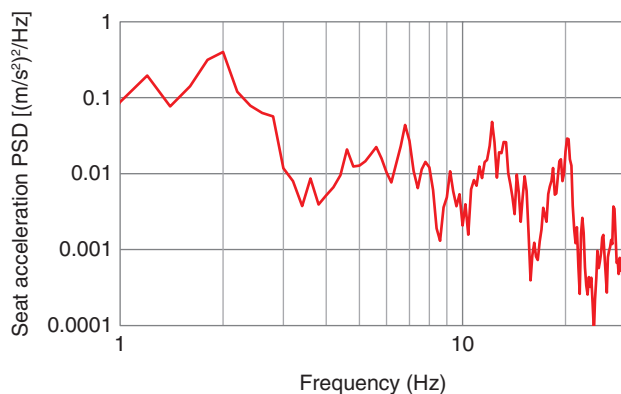


Fig. 5 Seat vibration during suburb area driving

Therefore, the road profile of the evaluation route in the US was measured to reproduce the ride comfort vibration that is an issue when driving in the US. Figure 7 shows the average wavelength and amplitude of the measured road surface for each of the four areas^{(3), (4)}. These results show that even when the road surface looks flat, such as in Fig. 2, each area of the US route has undulation with a shorter period and larger amplitude than that of a typical test course or a Japanese expressway.

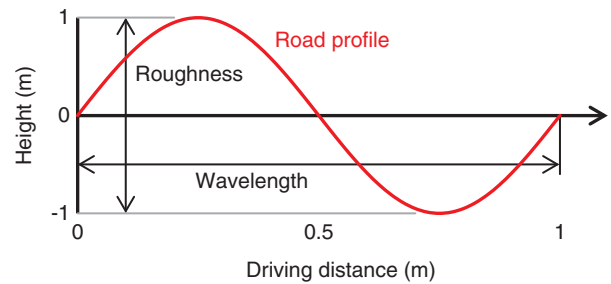


Fig. 6 Definition of pavement roughness

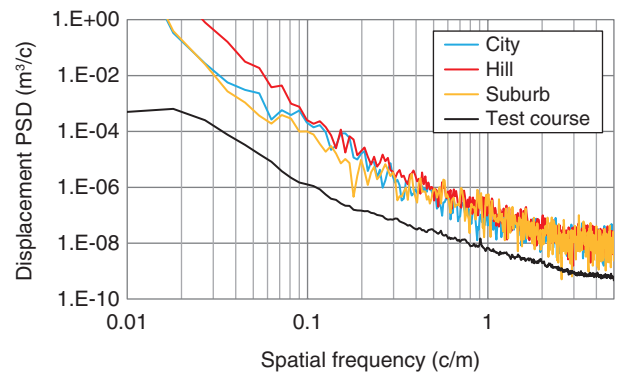


Fig. 7 Pavement roughness of evaluation route in US

4. New US Course Design

The new US course was laid out using part of the existing courses and some sloped land adjoining the Takasu PG (Fig. 8).

4.1. Planar Layout Design

The course design was based on the characteristics of the evaluation route in the US shown in Fig. 4. It was found that part of the existing high-speed oval course could be driven in place of the Freeway course. However, there were no existing courses corresponding to the City and Suburb areas, so these were newly created within the existing PG area. The existing PG area did not have an elevation difference like that of the evaluation route in the US, so some sloped land adjoining the existing site was newly developed to create the Hill course.

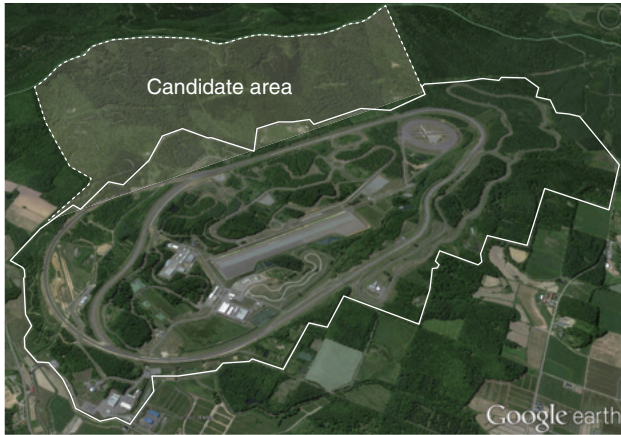
Figure 9 compares the Hill course characteristics of the evaluation route in the US and the PG course. This figure shows that in terms of the relationship between the turning radius and slope, the PG course reproduces characteristics resembling those of the evaluation route in the US.

In addition, the course layout enables to efficiently cruise through the City, Hill, Suburb, and Freeway courses while maintaining the same characteristics distribution ratio as that of the evaluation route in the US. This enabled to shorten the driving distance from 35 km for the evaluation route in the US to 16 km.

4.2. Road Profile Design

In order to reproduce the ride comfort of the evaluation route in the US, the road profile was designed while taking into account the difference in quality requirements when constructing ordinary roads and test courses^{(5), (6)}. Table 1 gives an overview of quality requirement standards for ordinary roads and test courses.

Figure 7 shows that the evaluation route in the US includes many undulation components with a wavelength



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Fig. 8 Candidate area for new US evaluation course

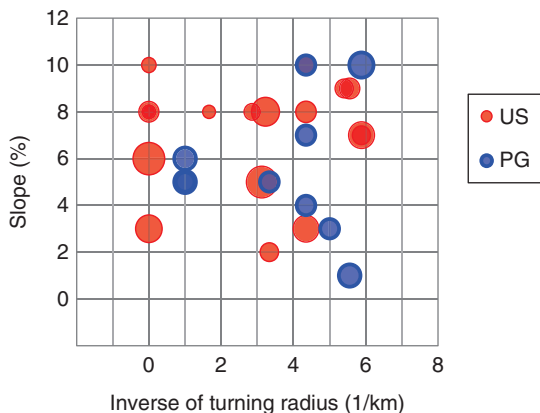


Fig. 9 Comparison of hill course characteristics

Table 1 Quality requirements for road construction

	Public road	Test course	
		High speed oval etc.	Ride road
Purpose	Driving safely for all cars under the law	Testing vehicles safely and stably at high speed	Evaluating vehicle vibration stably for a long period
Function	Stability, durability		
	Flatness	Flatness Surface strength Friction stability	Surface profile Wave length Amplitude
Quality requirement	Height, thickness, width, compaction density etc.		
	Flatness Friction	Flatness, Friction (High grade)	Road roughness Spatial frequency
Validation	Variance (± 2 mm)	—	Tolerance (± 1 mm)
Road structure	Surface course	Spread and leveled pavement made of asphalt mixture	
	Base course		
	Upper sub-base	Spread and leveled pavement made of asphalt mixture or crashed stone for mechanical stabilization	
	Lower sub-base	Spread and leveled structure made of crashed stone for mechanical stabilization	
	Anti-frost layer (Cold region)	Spread and leveled structure made of crashed stone	
	Subgrade	Leveled structure made of shaped soil	

around 1 m and an amplitude of ± 2 mm or less. However, the ordinary road standard allows an amplitude variance of approximately ± 2 mm as shown in Table 1, so it is a challenge to accurately reproduce the road surface shape of the evaluation route in the US.

4.3. Verification of Road Profile Design Values

The validity of the road surface amplitude to be used as the design value was verified by bench vibration tests to confirm the road surface wavelength and amplitude reproduction accuracy needed to reproduce the ride comfort vibration of the evaluation route in the US. Figure 10 shows the measured body vibration when driving on the evaluation route in the US, the results when vibrated using the road profile obtained by measurement, and the results with the vibration level corrected.

These results show that when reproducing the body vibration of the evaluation route in the US, it is necessary to accurately reproduce the amplitude to within ± 1 mm, which is smaller than the road surface amplitude obtained

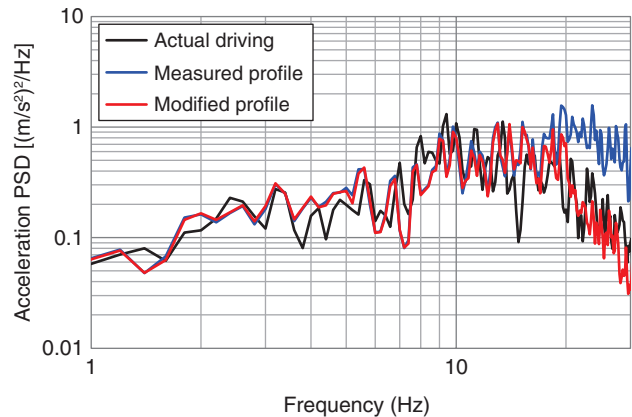


Fig. 10 Road profile correction by 4 poster testing

by surveying, in order to reproduce ride comfort vibration of 10 Hz or more.

5. Reproduction of Undulation with Short Wavelength and Small Amplitude

As described above, it is a challenge to accurately create undulation with the wavelength around 1 m and an amplitude of ± 1 mm needed to reproduce ride comfort using road construction methods for ordinary roads that emphasize flatness. Therefore, a method called three-dimensional paving was devised and applied to accurately reproduce the intended wavelength of around 1 m and an amplitude of ± 1 mm. This method consists of driving an asphalt finisher along guides on guide rails with a wavy shape in the normal surface paving method that emphasizes flatness (Fig. 11).

This method enabled accurate reproduction of the short wavelength and road surface amplitude design values needed to reproduce ride comfort as shown in Fig. 12.



Fig. 11 Proposed surface paving method

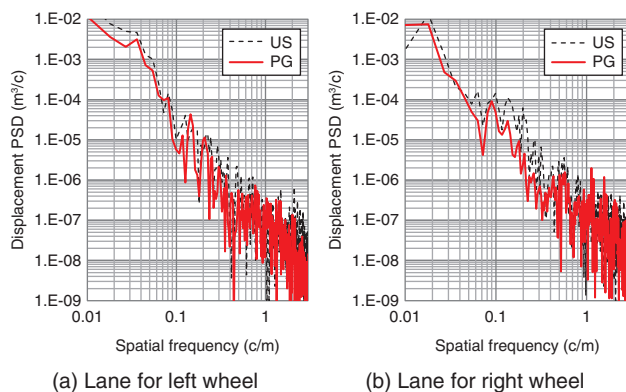


Fig. 12 Comparison of pavement roughness of suburb course

6. Verification Results

Figure 13 shows an overview of the completed new US course. From the starting point, the course enters a City course newly developed on the inside of the high-speed oval course. After finishing the City course, the newly developed Hill course can be accessed via a connecting road through a tunnel under the high-speed oval course, as indicated by the arrow in the figure. The Hill course is entered from the middle and forms a route with U-turns at both ends. The Suburb course newly developed on the outside of the high-speed oval course can then be accessed from the Hill course via a connecting road, and a new entry lane has been made enabling entrance to the high-speed oval course used as the Freeway course from the Suburb course while maintaining the vehicle speed.

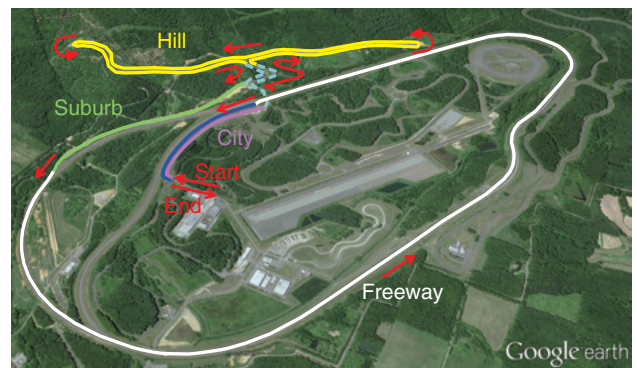
This new US course enables vehicles to drive through the four areas shown in Fig. 2 in the same order as the evaluation route in the US shown in Fig. 3. However, the overall distance is shortened from approximately 35 km from the route in the US to 16 km, and the acceleration, deceleration, and stopping ratios of occurrence are also reduced. This enabled to shorten the driving time from approximately 60 minutes for the evaluation route in the US to 15 minutes.

The driving results for the evaluation route in the US and the newly established evaluation course were compared to verify the reproducibility of the US road driving feel.

Figure 14 shows the relationship between the lateral acceleration and the yaw rate while driving. As shown in this figure, the relationship between the lateral acceleration and the yaw rate while driving on the new US evaluation course exhibits the same slope as that for the evaluation route in the US, which confirmed that the planar layout of the test course has the same characteristics as those of the evaluation route in the US.

Figure 15 compares the seat vertical vibration during Suburb driving, which is an issue for the ride comfort feel.

This figure shows that the vertical vibration level while driving on the new US Suburb course matches that for the



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Fig. 13 Overview of new US evaluation course

evaluation route in the US in the target frequency range of 10 Hz to 20 Hz. This confirmed that the test course road profile reproduces the ride comfort feel characteristics of the evaluation route in the US.

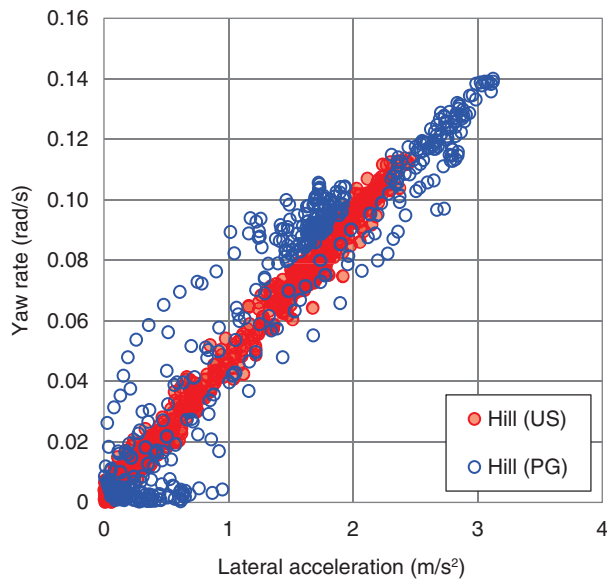


Fig. 14 Comparison of lateral acceleration and yaw rate

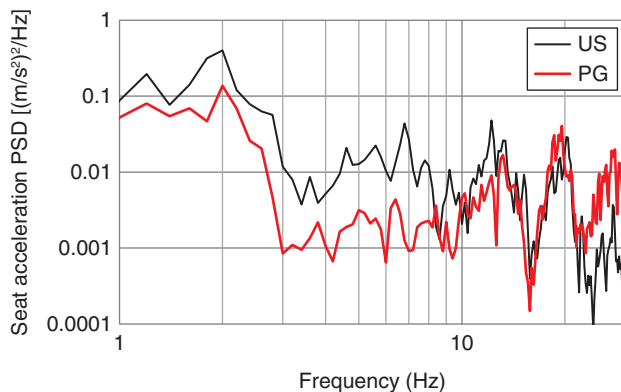


Fig. 15 Comparison of seat vibration during suburb course driving

7. Conclusion

A new US evaluation course was developed in the Takasu PG that enables performance of the same verification as local tests of North American models, and in a shorter time than when using the evaluation route in the US.

- (1) The course layout could be constructed within the PG site by shortening the length from 35 km for the evaluation route in the US to 16 km while maintaining the same characteristics distribution ratio as that of the evaluation route in the US for each of four areas. This enabled to

shorten the driving time from approximately 60 minutes for the evaluation route in the US to 15 minutes.

- (2) The characteristics of the evaluation route in the US were reproduced in the relationship between the turning radius and the longitudinal slope, enabling evaluation of combined performance. In addition, a course surface paving method was devised to construct the target road surface undulation with a wavelength of 1 m and amplitude of ± 1 mm, enabling evaluation of ride comfort.

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Development of Gap Mold Technology for RTM of CFRP Parts

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ABSTRACT

A mold structure making it possible to conduct gap resin transfer molding (RTM), a method that reduces the internal pressure of the mold during molding of carbon fiber reinforced plastics (CFRP) parts, using standard hydraulic pressing equipment with no position control function has been developed. Gas springs have been employed in order to maintain the necessary fixed gap in the mold from the vacuum process to the resin injection process. In addition, a specialized seal shape able to withstand both the negative pressure produced during the vacuum process and the positive pressure produced during the resin filling process was also developed. The results of gap RTM using a mold applying these technologies demonstrated that they made it possible to both realize reduced internal mold pressure and produce a good quality molded part even in the case of a large part (a lower dashboard).

1. Introduction

Today, the realization of increased automotive fuel efficiency is an urgent task as a means of responding to environmental issues. The achievement of automotive weight savings is a focus of attention as one method of increasing fuel efficiency. The use of carbon fiber reinforced plastics (CFRP), which are lightweight and high-strength materials, has been taken up as a means of realizing this goal. However, manufacturing costs are high for CFRP parts, not only due to the cost of the materials, but also because the molding cycle time may be from several minutes to several hours. Due to this, the application of CFRP has been restricted to small-lot parts for use in such applications as racing cars and airplanes, in which light weight is demanded even if it entails high costs. In order for the material to be applied in automotive parts, a manufacturing method making it possible to supply parts in high volume at low cost would be necessary⁽¹⁾. Resin transfer molding (RTM), which is capable of continuous molding and offers a variety of choices in terms of shape, provides prospects as one such method.

Figure 1(a) shows an overview of the resin transfer molding process^{(1),(2)}. First, preformed sheet fibers are set in a metal mold. A vacuum is generated in the mold in order to promote resin impregnation and help control the occurrence of air voids. Next, liquid resin is injected into the mold and

impregnated into the fibers. Following heating and curing, the product is removed from the mold. Methods of reducing RTM cycle time in order to reduce costs are available. Increasing the speed of resin injection during the molding process is one such method. However, high-speed injection of resin into a closed mold increases the internal pressure of the mold, making it necessary to employ specialized equipment capable of high-pressure resin injection⁽³⁾. In addition, as parts become larger, the injection pressure increases, and the load required for pressing also increases. As this indicates, the capabilities demanded from injection equipment and pressing equipment increase equipment costs, and it is challenging to realize cost-effectiveness when reducing RTM cycle time.

Against this background, gap RTM has been proposed as a method of reducing the internal pressure of the mold^{(4),(5)} [Fig. 1(b)]. In the gap RTM process, resin is injected with a gap set between the upper and lower molds. The fibers are impregnated with resin during the pressing process, and the entire mold is filled. Even if high-speed injection is performed using this method, the internal pressure of the mold does not increase, and RTM cycle time can therefore be shortened even for large parts. However, it is necessary to control the size of the gap when using this method, and this necessitates the use of high-cost equipment capable of position control, for example servo-press equipment. It was considered that equipment costs could be reduced if it were

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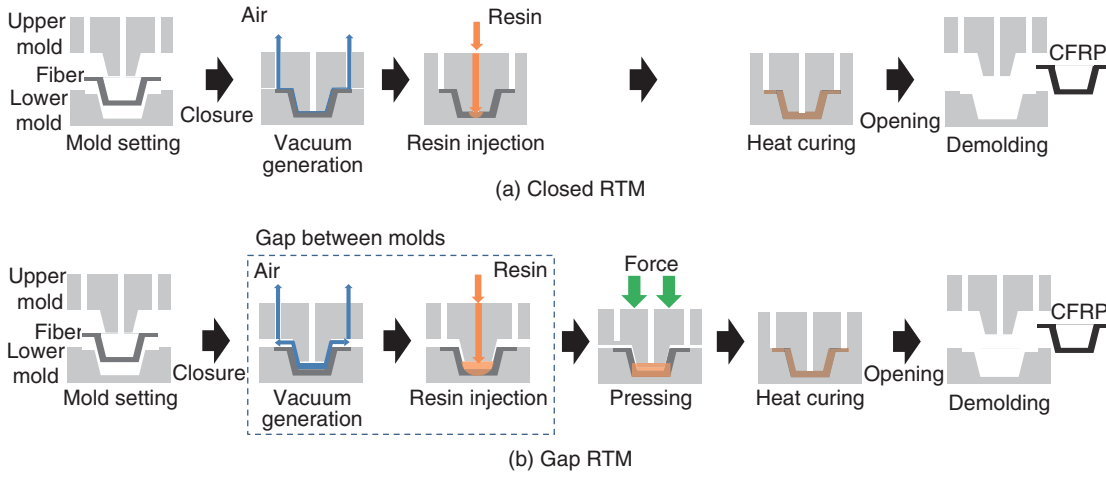


Fig. 1 RTM process

possible to implement gap RTM using hydraulic pressing equipment employed in conventional resin molding.

This paper reports on a mold technology that reduces the internal pressure of the mold during gap RTM by using conventional equipment.

2. Concept of Manufacturing Method

In the conventional RTM process, resin is injected into a mold in which preformed sheet fibers have been set. These fibers resist the flow motion of the resin. The creation of a space for the flow of the resin eases this resistance, reducing the pressure in the mold. Based on this concept, it was considered that the application of gap RTM would make it possible to reduce the resin injection period.

The relationship between resin flow velocity and pressure can be expressed as Eq. (1), based on the Hagen-Poiseuille law, which applies to the flow of viscous fluids through cylindrical pipes of fixed diameter.

$$Q = (\pi a^4) / 8 \times \Delta P / \mu l \quad (1)$$

Q : Flow rate; a : Pipe radius; ΔP : Pressure gradient; μ : Fluid viscosity; l : Pipe length

If the injection flow rate per unit time, Q , is increased in order to reduce molding time, the pressure gradient, ΔP , increases as shown in Eq. (2).

$$\Delta P / l = Q \times \mu \times 8 / \pi a^4 \quad (2)$$

The pressure gradient is proportional to viscosity, μ , and inversely proportional to the pipe radius, a , to the fourth power. Because the cross-sectional area of the flow motion can be increased via the gap between the upper and lower molds in gap RTM, this method can increase injection rate per unit time. This makes it possible to reduce the internal

pressure of the mold and injection time.

In the case of RTM, Darcy's law, as shown in Eq. (3), is almost always applied in studies of resin impregnation.

$$Q = \frac{-kA}{\mu} \frac{\Delta P}{L} \quad (3)$$

Q : Flow rate; k : Permeability; A : Cross-sectional area; ΔP : Pressure gradient; μ : Fluid viscosity; L : Flow distance

Logically, fiber density is zero in the gap section, and this section therefore may not suit the application of Darcy's law. However, taking into consideration the results of studies using, for example, the Navier-Stokes equation in combination with Darcy's law⁽⁶⁾, it can be considered that the permeability value of the gap section employed when Darcy's law is applied is between 1/100th and 1/1000th the value for the fiber section considered from Darcy's law.

During the vacuum generation process, a force equivalent to the vacuum pressure multiplied by the projected area of the mold is exerted in the direction of closure of the mold, and the gap tends to diminish. Due to factors such as the position control function of the hydraulic press machine and the rigidity of the mold affecting the precision of the gap, equipment costs are prone to increase. The research discussed in this paper therefore focused on a mold structure using spring response force.

The study set the target of maintaining any arbitrary gap for the 120 sec necessary for the vacuum process.

In addition, it is necessary for the seals in the molds employed in RTM to possess two performance capabilities: the ability to withstand both the negative pressure generated during the vacuum process, and the positive pressure generated during the resin filling. Conventional RTM is able to respond to both vacuum pressure and resin pressure via a seal structure that displays these performance capabilities

when flattened during pressing [Fig. 2(a)]. In the case of gap RTM, a shear-edge seal structure is conventionally employed⁽⁷⁾ in order to help ensure that seal performance demands are satisfied both when there is and when there is not a gap in the mold [Fig. 2(b)]. A shear-edge structure makes it possible for the seal to satisfy performance demands irrespective of the gap magnitude, but a high level of precision is necessary in the mold in order to help ensure seal performance. In addition, because the area in which the seal can be positioned is restricted to the outer circumference of the mold, the size of the mold increases.

The research discussed in this paper focused on a seal using the same groove structure as the seals employed in conventional RTM, but with a shape making it possible to be employed in gap RTM. Target conditions for the seal were set for two stages: the vacuum process and the pressing process following resin injection. The condition for the vacuum process was the ability to maintain a gap of 5 mm with a mold internal vacuum of 5 kPa or below for 120 sec. This gap magnitude was set with spring-back consideration of the preformed sheet fibers. The condition for the pressing process was the ability to maintain a resin pressure of 8 MPa for 120 sec. This resin pressure represented an upper limit value calculation based on the projected part size and the capacity of the pressing equipment; the time for pressure maintenance was the necessary time for the pressing process.

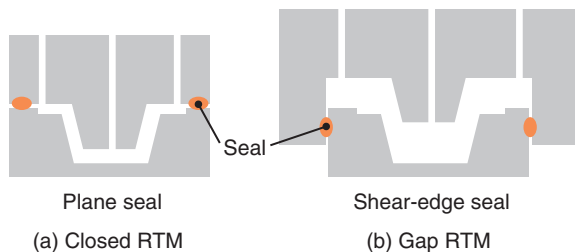


Fig. 2 Difference in seals for closed RTM and gap RTM

3. Stabilization Test of Gap during Vacuum Generation Process

3.1. Test Set-up

Figure 3 shows an image of the gap magnitude and the molding procedure in the gap RTM process. It is necessary for the springs to possess a stroke that will resist the force acting to close the mold during the vacuum process and maintain the gap at a fixed magnitude, and that will allow a gap of 0 mm to be reached when the load exerted by the pressing equipment is applied during the pressing process.

Gas springs were therefore employed. By adjusting the gas sealed inside a gas spring, it is possible to freely set the initial load at which the stroke commences. Multiple gas springs were set in the mold. By setting the sum of their initial loads at a level higher than the force acting to close the mold, it was possible to maintain the gap at a fixed magnitude. In addition, because this method makes it possible to exert a high load despite a compact size, it is suited for application in molds in which space is limited.

For these tests the load-stroke curve for the mold was set as shown in Fig. 4.

3.2. Test Results

The gap maintenance performance of gas springs was verified using an actual RTM mold. Using hydraulic pressing equipment without a position control function, changes in the gap magnitude from a gap of 5 mm were measured when a vacuum was generated in the mold. The results are shown in Fig. 5. When gas springs were not employed, the gap became progressively smaller. After 120 sec of the vacuum process had elapsed, the gap was less than 1 mm, and the mold had completely closed in another approximately 40 sec. This demonstrated that it was not possible to maintain the gap using standard hydraulic pressing equipment. By contrast, when gas springs were employed, a gap of 5 mm was maintained even after 120 sec, demonstrating the gap maintenance performance of gas springs.

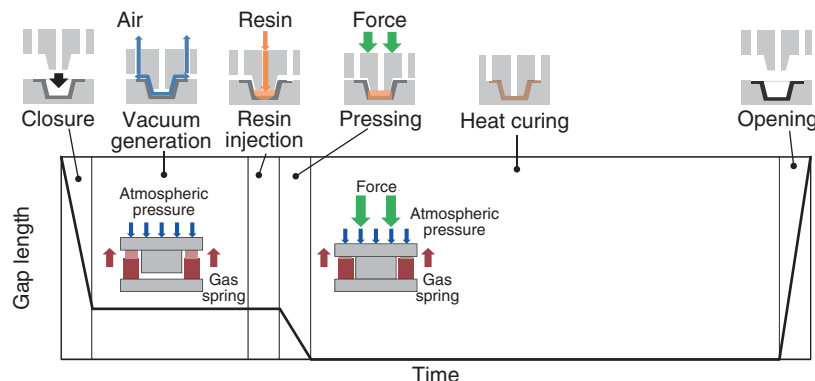


Fig. 3 Gap RTM cycle

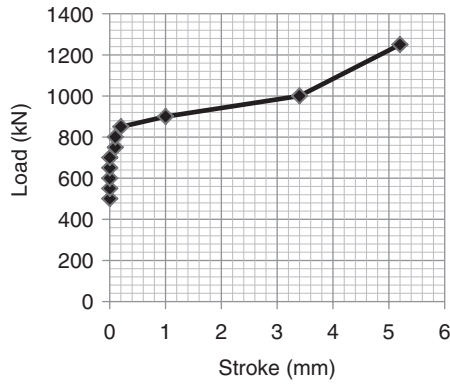


Fig. 4 Relationship between load and stroke for gas spring

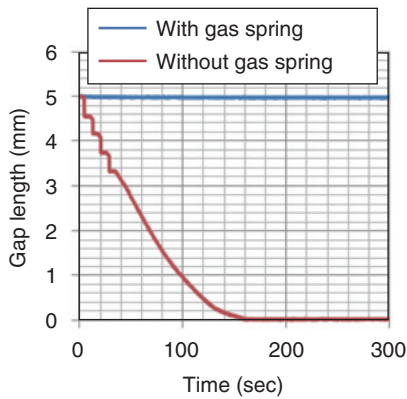


Fig. 5 Relationship between gap length and time during vacuum generation process

4. Proposal of Seal Structure and Test Results

4.1. Test Set-up

Figure 6 shows the concept for the seal shape able to be employed in gap RTM. This seal shape maintains the seal groove shape used in the seals employed in conventional RTM molds. The seal shape used in conventional RTM, (i), does not make contact with the mold at a gap of 5 mm. The seal shape produced when this solid seal is extended by the extent of the gap, (ii), does not fit within the seal groove when the mold is pressed. Given this, O-ring design^{(8), (9)} was used as a reference in proposing a hollow seal shape, (iii), with the aim of realizing a seal that made contact with the upper and lower molds even at a gap of 5 mm, and which progressively deformed under the load during the pressing process, until it finally fitted inside the seal groove. Silicon rubber was employed as the seal material based on considerations of mold releasability and heat resistance. Taking the ability of the seal to deform when the gap magnitude changed into consideration, the hardness of the seal material was set low within the hardness range

demand from O-rings in the JIS standards⁽¹⁰⁾.

Figure 7 shows seal cross-sectional shapes (a) to (c) which were examined during the research. For seal shape (a), a finely pointed shape leading up to the apex was employed to help ensure that the load was received at the apex of the seal and to help prevent the thicker sections at the sides from bulging outwards excessively to the left and right. In seal shape (b), inflection points were employed in order to help ensure that the seal bent in the desired positions when flattened. Seal shape (c) was designed based on different considerations to seal shapes (a) and (b). This shape connects an upper ring designed to maintain a vacuum with a lower square ring designed based on considerations of the ability to set the seal in relation to the groove, and the ability of the upper ring to fit in the groove. In addition, to help ensure the generation of a large repulsion force when the seal is flattened, the seal is designed such that the cross-sectional area increases in density when the upper section is pushed into the lower section.

4.2. Test Results

Figure 8 shows the seals in the direction of flattening with 5 mm and 0 mm gaps. In the case of the 5 mm gap, for all the seals only the hollow sections are deformed, with the seals themselves remaining uncompressed. Even in this state, each of the seal shapes maintained the vacuum in the mold at 5 kPa or below. Performance during the pressing process will be compared next. In the case of seal shape (a), because the hollow section was not flattened into the

		Gap 5 mm	Gap 0 mm
Solid shape	(i) Short type (for RTM)		
	(ii) Long type		
(iii) Hollow shape			

Fig. 6 Seal shape

	(a) Arrow model	(b) Revised arrow model	(c) Two-layer model
Initial shape			

Fig. 7 Hollow seal shape

interior when the seal was deformed, and expanded outside the groove, it was not possible to completely close the mold. Seal shapes (b) and (c) fitted into the groove, and it was possible to completely close the mold. Figure 9 shows results for performance in maintaining resin pressure. Seal shape (b) was unable to withstand the resin pressure, and a resin leak occurred. Seal shape (c) maintained a resin pressure of 8 MPa for 120 sec, which had been set as the target performance.

Figure 10 shows the relationship between the filling rate of the groove by the seal and the surface pressure at the area of contact between the seal and the mold, when the mold gap was varied from 7 mm to 0 mm for seal shapes (b) and (c). The groove filling rate was calculated from the cross-sectional area of the groove and the cross-sectional area of the seal, and the surface pressure at the contact area was measured using pressure-sensitive paper. The groove filling rate for seal shape (b) was around 70% even for a gap of 0 mm, and the seal was unable to withstand resin pressure. By contrast, the groove filling rate for seal shape (c) was close to 90%, and resin pressure was maintained by seal reaction force. Seal shape (c), with an upper and lower two-stage structure that fits into the groove, realizing a high-filling rate and helping to ensure a high-surface pressure, was therefore judged to be the suitable cross-sectional shape.

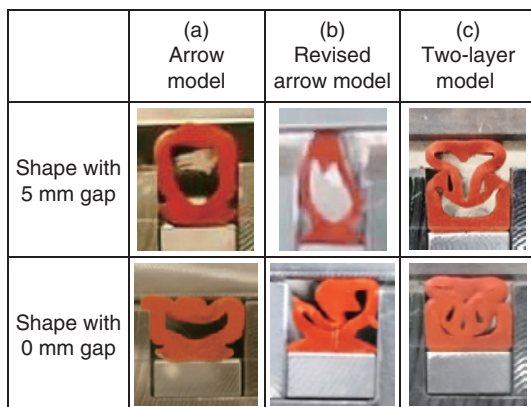


Fig. 8 Comparison of modified seal shapes

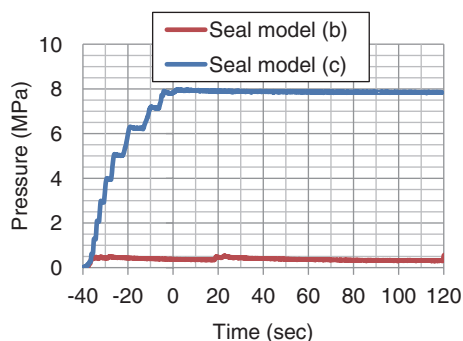


Fig. 9 Results of resin pressure test

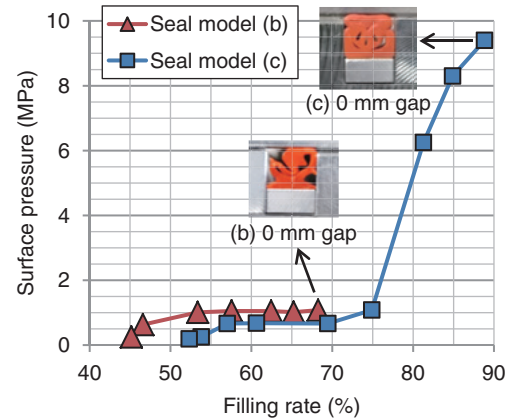


Fig. 10 Filling rate and surface pressure on seal contact area measured using pressure-sensitive paper

5. Molding Test

5.1. Basic Structure of Mold

The developed gap maintenance technology and seal technology were applied in an existing RTM mold (Fig. 11), and gap RTM was conducted using hydraulic pressing equipment without a position control function. The product was a lower dashboard, and the mold size was 1.8 m × 1.2 m. Pressure sensors were positioned in six locations in the mold in order to measure the internal pressure of the mold [Fig. 11(i)-(vi)]. In addition, temperature sensors were positioned in 24 locations inside the mold in order to determine how the resin fills the mold in the resin injection and pressing processes during gap RTM (Fig. 12).

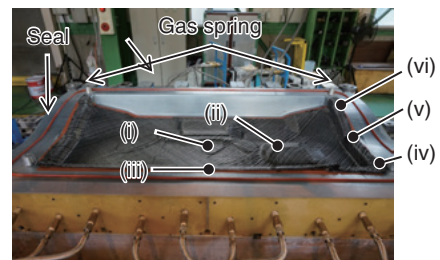


Fig. 11 Mold structure for gap RTM with gas spring, seal, and pressure sensor positions

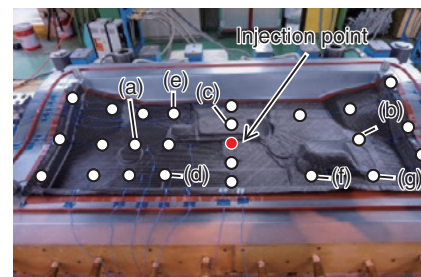


Fig. 12 Thermocouple measurement positions

5.2. Test Results

Changes in the gap magnitude during gap RTM were measured (Fig. 13). The results showed that a gap of 5 mm was maintained from the vacuum process to the resin injection process, and the mold was completely closed in the following pressing process. They additionally showed that the gas springs set in the mold functioned as desired in relation to gap control.

A vacuum gauge positioned in the mold verified that a vacuum of 5 kPa or below was achieved in the mold during the vacuum process. In addition, it was verified that there were no resin leaks to the exterior in the areas around the mold seal groove following molding, as shown in Fig. 14. These results demonstrated that the developed seal displayed adequate function in relation to vacuum pressure and resin pressure even in a large mold.

Taking advantage of the fact that the temperature of the resin and the temperature of the mold differ during molding, the status of resin filling during each process was verified from the responses of the temperature sensors. Figure 15 shows the changes in temperature at each representative measurement position [Fig. 12(a)-(g)]. During the resin injection, the sensors largely responded from positions close to the injection point. Even after the completion of resin injection, the furthest sensor from the point of injection [sensor (g)] does not respond, indicating that the resin has not reached this far. During the following pressing process, all of the sensors

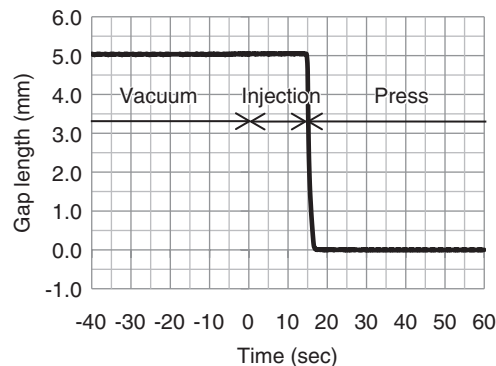


Fig. 13 Gap length in gap RTM process



Fig. 14 Result for gap RTM mold after shot

respond, indicating that the resin has filled the entire mold. Based on the above results, the areas of the mold filled by resin during each process were estimated [Fig. 16(a)].

Figure 16(b) shows an external view of the molded product. The different filling processes have not resulted in any external differences, and the product displays a good finish with no unimpregnated areas.

Figure 17 shows changes in the internal pressure of the mold for gap RTM and conventional RTM using the same mold. During conventional RTM, at a resin injection speed of 80 g/sec, maximum pressure exceeds 7 MPa. In the case of gap RTM, no increase in pressure was observed during the injection process even at an injection speed of 240 g/sec, three times higher. The maximum pressure during the following pressing process is 3.5 MPa, around half that during conventional RTM, and the time necessary for resin filling is also less than half the necessary time during conventional RTM.

Table 1 compares the results of theoretical calculations using Darcy's law and test measurements. As the vertical impregnation process in gap RTM is determined by the speed of the press machine, it was not incorporated in this study, and only the resin injection process was focused on. Table 1 shows the ratios of parameters for gap RTM and RTM, with the ratio of

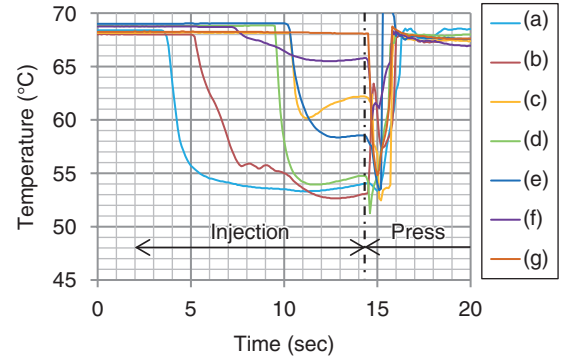


Fig. 15 Results for thermocouple temperature change

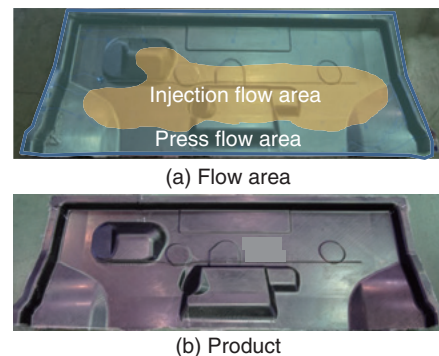


Fig. 16 Lower dashboard produced using gap RTM

Table 1 Comparison of test measurements and theoretical calculations using Darcy's law

	Measured pressure	Calculated pressure	Flow rate	Permeability	Cross-sectional area
Ratio with/without gap	146	100	3	100	3

permeability for the fiber section and space as 100. The same values were set for fluid viscosity and flow distance. A good correlation was obtained between test measurements and calculated values.

These results demonstrate that the developed method reduces the internal pressure of the mold even during high-speed resin injection, and is able to realize high-cycle molding of CFRP parts.

6. Conclusion

A mold structure making it possible to conduct gap RTM using standard hydraulic pressing equipment without a position control function has been developed.

- (1) Positioning gas springs in the mold made it possible to maintain a fixed gap for 120 sec during the vacuum process using standard hydraulic pressing equipment.
- (2) The development of a specialized seal shape made it possible to conduct gap RTM using molds employed in conventional RTM. The developed seal structure was able to maintain an internal vacuum of 5 kPa when the gap was present and a resin pressure of 8 MPa during resin filling for the target 120 sec.

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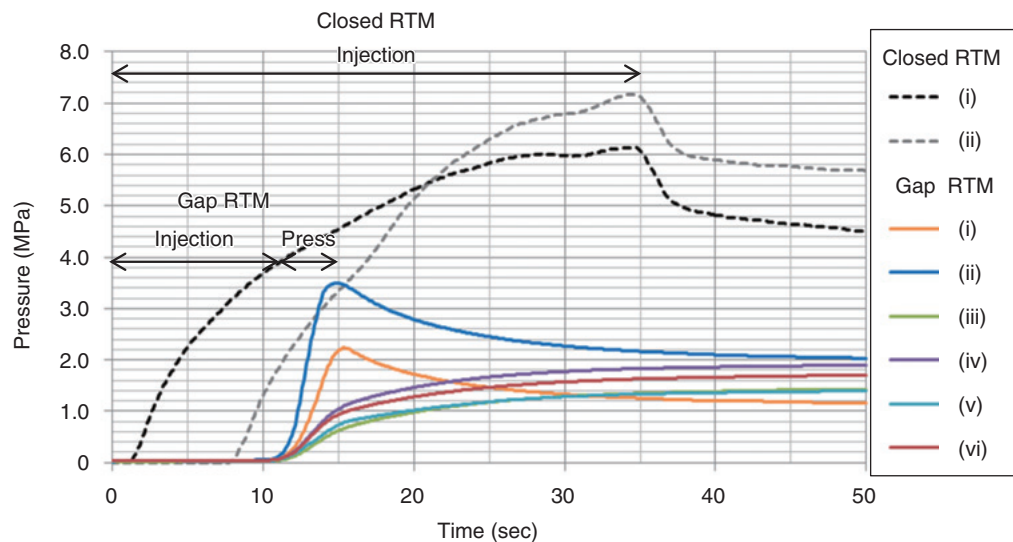


Fig. 17 Pressure profiles for closed RTM process (injection rate: 80 g/sec) and gap RTM process (injection rate: 240 g/sec)

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Editorial Afterword

Honda has set “Blue Skies for Our Children” as its global environmental slogan, and the entire Group, including Honda R&D, is working as one to respond to environmental challenges.

California has long had stringent ZEV regulations targeting automotive exhaust gases; now China has decided to introduce similar NEV regulations. Across Europe, against the background of “Dieselgate” in Germany and measures to respond to environmental pollution, focusing in particular on metropolitan areas, restrictions will be placed on the production and sale of automobiles powered by internal combustion engines. India, which suffers from similar levels of air pollution to China, has joined this trend. We have no time to lose in developing highly environmentally-conscious technologies and applying them in products.

Up to the present, automakers have distinguished themselves from their competitors and restricted new entry to the industry by means of their unique internal combustion engine technologies. However, in the future, these companies will be unable to avoid the necessity for electrification of their lineups if they are to respond to the trend towards increasingly stringent regulations. The electrification of automotive powerplants will result in a reduction in the number of components employed in automobiles, and thus has the potential to greatly transform the structure of the automotive industry. Honda should also respond to this state of affairs rapidly and in an appropriate fashion.

I believe that in this era of major transformation, Honda R&D, the wellspring of Honda’s technological power, needs to apply its comprehensive abilities to the greatest possible extent in relation to the issues outlined above and respond to the expectations not only of Honda as a whole but also of our customers throughout the world.

It is my hope, and the hope of the entire Paper Committee, that the biannual Honda R&D Technical Review will, in addition to serving as a record of the research outcomes that this process generates, also be actively utilized as a forum for presenting Honda technologies to the world.

Yoshiya Fujiwara

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