B-14.3.1 Social Acceptance of a Commuter Car(Final Report)

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Total Budget for FY 1994-1996 ; 61,000,000 YEN(FY 1996; 21,056,000 YEN)

Abstract

About 20 % of CO_2 emission in the world was caused by the usage of automobiles. To reduce the emission, an electric vehicle(EV) is useful. But it is not spread in the society. The purpose of this project is to find the way to spread it. For the purpose, a ground up EV named ECO-Vehicle was designed and constructed. The completed vehicle was shown to and driven by many people to ask if this kind of EV could be selected or not.

Key Words Electric Vehicle, Commuter Car, Social Acceptance

1. Introduction

To be selected by consumers, it is necessary to develop a vehicle which clearly shows the advantageous characteristics of EVs. For this reason, we started this project as an experiment to add new technology, and to identify the best usage for electric vehicles.

The ECO-Vehicle project aims to facilitate:

1. Introduction of new technology into EVs
2. Use solar cells to assist in battery charging
3. Achievement of ultra-small vehicle bodies for convenient city commuting

The goal is to realize a "small, high performance, ultra-safe, extra comfortable, and high fuel efficiency" vehicle. This paper describes the ECO-Vehicle in detail.

2. Basic concept of the ECO-Vehicle

To become popular, EVs must have enough performance and utility to satisfy consumers. If we use present technology lead-acid batteries to power an EV, it is hard to achieve the same range as that routinely achieved by internal combustion engine vehicles (ICEVs). Therefore, EVs with lead-acid batteries are not suitable for travelling a long distance travel. However, there are many markets for second and third cars in the industrialized countries. Vehicles in this category are generally used only for short trips such as daily commuting to nearby offices or for shopping. In such cases, the car usually carries only a driver,and only rarely, an additional person or large baggage.

In addition, there is a forecast that motor vehicles will become very popular in developing countries in the near future. Thus, besides large increases in energy consumption and environmental degradation, traffic jams will also become a more serious problem.

For these reasons, we tried to achieve high performance with a lead-acid battery powered EV in the ECO-Vehicle project by adopting new technology. The innovative technologies used in this project were:

a. New type of drive system
   (In-wheel motor drive system)
b. New concept frame structure
   (Battery Built-in Frame (BBF))
c. New battery management technology
   (Battery management system)

The most striking characteristic of the vehicle is that it carries 2 passengers seated in-line. This tandem-style has been tried before in the German ICEV Messerschmitt and it would be more reasonable and realistic to adopt this style for EVs designed with the above mentioned new technology. This type of seating has several advantages. First of all, the vehicle can be parked easily, as it has a narrow body. Also, road lanes could be narrower if this design were to be widely adopted. The widths of present full-size buses and trucks are 2.5 m. The present width of parking spaces are set between 2.5 m to 3.0 m. However, the ECO-Vehicle is only 1.2 m in width, making possible to park two ECO-Vehicles in one parking space. If all vehicles were of this size, then each existing road lane could be used as two lanes. This feature would be a great advantage of such vehicles for city usage.

Second, although the vehicle is narrow externally, interior personal space remains large. For a typical person, this width is more than sufficient, even if the vehicle has the thick doors to protect against side impacts.

The third characteristic of this design is easy operation. The narrow body and central driving position make driving remarkably easy. This ease of operation is helpful for beginners, and reduces the probability of traffic accidents.

Fourth, air drag is relatively low because of the narrow body.

On the other hand, there are some disadvantages to these tandem two seat vehicles. One is the low vehicle stability caused by the extremely narrow tread. As for the ECO-Vehicle, however, the BBF design can solve this problem. As a result of under-the-floor battery storage with BBF, the ECO-Vehicle has a fairly low center of gravity and remains highly stable.

The other problem of the tandem seating arrangement is the relatively small space in front of and behind the passengers. However, on this particular EV, this was not a big problem. Because of the in-wheel motor drive system, the space like 'engine compartment' like that required in ICEVs was not necessary at all and that space can be used for the passenger cabin. Thus the passengers have enough room.

Additional characteristics of the ECO-Vehicle aside from its external style are described below. First, the acceleration performance and the maximum speed are higher than those of current ICE powered 'minicars'. This power is achieved with high power twin in-wheel motors of 36 kW output each, for 72 kW overall. Also, the range per charge was considerably expanded despite the use of conventional lead-acid batteries. This extended range was the result of the low energy consumption of this ground up electric vehicle design. Each component was appropriately designed for electric vehicles and achieved extremely low energy consumption.

The miniaturized body also contributed to high efficiency. Noise and vibration are low because the car has the electrically-powered system that makes the vehicle fairly comfortable. The lack of a transmission makes the car easy to drive.

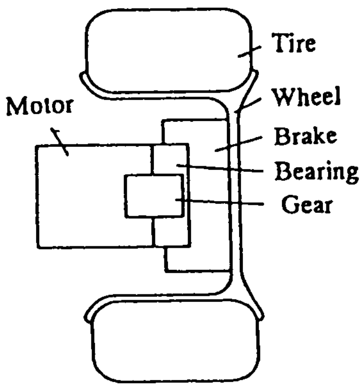

Fig.1 Conceptual Drawing of the in-wheel drive system

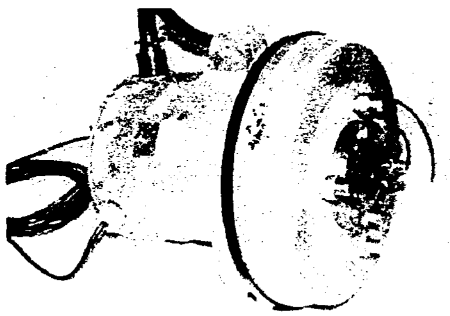

Fig.2 Photo of the Driving System

3. The new technologies for the ECO-Vehicle

Several innovative solutions which were incorporated into the ECO-Vehicle are described below.

3.1. In-wheel motor drive system

In the EV named IZA, which had been developed by one of the authors, the in-wheel motors directly drove the wheels. The motors were of the outer rotor type, and were connected directly to the wheels. This mechanism was simple and highly efficient at constant speed. However, the motors had to be heavy and efficiency during acceleration was not good.

Inserting deceleration gears between the motors and the wheels was an effective way to solve this problem.

Figure 1 shows the conceptual design of the in-wheel motor drive system. We used inner rotor type brushless DC motors to achieve high efficiency. The output of the rotation axis was decelerated with planetary gears. Hub bearings and drum brakes were also built into the structure of these motor-wheel units. The drive system which was developed based upon this concept was directly installed on the suspension arms of the car (Fig. 2). Simply installing the wheels and tires of this driving system, makes the car ready to run. On the ECO-Vehicle, the drive system was installed in each rear wheel.

The specifications of this drive system are shown in Table 1. The maximum torque of each motor was 74 Nm, with a maximum speed of 8700 rpm, and a maximum power output of 36 kW. The maximum efficiency of the motor was 92%, and the transmission efficiency of the deceleration gear system was 95% to 97%, thus the maximum efficiency of the whole drive system became 88%.

The total weight of the drive system, consisting of the motor, the gear, the bearings, and the brake, was 25 kg. This remarkable lightness was achieved to optimize efficiency. The switching elements for the invertor were IGBTs.

Table 1 Specifications of the ECO-Vehicle's drive system

System	In-Wheel System with Reduction Gear
Motor	
Type	Brushless DC
Maximum Power Rating	36 kW
Maximum Torque	74 Nm
Maximum Speed	8700 rpm
Reduction Gear	
Type	Planetary System
Reduction Ratio	5
Brake	
Type	Regenerative plus Mechanical
Mechanical Brake Type	Leading and Trailing Drum Brake
Drum size	8 inch diameter
Weight of the Drive System	25 kg

3.2. Battery built-in frame

It has been said that the heavy weight of the batteries is one of the technological problems of electric vehicles. Moreover, the bulk of the batteries is a big problem. The volume of the approximately 300 kg of batteries necessary for an EV would be 1.5×10^5 cm^3 because the density of the batteries used in EVs is about 2 g/cm^3. The space under the front hood and the trunk have been used to store the batteries in many converted EVs. Some EVs required the use of a part of the cabin as well. Even the height of some vehicles must be raised to fit the batteries beneath the floor. Each of these alternatives reduces the usable space in the vehicle.

On the other hand, the exhaust pipe of ICEVs must have 8 to 10 cm beneath the floor. Multiplying this height by the floor area implies a much bigger volume available than the capacity of the batteries we use in our EV. Therefore, if we place the batteries beneath the floor, then it is not necessary to sacrifice space for them from elsewhere and our EV could have the same floor height as is found in ICEVs.

The Battery Built-in Frame is an effective way to store the batteries beneath the vehicle floor. The BBF was made of aluminum (Fig.3) by taking advantage of new technologies for aluminum extrusion. We installed 56 batteries in our BBF. The twin center frames each included 18 batteries, and the side frames held 10 each. The size of each battery was 135 (length) × 167 (width) × 81 mm (height). The thickness of the aluminum structural material was 2 (lower) and 2.5 mm (upper).

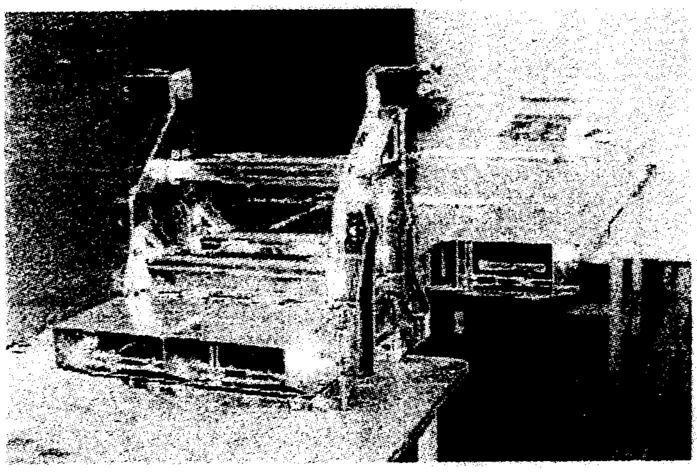

Fig.3 Photo of the BBF

3.3. Battery Management System

The lifetimes of series-connected batteries in EVs are much shorter than those of single batteries. Recently, this shortening of lifetimes of series-connected batteries was found to be the result of unequal charging due to differences among batteries in performance or temperature. Repetition of this uneven battery charging will cause the differences between batteries to increase. The lifetimes of less-charged batteries shorten, and they, in turn, shorten the lifetime of the entire series as well.

To solve this battery lifetime problem, it is necessary to reduce the temperature differences between the batteries, and to charge them evenly. The batteries in the BBF were placed on the trays which includes heat pipes to equilibrate their temperatures and cool them with air flow. The batteries were equipped with local 12 V chargers (65 × 127 × 14 mm; 150 g) to charge them equally in groups of 3 (Fig.4).

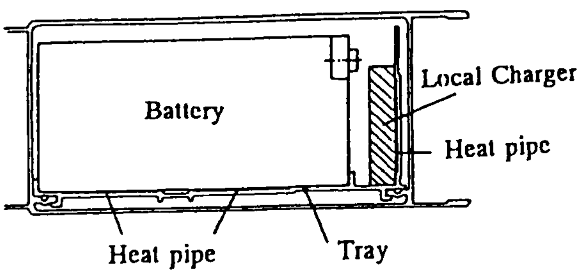

Fig.4 Section of the BBF

4. Other vehicle components

4.1. Body

The BBF comprised the lower part of the vehicle body. The upper part of the body was structured and held rigid by an extruded aluminum frame (Fig.5). The external body was molded of Carbon FRP and connected to the frame with bonding compound, rivets, and bolts. As a result, the body was light, in addition to being strong and rigid. Doors were installed on both sides of the vehicle to facilitate passenger entry and egress from either side. The body was designed to decrease air resistance as much as possible (Fig.6).

The air drag coefficient of this mock up was 0.25 and its front area projection was 1.22 m^2.

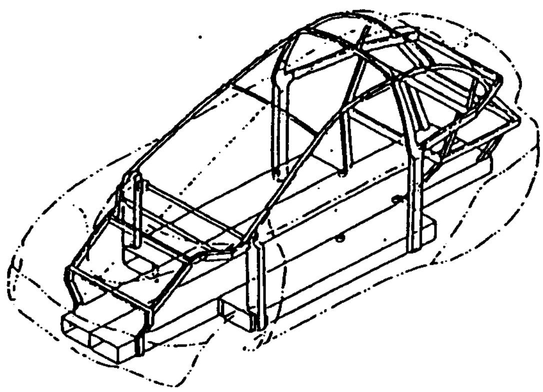

Fig.5 The body structure of the ECO-Vehicle

Fig.6 Exterior design of the ECO-Vehicle

4.2. Suspension

Double-wish-bone suspension structures were installed on both the front and the rear to maintain stability. The suspension arms on the rear wheels were directly attached to the casings of the in-wheel motors.

4.3. Steering System

The steering gear was of rack and pinion type and the maximum inside-wheel steering angle was 36.7 degrees. An electric operated power steering system was installed on the steering shaft.

4.4. Brakes

The ECO-Vehicle has both regenerative and mechanical brakes. It was important to consider the correspondence between the regenerative brakes and the mechanical brakes. We decided to apply the brakes differently according to the following 3 criteria:

a. Under deceleration of 1.5 m/sec^2:
   Only the regenerative brakes (rear wheels)
b. Between 1.5 m/sec^2 and 3.0 m/sec^2 of deceleration:
   Both the regenerative brakes (rear wheels) and the mechanical brakes (front wheels)
c. Over 3.0 m/sec^2 of deceleration:
   Both the regenerative brakes (rear wheels) and the mechanical brakes (all wheels)

Under typical daily driving conditions, most of the braking deceleration is less than 1.5 m/sec^2.

Thus, most of the braking power of the vehicle could be re-generated to electricity by the regenerative brake system. When more deceleration power is necessary in emergencies, the four mechanical brakes of the four wheels are used for safety.

4.5. Batteries

The batteries of the ECO-Vehicle were the sealed lead-acid type. Each one of the batteries were 4 Volts and 40Ah. 56 packs of these batteries were serially connected to output 224 Volts. Each battery weighed 4.8 kg and the total weight of the batteries was 269 kg.

4.6. Tires

The tires for any electric vehicle need to have a low coefficient of rolling resistance. Furthermore, they should also be safe and provide a comfortable ride. Therefore, we decided to use radial tires. To improve comfort, we selected aramid fibers to replace the steel belts, and used a silica mixed compound for the tread rubber. As a result, the coefficient of rolling resistance was reduced to 0.0068.

4.7. Solar Cells

On the ECO-Vehicle, multi-crystalline type solar cells were attached to the roof and to the rear spoiler to supplement the energy available for running as much as possible. The total area of the solar cells was 0.6 m^2, and they generated a maximum of 70 W. If the vehicle were to be parked outside under full sunshine, then the maximum possible electricity generation each year would be about 72 kW because total Japanese daylight time is about 1800 hours per year. This is equivalent to fully charging the batteries of the ECO-Vehicle 8 times.

4.8. Lighting System

The lights of EVs must be energy efficient. Therefore, High Intensity Discharge (HID) lamps were selected as the lower front lights, which were more frequently used.

The efficiency of these discharge lamps was about 20%, while that of conventional filament type lamps is only about 5 %. For the tail lamps, LEDs with efficiency of about 30 % were used.

4.9. Air Conditioning System

An electric heater was installed in the seat. An invertor controlled heat pump system with an electric compressor was used for air conditioning.

4.10. Interior Parts

The instrument panel (Fig.7) was a one piece plastic mold type, with meters and switches for the seat heater, defroster, and audio. The front bucket-type seat could slide back and forth over a range of 180 mm. The rear seat was 600 mm wide and could be occupied by two children.

One of the prototype vehicles selected had a specially designed interior true to the new electric vehicle image: 'ecology', 'quiet', and 'clean energy'.

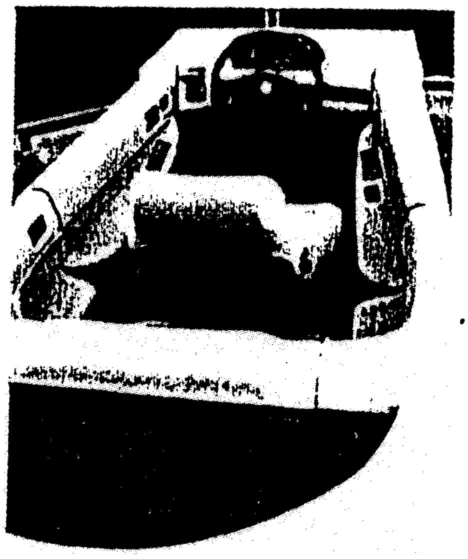

Fig.7 Interior design of the ECO-Vehicle

5. The performance forecast

The vehicle performance was estimated by a computer simulation (Table 2). The range per charge would be 140 km at a constant speed of 80 km/h. On a Japanese 10.15 mode city driving schedule, the range would be 130 km. 0-400 m acceleration time from a dead stop would be 17.9 seconds and the maximum speed would be 130 km/h. The energy consumption rate would be 0.064 kWh/km for 10.15 mode schedule driving. If we assume efficiencies of power generation, transmission, and charging of 37%, 94% and 77%, respectively, then the range for 1 liter of oil consumption would be 50 km. The annual 10.15 mode driving distance which the ECO-Vehicle could travel by solar power alone would be about 1000 km.

Table 2 Specifications of the ECO-Vehicle

Length:	3.3 m
Width:	1.2 m
Height:	1.34 m
Passenger:	2
Gross Vehicle Weight:	910 kg
Battery Weight:	269 kg
Range	
40 km/h const. speed:	300 km
80 km/h const. speed:	140 km
4 mode Schedule:	190 km
10•15mode Schedule:	130 km
Acceleration	
0 to 40 km/h:	3.9 sec.
0 to 400 m:	17.9 sec.
Maximum Speed:	130 km/h
Energy Consumption:	50 km/liter

6.Result of interviews after driving

The selection of about 80 persons to drive the ECO-Vehicle was made to ask the feeling of it. Before the driving, most of people are believing that it was not practical. But, after they drove it, most people changed their mind. They said "no noise, no vibration and easy to drive". Several people were afraid that the vehicle was too quiet. And more than 20% of people showed the willingness to buy it, if its price will go down to a reasonable level.

7. Summary

We had developed the ECO-Vehicle as a dramatic solution to the problems of motorized societies; environmental degradation, profligate energy consumption, traffic accidents, and traffic jams. This tiny vehicle has extraordinarily high performance, safety, and comfort. Needless to say, low energy consumption was achieved as well.

If large quantities of such vehicles were to be produced, then there would be no reason why they should cost more than current ICE cars, because the EV has many fewer parts. Moreover, we used lead-acid type batteries in this project, but there is a possibility that the range per charge could be rapidly improved with nickel hydrogen or lithium ion type batteries which are now under development.

We are eager to popularize these EVs as personal transportation systems for the next generation.

REFERENCES

[1] H. Shimizu et al., "Development of a high performance electric vehicle, IZA", JSAE Review, Vol. 14 No. 2, pp. 76-80, April, 1993.

[2] H. Shimizu, "The new possibility of electric vehicles", IATSS Research, Vol. 17 No. 2, pp. 24-33, 1993.

[3] H. Shimizu, "A proposal for sustainable development: the Asia-car", the Second 21st Century Earth Awards, pp. 21-30, 1993.
[4] H. Shimizu, and K. Sugiyama, "The battery built-in frame - A new frame structure for an EV", Symposium Proceedings of the 12th International Electric Vehicle Symposium (EVS-12), pp. 609-614, December, 1994.
[5] H. Shimizu, J. Harada, and C. Bland, "The role of optimized vehicle design and power semiconductor devices to improve the performance of an electric vehicle", Proceedings of the 7th International Symposium on Power Semiconductor Devices and ICs (ISPDS '95), pp. 8-12, May, 1995.
[6] H. Shimizu, J. Harada, C. Brand, K. Kawakami, and L. Chan, "Advanced Concepts in Electric Vehicle Design", (To be published).