

Design of Hitachi's Carbon-fiber-reinforced Plastic Head and Pipe and Easy Grip: A Vacuum Cleaner with a Lightweight Feel

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OVERVIEW: When designing home appliances, Hitachi's Design Division aims to create devices that support people's everyday lives and are easy to use. Its traditional approach had been based on a process of observing actual appliance use to gain ideas, and then building and testing prototypes to create a potential product. This approach was also adopted for a project to design a new vacuum cleaner that began in the summer of 2010. The carbon-fiber-reinforced plastic head and pipe and easy grip vacuum cleaner, launched in July 2011, was designed and developed by using the experience design approach to home appliances, which involves the use of specific methods for discovering issues and solving problems.

INTRODUCTION

BECAUSE home appliances are widely used in everyday life, comfort and ease of use are key features. As vacuum cleaning is not a part of daily housework that people tend to enjoy, in developing this new vacuum cleaner, Hitachi sought to relieve some of the drudgery of the task by making it more relaxing and pleasant. To this end, various convenience features were developed for the new vacuum cleaner. These included a multi-angle head (vacuum mouthpiece) that can swivel 90° left and right to facilitate cleaning in narrow spaces and near walls. Another feature was a mechanism that allows the head and connecting pipe tube to lie flat on the floor, making it easier to clean under beds. The vacuum cleaner also has a one-touch zoom pipe for easy adjustment of the pipe length.

When developing the fiscal 2011 model, fiscal 2010 research by Hitachi found that "head operability" was ranked as one of the most important points when purchasing a vacuum cleaner. Therefore, when developing the new model, Hitachi focused on designing a head that would provide a better vacuuming experience for the user. This focus on operability was needed because, while the new vacuum cleaner would make the head, extension pipes, and grip functions more convenient, in doing so the structure of the vacuum cleaner would become more complicated, increasing both its weight and number of parts. The risk was that this would leave the vacuum cleaner feeling heavy and difficult to operate, leading to user dissatisfaction.

The objectives of the designers were to improve the vacuum cleaner's operability and reduce its weight

without impairing its convenience. Therefore, the behavior of users was closely observed, and research was conducted to identify how to solve this problem. While seeking to make the vacuum cleaner physically lighter, they also focused on making it look and feel lighter in operation, even while the weight remained the same. The design of the carbon-fiber-reinforced plastic (CFRP) head and pipe and easy grip was developed by concentrating on these goals (see Fig. 1).

The design and development of the CFRP head and pipe and easy grip aimed for a feeling of lightweight operation. This article describes the methods used to discover issues and solve problems so that the user experience of the vacuum cleaner would be one of surprise at how light and easy to use it feels.

UNDERSTANDING BY OBSERVING ACTUAL USE

To develop the new vacuum cleaner, Hitachi conducted research and visited the homes of people using Hitachi vacuum cleaners (seven persons, aged 30 to 50) to understand and observe how their vacuum cleaners were actually used.

For the research, acceleration sensors and angular velocity sensors were attached to record information on movements of the head of the vacuum cleaner, and interviews with the users were videoed (see Fig. 2).

Study of the movement information recorded for the head showed a greater than anticipated frequency of up and down movements. In other words, lifting the head is a commonly performed action. An analysis of the reasons for this frequent up and down movement found that it was to perform the following actions.



Fig. 1—CFRP Head and Pipe and Easy Grip (CV-SU7000).

Along with physically reducing the weight of the extension pipes and head, Hitachi sought to give the vacuum cleaner a lighter feel and appearance for the same weight. In addition, the CFRP head and pipe and easy grip design was adopted for the CV-SU7000, CV-SU5000, CV-SU3000, CV-SU20, CV-PU300, and CV-PU20 models.

(1) Lifting the head for floor coverings

To prevent mats and other floor coverings from getting snagged or entwined in the head and slipping during vacuuming, the user places a foot on the covering and lifts up the vacuum head. When putting the head on the covering, the user lifts the head to keep it from snagging.

(2) Lifting the head when moving or changing direction

When moving to a new location, the user lifts the head and changes position. (When the user lifts the head, turns, and changes direction after vacuuming the corner of a room, for example.)

(3) Crossing over cords and other obstacles on the floor

The user lifts the head to avoid the vacuum cleaner power cord and other obstacles on the floor.

(4) Crossing thresholds

When cleaning split-level rooms or crossing thresholds, the user repeatedly lifts the head off the floor during vacuuming.

(5) Lifting the head on the stairs

When vacuuming stairs, the user has to lift the head when moving up and down the stairs.

Table 1 shows the average number of times a user lifted the head during each of the five situations described above. When the number of times the head was lifted was calculated, a great variation was found between different users. Users who lifted the head infrequently did so about once every 25 s, whereas users who lifted it most frequently did so about once every 5 s.

These observations and analyses indicated that making the vacuum cleaner head lighter to lift would make it much easier to use.



Fig. 2—Results of Research at Users' Homes. Rather than trying to predict users' behavior without having any real appreciation of the task, the development team were able to understand and experience the actual situations involved in vacuuming by directly observing users' behavior.

TABLE 1. Number of Times User Lifted Vacuum Head during Vacuuming
The head was lifted more frequently than expected.

Situation	Average number of times head lifted
(1) Lifting the head for carpets, rugs, etc.	About 24 times
(2) Lifting the head when moving or changing direction	About 15 times
(3) Lifting the head over a cord or other obstacle on the floor	About 7 times
(4) Going to rooms on another level, crossing door thresholds*	About 15 times
(5) Lifting the head on stairs*	About 14 times

* Average number of times for houses or apartments where this situation applied

DESIGNING EXPERIENCE OF “LIGHTNESS”

One of the aims of the product development was to provide the user with an experience of “lightness.” In other words, making a vacuum cleaner that would look and feel light to users and convey an immediate impression of being easy to use. This led the developers to set themselves three targets for the design: making the vacuum cleaner physically light, making it feel light, and making it appear light.

Making Vacuum Cleaner Physically Light

To make the vacuum cleaner physically light, a project team was created from various divisions, consisting mainly of staff from the Strategy Planning Division of Hitachi Appliances Inc., but also including people from other divisions, such as Product Planning, Production Technology, and Design. Staff from Hitachi's Design Division also joined the project team. The team held a number of discussions and made prototypes.

The main user actions when lifting the vacuum cleaner's head involve handling four parts: the head, the extension pipe, the grip, and the hose. Of these, the developers chose to focus their attention on the material used in the head and the extension pipe, the parts located in front of the user's hands, selecting a strong and lightweight carbon-fiber-reinforced plastic. The development work included an investigation of the material's strength and external appearance.

For strength, a conventional pipe die was used and several samples of different thicknesses were made. Endurance testing was used to determine the minimum thickness, resulting in a lightweight sample capable of maintaining its strength.

For the exterior, it was found that the method used to mix the CFRP resulted in uneven areas appearing on the fiber surface of parts after injection molding. In response, the project team studied the molding conditions (injection speed) and selected conditions that would smooth out the uneven carbon spots. A surface graining process was devised to make the uneven spots difficult to see (see Fig. 3).

CFRP was also used in the head. Specifically, it was used in the core (axis) of the revolving brush and the upper case. The aim was to make the structure of the head thinner and lighter while keeping its strength and making the internal motor smaller (see Fig. 4).

Through this process, Hitachi was able to reduce the total weight of the extension pipe and head in the development model from 940 g to 820 g (13% reduction).

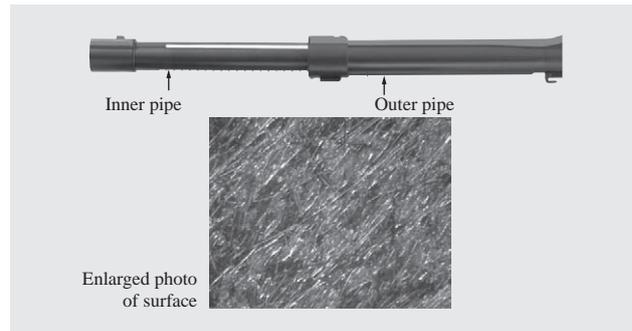


Fig. 3—Use of CFRP in Extension Pipes.

Adopting CFRP for the inner and outer pipes made the pipes thinner while maintaining strength, resulting in a reduction in weight.

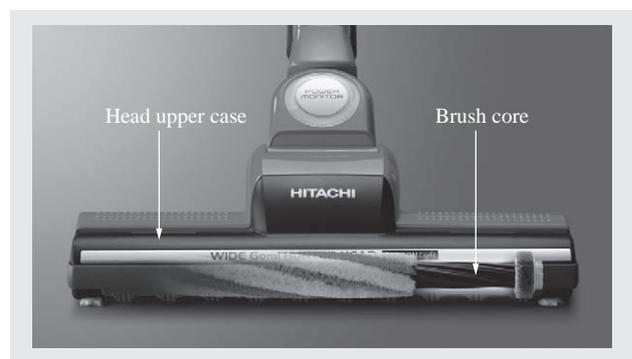


Fig. 4—Head Made from CFRP.

CFRP was used in the head upper case and in the revolving brush core (axis). The size and weight of the internal motor were reduced.

The developers then reviewed and optimized the length of the extension pipe and grip to reduce further the physical weight of the vacuum cleaner. The determining factor here is that the shorter the distance between the user's grip and the weight-bearing head, the lower the perceived force (moment) on the user's fingers and hand and the more easily the head can be lifted (see Fig. 5).

Statistical data on the height of Japanese people were used to characterize vacuum cleaner users. User height was assumed to be between 140.9 and 178.0 cm, which covers 98% of women aged between

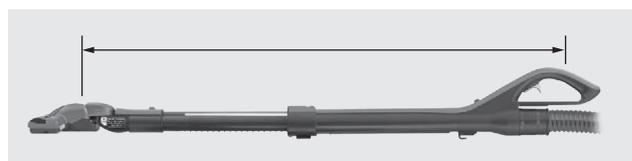


Fig. 5—Length from Head to Grip.

The length from the heavy head to the grip was optimized. The aim was to make the vacuum cleaner feel lighter by making greater use of the force exerted by the user's hand and fingers.

25 and 69, centered on the median height. In the case of men, it covers 85% of this age group although it is offset toward the shorter end of the height distribution.

A series of investigations was then performed to assess the optimum head-to-grip length that would allow persons in this height range to use the vacuum cleaner comfortably. This produced a head-to-grip length (for the case when the extension pipe is at its maximum length) that was 40 mm shorter than previous models. In other words, the vacuum cleaner was also made lighter in terms of the force a user would exert when using it.

Making Vacuum Cleaner Feel Light

Along with physically reducing the weight of the extension pipes and head, Hitachi also sought to give the vacuum cleaner a lighter feel for the same weight by changing the shape of the grip. To achieve this objective, a workshop was held by a project team consisting of staff from Hitachi's Design Division

and from various divisions in Hitachi Appliances Inc., including the Design Division, Lifecycle Research Center, and the Strategy Planning Division.

The workshop participants started by trying out vacuum cleaners made by Hitachi and other companies. They then engaged in a detailed discussion of the elements that make a vacuum cleaner feel lighter, with a particular focus on the shape and cross-section of the grip.

Next, they built models to try out different grip angles and assess the optimal position for the grip. These included simple models with straight, convex, and concave profiles; models of varying grip thickness diameters; models that gradually narrowed or widened toward the grip end; and models in which the shape of the grip cross-section was a vertical or horizontal ellipse. The workshop participants subjectively evaluated these models (see Fig. 6).

As a result, they came up with the following hypotheses.

(1) A thicker grip feels lighter

A thicker grip is easier to hold, so the user grips it more lightly when moving the head over the floor. As a result, it feels easier to use.

(2) A thinner grip makes it easier to lift the head

When cleaning stairs or moving over a difference in floor level (such as a door threshold), the user lifts the head with one hand. In this case, a narrow grip makes gripping and applying force easier. It is also easier to lift, compared to a thick grip.

(3) A grip with a wider area for finger placement feels lighter

When the head is lifted with one hand, support comes from the index finger holding the grip from below. If the grip has a horizontal cross-section, this area is wider than it is if the grip has a vertical cross-section. This wider area makes it easier to transmit force and prevents discomfort when holding the grip [see Fig. 7(a)].

(4) A vertical elliptical grip fits easier into the hand

For a vacuum cleaner grip, a vertical elliptical cross-section fits the hand better than a horizontal elliptical cross-section. In addition, a vertical elliptical cross-section transmits force more easily and the grip can be more lightly twisted when held [see Fig. 7(b)].

(5) The head is easier to lift if the grip has a straight or concave profile

A grip with a straight or concave profile makes the head easier to lift with one hand because leverage can be applied at two points: with part of the hand and with the index finger. Conversely, with a convex

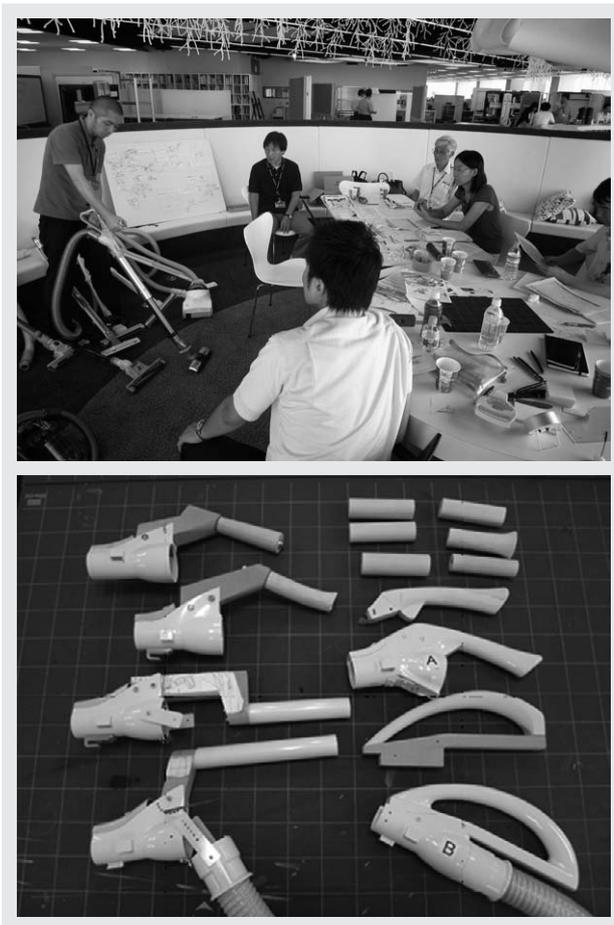


Fig. 6—Workshop in Progress. The workshop included a detailed discussion (above) that covered even minor points. A number of simple grip models were produced to evaluate their performance.

grip, it is difficult for leverage to be effective, and force applied by the user is more likely to result in slip [see Fig. 7(c)].

(6) A grip with changing thickness fits easier into the hand

Given the shape of the palm and the length of the fingers, a grip with changing thickness is a better fit with the hand. However, preferences differ as to the direction of tapering.

(7) The grip can be held more firmly when the grip end is thick

As with a baseball bat or golf club, the vacuum cleaner grip is tapered so as to be thicker at the end. Thinking of the vacuum cleaner as a tool used to move the extension pipe and grip forward and backward in front of the user, this thick-ended grip prevents the user's fingers from slipping and allows it to be held securely in the hand. Also, the vacuum cleaner's self-propelling head has an internal motor that drives a revolving brush, assisting forward movement and making head movements feel lighter. On the other hand, the user has to apply extra force when pulling the head back toward themselves, so a grip-end that prevents slipping is better [see Fig. 7(d)].

(8) The angle of the grip with respect to the extension pipe should be 20° to 25°.

When vacuuming stairs or moving between small differences in floor level, the best grip angle for normal vacuuming and the best angle for lifting the head are not the same. A grip angle in the 20° to 25° range was found to provide the best compromise between these competing requirements [see Fig. 7(e)].

The workshop participants used a number of simple models to assess the various elements that made a grip feel lighter. It was from these that the eight ergonomic hypotheses listed above were derived. These hypotheses were then used as the basis for designing the easy grip. The design process included changing the cross-section of the grip from a narrow, horizontal ellipse in the front to a thick vertical ellipse in the back, and straightening the upper surface of the grip to provide more effective leverage. Furthermore, a closed-end grip was adopted instead of a conventional open-end grip. This means that the grip will not slip from the user's fingers when pulling it toward them, and the user can carry it simply by using the grip as a handle (see Fig. 8).

Making Vacuum Cleaner Appear Lighter

Innovative ways were also devised to give the vacuum cleaner a new appearance, one that would give an immediate impression of being light and easy to use.

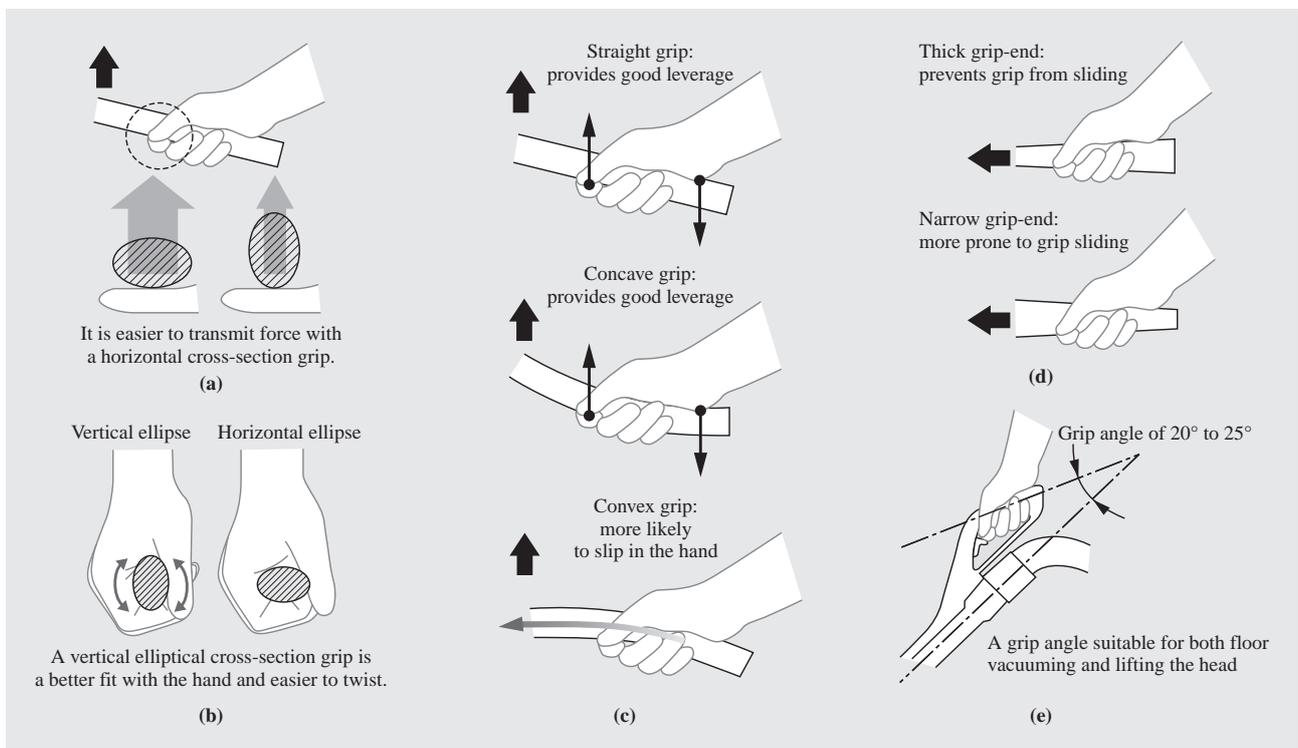


Fig. 7—Subjective Evaluation of Grip Shapes.

Simple grip models were created and subjectively evaluated. Hypotheses were established as to which elements made the grips feel light.

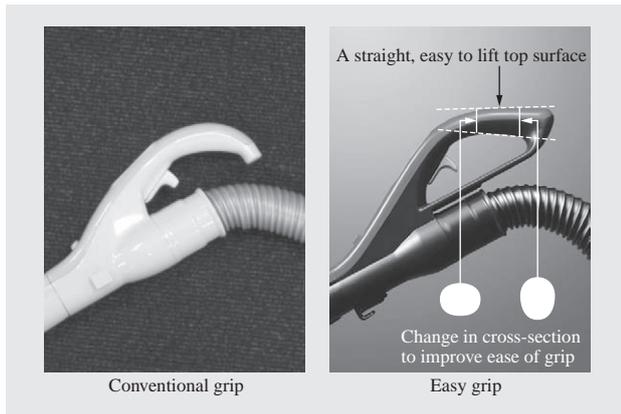


Fig. 8—Conventional Grips and Easy Grip.

The conventional grips are open-ended, with a curved convex shape at the back end of the grip. The easy grip, on the other hand, is closed at the back and straight along the top surface. Furthermore, its cross-section varies to improve ease of grip.

An attractive shape was achieved by giving the vacuum cleaner a sleek appearance while reducing concavity or convexity as much as possible.

The colors for the cover were chosen to reflect the black carbon of the head and extension pipe. The contrast between these colors and the strong-toned black makes the vacuum cleaner appear slim.

Metallic paint in colors that matched the vacuum cleaner body were also used for part of the cover. The metallic finish gave the vacuum cleaner a high-class modern appearance (see Fig. 9).

ATTEMPTS TO QUANTIFY EASE OF USE

While words and numbers can explain how the vacuum cleaner was made physically lighter and the ingenious methods devised to make it feel and appear light, phrases such as “feels light” and “easy to use” depend ultimately on subjective feelings, with meanings that vary from person to person.

For this reason, monitor tests were also conducted to make quantitative evaluations of the improvements in ease of use that resulted from the use of CFRP materials and the easy grip (which were developed to make the vacuum cleaner feel lighter during use).

(1) Actions evaluated

- (a) Forward and backward movement in a straight line: moving the head 60 cm back and forth over a carpet
- (b) Forward movement following a winding path: moving the head forward along an S-curve (like in a ski slalom) with a curve radius of 50 cm
- (c) Lifting the head over small obstacles: a number of 3-cm diameter pipes were placed across the path

of the vacuum cleaner and the user was required to move in a forward and then a backward direction, each time lifting the head over the pipes without touching them. This sequence of movements was repeated three times.

(d) Lifting the head on to stairs: the user was required to lift the head onto each stair in turn, up to the third step, where each step was 20 cm in height.

To achieve a consistent speed, the movements in (a), (b), and (d) were done to the sound of a metronome.

(2) Evaluation of grip, head, and extension pipe combinations

To distinguish between the effects on lightness of the CFRP materials (in the head and extension pipes) and the easy grip respectively, tests were conducted to evaluate the following combinations:

- (a) Easy grip + CFRP head and pipe
- (b) Conventional grip + CFRP head and pipe

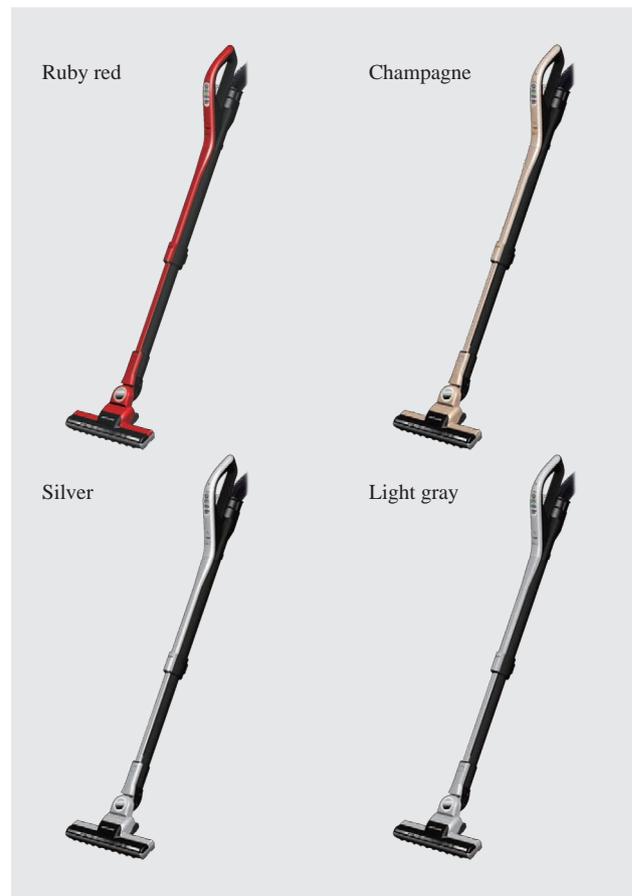


Fig. 9—CFRP Head and Pipe and Easy Grip Colors.

The ruby red and champagne colors are metallic paints. The silver color is a metallic plastic silver. The light gray color is a general-purpose plastic finish.

TABLE 2. Evaluation Results for Ease of Movement and Ease of Lifting
In conjunction with the CFRP material's effectiveness in reducing weight, the easy grip's ease of movement and ease of lifting were an improvement over conventional models.

		Movement			
		Straight	Curved	Over obstacles	On stairs
Easy grip	Developed CFRP head and pipe	71.0	77.3	59.2	59.3
Conventional grip	Developed CFRP head and pipe	69.7	70.9	52.5	59.2
	Conventional grip, conventional pipe	67.4	71.3	30.4	22.7

(c) Conventional grip + conventional head + conventional extension pipes

(3) Evaluation method

Performance measures such as “ease of movement” and “ease of lifting” (level of physical effort required) were evaluated using the visual analogue scale (VAS). The VAS method is based on users' self-assessment. A VAS is a 100-mm horizontal line on paper, with the left edge of the line representing the worst condition and the right end of the line representing the best condition. The subject of the experiment marks the point on the line that best represents their impression of the task. In other words, the user's evaluation of the experience is indicated by the position of the mark on the line.

(4) Evaluation participants (“monitors”)

48 people: all were housewives unaffiliated with Hitachi, aged between 32 and 61 (average 48.9 years), and with heights between 146 and 165 cm (average 157.0 cm).

(5) Evaluation results

Table 2 shows the average scores for the 48 monitors. The closer the value in the table is to 100, the higher the evaluation.

The easy grip and CFRP head and pipe combination received the highest score in all four movement categories (straight line, curved, lifting over obstacles, and lifting onto stairs), with the score for curved movement being especially high. The scores also indicate that the lighter weight of the vacuum cleaner resulting from use of CFRP materials made lifting onto stairs easier. Furthermore, the easy grip received higher scores when used with the CFRP materials than did the conventional grip used with the same materials.

These quantitative evaluations showed that, in conjunction with the CFRP material's effectiveness in reducing the weight, the easy grip's ease of movement and ease of lifting were an improvement over conventional models.

CONCLUSIONS

The design and development of the CFRP head and pipe and easy grip aimed for a feeling of lightweight operation. This article has described the methods used to discover issues and solve problems so that the user experience of the vacuum cleaner would be one of surprise at how light and easy to use it feels.

Sales presentations were held with representatives of retailers, and briefing sessions were conducted with salespeople about the CFRP head and pipe and easy grip vacuum cleaner. These provided the participants with an opportunity to try the vacuum cleaner for themselves. As expected, there were a large number of reactions such as, “It certainly is light, isn't it?” In-store presentations using demo models were also prepared, and sales models were provided so that customers could experience the product's lightweight features first-hand. As users' favorable responses to the demo models show, fiscal 2011 sales also increased greatly over fiscal 2010 sales.

In the home appliance market, a balance is required between a product's functions and its performance. It is difficult for a company to differentiate its products from those of other companies. In this type of market, the affective aspects of a product, such as its “ease of use” and “familiarity,” are thought to be important factors. A significant future issue will be to express these affective aspects of a product's quality coherently in its design and to evaluate them quantitatively.

Hitachi continues making efforts to create products that make the experience of daily housework easier and more comfortable for users, and hopes to increase the number of Hitachi fans.

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