

Research on Electrically Powered Small Commuter Scooter

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ABSTRACT

For the study of electrically powered small commuter scooter, we focused on short distance urban travel to set a practical cruising distance. High energy density Ni-MH battery, power unit module with inverter, and a motor with single gear reduction were selected to ensure a compact lightweight design with necessary drive power. Part layout was optimized with consideration for front axle weight to provide good handling and stability while reducing vehicle size. While keeping the riding posture the same as a basic scooter, the lower seat height and narrower floor enhanced handling and the user's ability to touch the ground. A lever type accelerator was applied to enhance the operation of this scooter. As a result, an electrically powered small scooter with flat floor which is clean, quiet, and smooth, was realized with practical handling and stability. The scooter with its 1 285 mm in length, 44 kg mass, and 15 km cruising distance can be easily handled even by novice riders.

1. Introduction

During the 1980s the number of scooter users increased rapidly as a result of the commercialization of the lightweight low-priced class 1 motorized bicycle which could be easily used by people switching from a bicycle to a scooter for the first time. With the subsequent evolution of scooters however, their size and mass have increased which has made it more difficult for first-time scooter users to adequately handle a scooter.

In 1994, Honda commenced mass production of its first electrically powered scooter, the CUV-ES. This scooter was intended as a replacement model for some engine-driven small scooters and was aimed at keeping the same driving performance as an engine-driven scooter. However, to attain the target cruising distance it was necessary to install a large capacity battery which

posed the issue of increased mass of the scooter. Also, because this scooter was sold on a lease basis it did not become common on the market. Subsequently, Electric Vehicle (EV) technology for the battery, power devices for the inverter, and control of the motor current have evolved, making it possible to achieve higher performance with a greater degree of compactness.

In light of this situation research started on an electrically powered small scooter suitable for first-time scooter users which was intended to be quiet, smooth running, and easy handling. From the viewpoint of popularizing electrically powered scooters the concept of the scooter was developed to that of a commuter for city driving. Under this concept, easy handling and the ability to park it in small spaces were featured. The mass of the expensive battery was reduced with limitation to driving performance and cruising distance and research was carried out accordingly.

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This paper describes the vehicle concept of a prototype electrically powered small scooter and the main technologies used in it (Fig. 1).

2. Vehicle Concept

2.1. Size and Mass of the Body

As a result of analyzing the body size and mass of a class 1 motorized bicycle (gasoline engine) it was considered desirable to use a small lightweight EV scooter as the target of research.

In the 1980s, small, lightweight scooters were commercialized, and because of their ease of handling the number of users increased, particularly first-time users switching from bicycles. These scooters were further evolved to meet the needs of the market by enhancing performance and providing storage space for a helmet among other features. Subsequently, scooters became progressively larger and heavier (Fig. 2). At present, there are no scooters with an overall length of 1 500 mm or less and a mass of 50 kg or less. These are the scooters that are gladly accepted by first-time users. It is thought that people still need to switch from using a bicycle to using a scooter so the target of the research was set as a compact and lightweight EV scooter that first-time users could handle easily.

2.2. Driving Performance and Cruising Distance

Increasing the mass of the battery to obtain the required driving

performance and cruising distance causes the mass and the cost of the EV scooter to increase. In this research, it was considered important to restrict the scope of application of the electrically powered small scooter to a certain extent and set the driving performance, cruising distance, and battery weight to match this scope of application.

In 1994, development of the CUV-ES (Fig. 3) for mass production started. This scooter was intended as a substitute for conventional scooters powered by engines and was designed to equal the driving performance of a conventional scooter as well as a relatively long cruising distance. Although this scooter had a maximum speed of 60 km/h and a cruising distance of 35 km (ECE40 mode), the amount of batteries required for this performance level were largely responsible for the scooter's overall mass of 130 kg, which was roughly twice that of a conventional scooter powered by an engine. Also, since the retail price was 850 000 yen (3-year lease), it could not satisfy users of conventional scooters. The EV scooter was commercially practical at that time, but it was unable to penetrate the market.

In the next approach, the CAIXA, MOBIMOB, and other concept models were announced at the 2001 Tokyo Motor Show (Fig. 4). Although these models were manufactured for separate applications, all of them were EV that used a motor as the power source. While complementing the applications of automobiles, these scooters were good for city driving or limited-distance urban travel and all featured reduced body size, limited driving performance, and cruising distance due to a smaller battery.



Fig. 1 Appearance of prototype small EV scooter

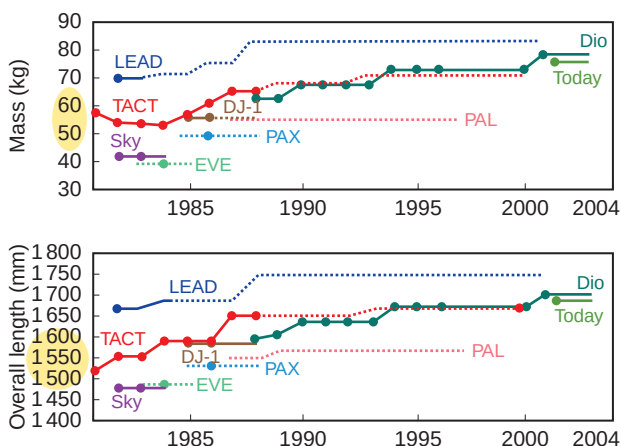


Fig. 2 Changes of size and mass of scooters



Fig. 3 Appearance of CUV-ES



Fig. 4 Appearance of concept models

From the above, it was judged best from the viewpoint of lowering the overall mass and price to design all EV small scooters specifically for city driving and to set the size of the battery, driving performance, and the cruising distance with consideration of practical applications.

2.3. Concrete Concept

A concrete concept was determined taking into account the fact that the scooter was intended for users who were switching from bicycles to scooters for the first time and the scooter would have various features as an EV. Based on that concept, we studied the direction to be emphasized to design an electrically powered small scooter that would be more readily accepted by users (Fig. 5).

For short distance urban travel, bicycles are used as well as scooters. It is anticipated that bicycle users who do not demand the cruising distance or driving performance of a full-fledged scooter will become users of electrically powered small scooters. We decided that it would be desirable to appeal to these users using the fact that this scooter uses a motor instead of an engine as the power source and is easier than a bicycle to use. Thus, the main concept was condensed into the catchphrase “Comfortable mobility appliance.” Based on this catchphrase, it was necessary to provide functions and performance that emphasized user-friendliness, convenience, and a compact lightweight body which represent the image of an electrical appliance.

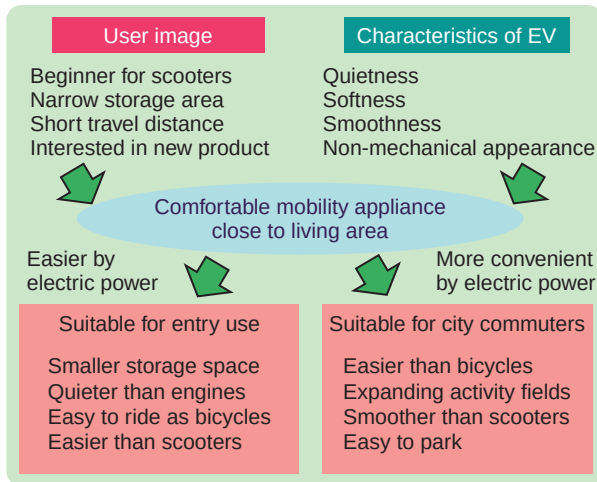


Fig. 5 Concept map of small EV scooter

Also, it was thought the ability to use such a scooter over a wide area, its small size, easy handling, and parking would contribute to easy use and convenience. Regarding driving performance, it was thought that potential users would make a comparison with a bicycle and would therefore not make strong demands for high performance.

3. Outline of an Electrically Powered Small Scooter

3.1. Specifications of an Electrically Powered Small Scooter

Table 1 shows the major specifications of an electrically powered small scooter. Emphasis was placed on reducing overall length. At the same time, the type and size of the battery was set by balancing mass, price, and performance.

The overall length was made 1 285 mm to allow the scooter to be parked inside the front entrance of a home or taken into the elevator of a condominium and smaller than the width of the rear hatchback door of a minivan. To enable the overall length to be reduced small diameter 8-inch tires were used instead of 10-inch tires which is the normal size of tires used on a scooter or motorized bicycle. The maximum speed was set to 40 km/h and the practical cruising distance was set to 15 km as the minimum performance required for a scooter used for city driving. The maximum speed setting was determined as the speed that enabled the difference in the time required to travel a short distance to be ignored and that was fast enough that the driver felt no psychological pressure on a road with other vehicles. The practical cruising distance was determined from the data in Fig. 6, which indicates that 92% of bicycle users travel no more than 9 km in a day⁽¹⁾ and also that 77% of users of engine-driven scooters rode an average distance of no more than 10 km per day⁽²⁾. The practical cruising distance of 15 km that was set included an allowance factor of 1.5. To reduce the body size, mass, and price while achieving the determined target driving performance and cruising distance, a high energy density Ni-MH battery was used. A specification comparison with the CUV-ES which has the same performance as a general engine-driven scooter shows that the vehicle curb mass is about 1/3 and the capacity of the battery is about 1/5. These specifications coupled with the easy handling and reduction of price of the battery resulted in specifications that are near the realistic zone in which popularization of the scooter is feasible.

Table 1 Specifications of EV scooter and CUV-ES

Items	Specifications	
	Small EV scooter	CUV-ES
Length × Width × Height (mm)	1 285 × 600 × 930	1 785 × 615 × 1 035
Vehicle curb mass (kg)	44	130
Motor type	Permanent magnet synchronous motor	Permanent magnet synchronous motor
Rated power (kW)	0.58	0.58
Maximum power (kW)	1.15	3.25
Battery type (V-Ah)	Ni-MH 48 V-7.5 Ah	Ni-Cd 86.4 V-20 Ah
Maximum speed (km/h)	40	60
Cruising distance (km/charge)	15 (300 m go-stop)	35 (ECE40 mode)
Charging hours (hr)	3	8

3.2. Electrically Powered System Configuration

Figure 7 shows the configuration of the electrically power system. A rated power supply voltage of 48 V was applied with consideration of capacity of cell, discharge performance of the battery, breakdown voltage of the power devices in the inverter, and the allowed voltage and current capacity of the wiring components. The rated voltage of the lights and other components was 12 V, so the 48 V power was converted by a DC-DC converter to 12 V and supplied to the lighting components. The 48 V drive system circuit was isolated from the 12 V lighting circuit.

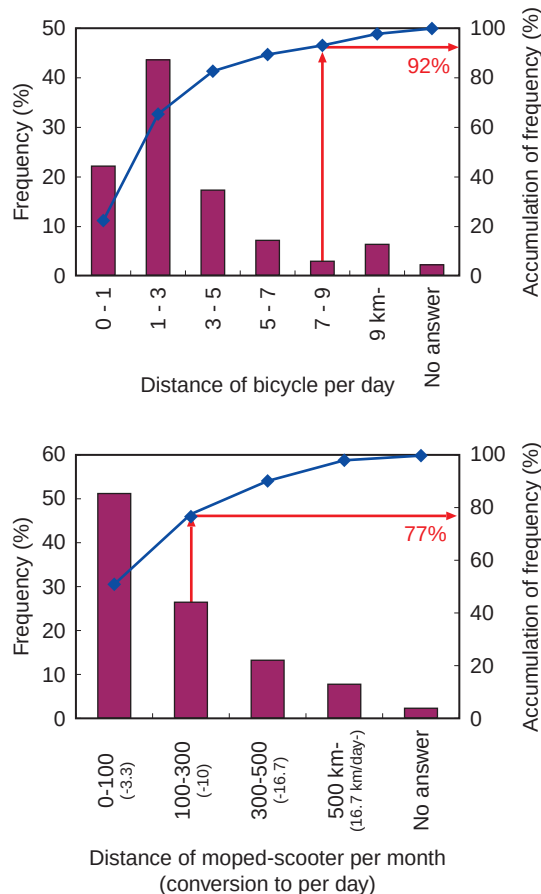


Fig. 6 Travel distance of bicycle and scooter users

The battery is a permanent type on the vehicle body. It is charged from a 100 V domestic power outlet. The fixed type battery has fewer electrical and mechanical components than those of a replaceable battery, thus contributing to the overall lightness and low price of the scooter.

3.3. Energy Consumed while Running

By making the body compact and light, running resistance is reduced and it is projected that the energy consumption of the scooter will be reduced. Energy consumption of the small EV scooter in an urban area running mode was compared with that of the CUV-ES and the Smart Dio Z4 (engine-driven scooter). The urban area running mode consisted of repeatedly starting and stopping every 300 m with the throttle fully open, and the maximum speed of 40 km/h regardless of the model.

Figure 8 shows energy consumption in terms of the energy extracted from the battery (or gasoline tank) per 1 km and also the energy consumption in terms of the energy drawn from the energy source which takes into account the energy generation process. The energy consumption of an electrically powered small scooter is 83 kJ (23 Wh)/km in terms of energy extracted from the battery and 172 kJ (48 Wh)/km as the energy generation converted value. From these results it was confirmed that if the scooter was restricted to short distance urban travel the energy efficiency in terms of energy drawn from the source was 1.6 times that of the CUV-ES, and approximately 4 times that of the Smart Dio Z4.

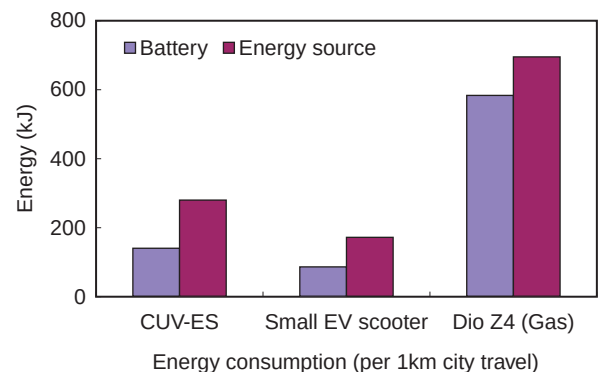


Fig. 8 Comparison of energy consumption of scooters

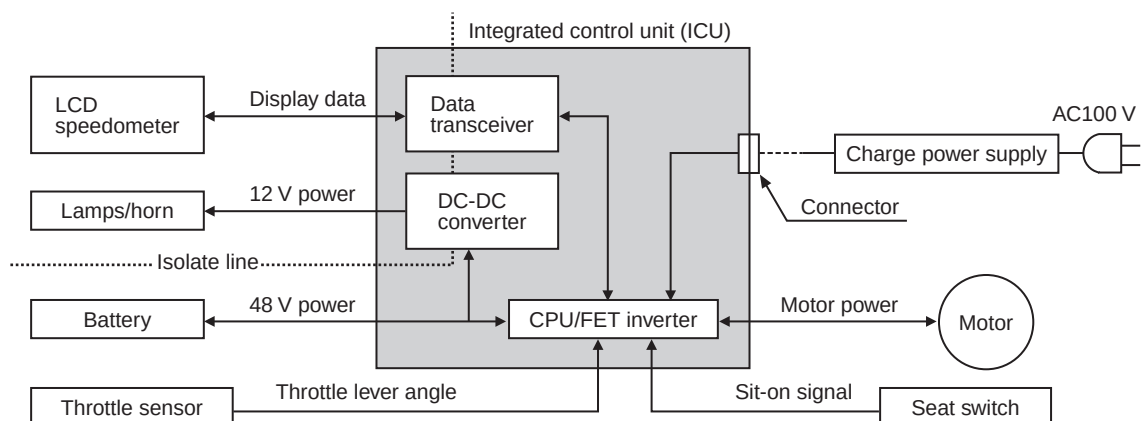


Fig. 7 Diagram of EV system

4. Major Technology

4.1. Electrically Powered Components

4.1.1. High energy density battery

To obtain the necessary driving performance and cruising distance while keeping the body compact, a high energy density Ni-MH battery was used. This battery is based on the one developed and mass-produced for the Racoon STEP COMPO (1999) power-assisted bicycle. The distribution and overall quantity of the active material was re-examined and both the mass- (weight-) energy density and volume-energy density were increased by 40% (Fig. 9). Generally, if a high energy density type battery is used the cyclic life tends to fall. By using an appropriate depth of charge for the full charge to minimize deterioration of the hydrogen storage alloy a cyclic life the same as that of a conventional battery could be achieved.

The battery used consisted of two packs each consisting of 20 cells of 1.2 V-7.5 Ah connected in series. The dimensions of each pack were $279 \times 80 \times 48$ mm with a mass of 2.9 kg. The total capacity of the two packs was 360 Wh (Fig. 10).

To reduce the time required to cool a battery heated as a result of use to a temperature low enough to charge it an intermediate material consisting of a silicone filler and rubber was inserted between the aluminum frame and the battery pack to enhance the thermal conductivity. As a result the time it takes for the battery temperature to fall from an initial value of 60°C to 40°C , a

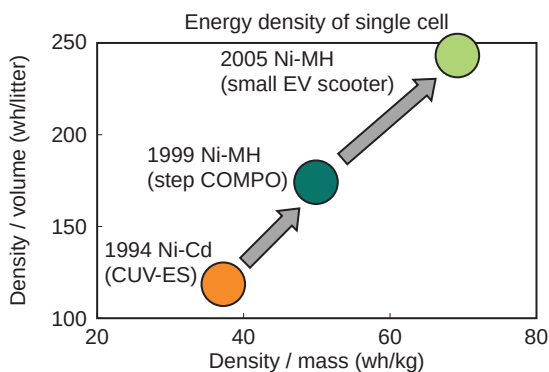


Fig. 9 Enhancement of battery performance

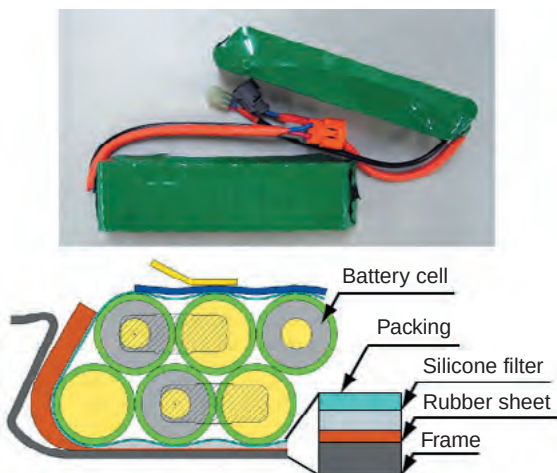


Fig. 10 Battery packs and cooling structure

temperature cool enough to allow the battery to be charged, was reduced from 95 minutes to 80 minutes.

The use of the high energy density battery as well as the use of the frame as a heat release structure contributed to body compactness.

4.1.2. Modular power unit

To reduce the size of the body the electrical and mechanical components of the driving system were modularized (Fig. 11). The engine, transmission, centrifugal clutch, and reduction gears of the scooter were integrated as a power unit inside the swing arm of the rear wheel which allowed the power train and the drive system to be laid out neatly. In this research the following configuration was used for increased compactness, lightness, and simplicity.

- (1) A high-torque low-speed outer rotor type motor was combined with a small 8-inch tire and the drive system between the motor and rear wheel was simplified consisting of a single gear reduction.
- (2) Current vector control was used to expand the range of rotational speed of the motor to the flux-weakening area while ensuring high driving efficiency thus eliminating the transmission and a clutch for starting.
- (3) The rear wheel, motor, and inverter were arranged as close as possible to each other and incorporated inside the swing arm enabling the overall length of the swing arm to be shortened. Also, the swing arm was made of cast aluminum allowing it to be used as a heat sink for the inverter.

As a result of the above a small power unit (overall length $356 \times$ width $199 \times$ height 175 mm) that was capable of efficiently converting the energy of the battery into drive power was developed for a small electrically powered scooter.

4.2. Frame and Parts Layout

To reduce the size of the body small diameter tires were selected and the wheelbase was shortened. Also, to obtain good handling and stability the layout of the parts was optimized.

With an EV it is possible to separate each component and also to select the parts layout relatively easily by adjusting the length of the wiring. This allows the benefit of adjustment of the weight distribution in the longitudinal direction.

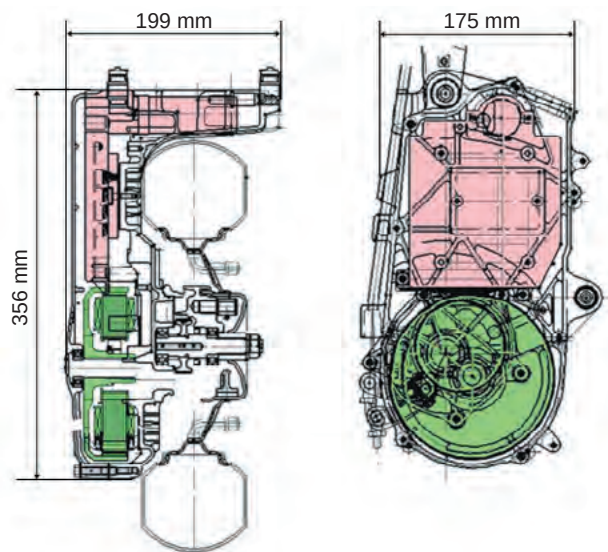


Fig. 11 Cross section of power unit

The weight of the overall vehicle was reduced with one of the two battery packs mounted on the down tube of the frame while the other one mounted on the step (Fig. 12). As a result the ratio of the front and rear weight distribution with a rider sitting on the seat was 34:66. Compared to an engine-driven scooter of the same class with a short wheelbase using 8-inch tires the weight was about the same and the distribution ratio was 3 points higher. As a result it was possible to obtain the same level of handling and stability as that of a scooter fitted with 10-inch tires.

4.3. User Convenience

4.3.1. Usability and riding feel

To make it easier for the rider to move the scooter or change direction while in a riding posture with both feet on the ground and to facilitate starting from a stable standing posture the seat height was made 700 mm with a floor width of 260 mm which is the minimum width over which both legs can be placed. As a result not only does the scooter handle well, but it also provides the sense of security for a first-time scooter user who has changed over from a bicycle. The body was designed in such a way that the rider can maintain the same riding posture as a conventional scooter with acceptable riding quality though overall size of the body was reduced (Fig. 13).

4.3.2. Lever type accelerator

Some first-time users of scooters complain it is difficult to use the twist grip type accelerator because the speed adjusting function of this type of accelerator is not separate from the steering function. A separate lever type accelerator was used in the new scooter enabling even first-time users to use it easily. A step was added to the operating load before and after a set operating angle of the lever and immediately before this step the motor output was set so that the scooter travels at a constant speed of about 8 km/h. The aim of this was to enable users who are not familiar with the speed adjusting function of a scooter to understand the relationship between the operating load, lever angle, speed of the scooter, and to become skillful at starting off at a moderate lower limit speed (Fig. 14).

As a result of conducting test-rides on the in-house test course using people who possessed a license but mainly used a bicycle, it was found that 88.3% of the subjects gave positive opinions concerning the operability of the lever type accelerator. 6.5% of the subjects said that operation was easy because they could adjust the speed using one finger, thus indicating that the lever type accelerator was preferred over the twist grip type.

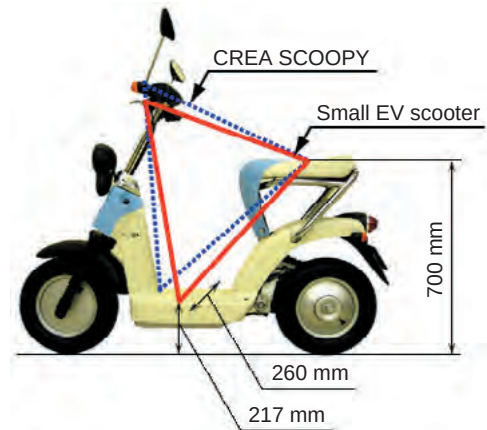


Fig. 13 Floor dimension and riding position

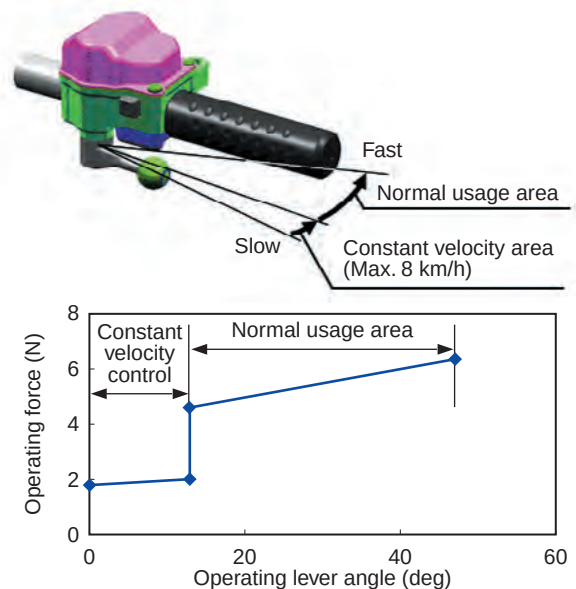


Fig. 14 Structure and characteristics of lever accelerator

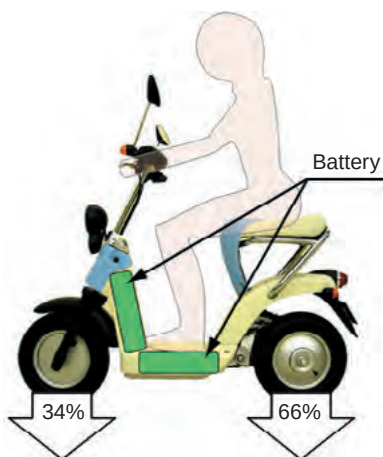


Fig. 12 Battery position and mass distribution

5. Conclusion

The following results were obtained from the research into the electrically powered small scooters.

- (1) A new scooter was tailored to meet the needs of city commutings. A small lightweight body was combined with a small as practically possible battery resulting in higher energy efficiency compared to a conventional engine-driven scooter.
- (2) By optimizing the parts layout to maintain weight distribution on the front axle it was possible to obtain adequate handling stability despite the use of small diameter tires and a small lightweight body with a short wheelbase.
- (3) A lever type accelerator with a stepped operating load was used with a motor output characteristic that produced a constant speed of 8 km/h in the vicinity of the step, allowing first-time users of scooters to quickly acquire skill in using the accelerator.

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