Designing Engines of Compact Battery-cars for the Target Speed of 100 km/h Using Nickel-system Primary-cells (Oxyride Dry-cell Batteries) : Part 1 Optimization of the Body

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Abstract
In an attempt to convince people that battery-cars are high-efficiency vehicles, a project was conducted to demonstrate that dry-cell battery-powered vehicles can carry people and run at 100 km/h. Various types of resistance to run were reduced; the numbers of batteries on board, the shape of the vehicles, and the power-train were optimized; and the cars accomplished a top speed of 115.9 km/h at the Shirosato Test-course of the Japan Automobile Research Institute in Ibaraki-prefecture, on August 4, 2007. This paper describes the designs of the vehicles, and the motors and tires, in this research project.

Keywords
electric vehicle, dry battery vehicle, 100 km/h project, oxyride battery, high efficiency vehicle, DD motor, Guinness Book, high-efficiency tire

1. INTRODUCTION
As a global-warming control measure, vehicles for which the source of power is not fossil fuel are being actively developed all over the world. Most of these vehicles are not developed to satisfy convenience, comfort and other such demands by people. They inherit the modes of fossil fuel-powered vehicles and they don't go beyond this category. This project attempted, from a largely different point of view, to show that battery-cars are so high in efficiency that, even if they are powered by commercially-supplied dry-cell batteries, they can still run at a speed of 100 km/h (because such battery-cars are highly efficient). The type of dry-cell batteries used in this project are the highest-output Nickel-system primary-cells (hereafter called Oxyride dry-cell batteries). Designs and developments were carried out to realize a target speed and to create a compact battery-car which can run at a high speed.
On April 29, 1899, Mr. Camille Janatzy, a Belgian, recorded at speed of 105.88 km/h in Achères, France. It was the first time for a human to go beyond the speed of 100 km/h. Since the record was achieved by means of a battery-car, the aim of this project is "to attain a speed of 100 km/h by using Oxyride dry-cell batteries," and an additional aim is "to go beyond the maximum speed of 105.88 km/h." As far as we know, there are no other projects for high-speed running using dry cells.
Production of high-efficiency and low-resistance power systems and the maximization of cell output are essential in the development of compact battery-cars using dry cells, where output is limited. This paper describes the designing of the power systems and the development results. Examination of the output performance for Oxyride dry-cell batteries is discussed in another paper, "Designing Compact Battery-car for which the Target Speed is 100km/h Using Nickel-system Primary-cells (Oxyride dry-cell Batteries) Part 2: Battery System Optimization." [Ashida and Minami, 2007] For the design of power systems, the engine performance needed to achieve the goal was calculated, and the specifications of the special compact battery-car needed to achieve the goal were decided. Then the special body, motors, drive-trains and tires were developed in accordance with the specifications.
Figure 1 shows the photograph when the max. Speed of

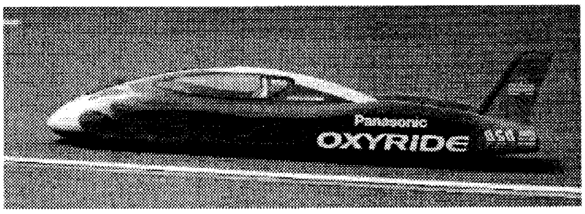

Fig. 1 A picture of when the max speed of 115.9 km/h was recorded during the running test.

115.9 km/h was recorded during the running test.

2. DEVELOPING THE BODY

Production of high-efficiency and low-resistance power systems and the maximization of battery-output are important elements in the attempt to achieve a goal of 100 km/h with a compact battery-car. Safety is also important, in addition to the importance of weight saving and high efficiency in performance. The list below shows what we should resolve in the design development of compact battery-cars which can perform at a high speed.

(1) Development of car bodies which are light, high-strength and excellent in aerodynamic performance
(2) Development of light, compact and high-efficiency motors and drive-trains
(3) Development of exclusive tires with little rolling resistance
(4) Optimization of the number of Oxyride dry-cell batteries on board

This paper describes items no.1 to no.3 listed above. No.4 will be described in another paper [Ashida and Minami, 2007].

2.1 Development of light and safe car bodies with high performance power

Car bodies with high performance power are required with lightness, strength and a little cruising resistance. The cruising resistance related to car bodies varies, and air resistance, rolling resistance, grade resistance and acceleration resistance are discussed here.

Air resistance, Ra, is a formula of $Ra=\rho\lambda Sv^2/2$. Here, ρ represents air density, λ is the air resistance coefficient, S is the car frontal projected area, and v is the running speed. [Ikegami, 2007] Since air resistance increases in proportion to speed squared, resistance becomes extremely large at 100 km/h; thus, reducing air resistance is an important factor in achieving the overall aim. "Minimization of the car frontal projected area," a body size which helps air to flow easily," and "control of the air-flow turbulence towards the rear area of the car" are some methods used for reducing resistance. The air-resistance coefficient of commercially-supplied cars today is at the level of 0.23-0.5. Based on the experiences of the past, the compact battery-car used in this project is designed with the aim of keeping the coefficient at a level of 0.13, which is lower than half the level of commercially-supplied cars.

Rolling resistance, Rr, is the formula $Rr=W\mu$. Here, W represents the gross weight of the car, and μ is the coefficient of rolling resistance [Ikegami, 2007]. The rolling-resistance coefficient is greatly influenced by such elements as road-surface condition, the friction resistance of tires, load on wheels and car bearing. Reducing the rolling friction resistance of tires and the total weight of the car are important elements in developing the car. One of the goals of this project was to make the total weight of the car under 100 kg, including consideration of human body weight, without compromising car safety.

Grade resistance, Re, is the formula of $Re=W\sin\theta$. Here, W means the total weight of car and è is the gradient [Ikegami, 2007]. Traveling on a slope with a gradient is not planned for with the developed car, and thus Re=0 here.

Acceleration resistance, Rc, is the formula of $Rc= b(W+\Delta W)$. Here the accelerated velocity is b, W represents the total weight of car, and ÄW is equivalent inertia weight of the rolling part of the driving area. Though reducing the total weight is an important element in developing this particular car, acceleration performance is also an important in order to achieve 100km/h within a limited time and distance. Acceleration resistance is also largely influenced by the driving techniques of the driver. In this paper evaluations are conducted on the assumption that a 60-second constant acceleration is carried out until the travel speed of the car reaches 100km/h after its start. This is based on the concept that acceleration is constant as a primary proximity when constant power is input.

2.2 Development of light, compact and high-efficiency motors and drive-trains

Developing a motor and drive-train with high total efficiency with assured basic performance is essential in order to take full advantage of the properties of Oxyride dry-cell batteries as a source of power for the developed car. As much weight saving for the motor and drive-train as possible is important in addition to the development of the body, while satisfying the demand for performance. More than 90 % efficiency for the wide current range was targeted in developing the motor in this project. The design was made by using an in-wheel motor system which has no mission-gear, no differential gear, as well as no drive-train, and with drive motors built in on both rear wheels, in order to minimize the transmittance loss.

2.3 Development of exclusive tires with a little rolling resistance

Reduction of rolling resistance is an extremely important element in this project, as is described above. Thus, exclusive tires were to be developed while placing importance on lower rolling resistance and puncture-resistance. The aim was to develop safe tires with a 20 % weight-saving in comparison to standard bicycle tires.

2.4 Safety

The problems that should be resolved in developing the car are: a car shape with small air resistance (which is known as aerodynamic performance), a high-efficiency motor and drive-train, development of tires with small rolling resistance, and the production of a light car body. High strength for the car body is necessary in order to secure the safety of the driver in a situation where the target speed is also as high as 100 km/h. A design is necessary which can balance the competing goals of securing safety and the weight-saving of car body.

3. DESIGND AND PRODUCTION OF THE CAR BODY

In this chapter, the car performances needed to achieve the goal of this project are sought, and the specifications are decided, including the size and shape of the car to be developed. The designing of the body, motor and drive-train were carried out based on the results.

3.1 Plan and design of the body

Table 1 shows the specifications of the targeted body. Transmittance efficiency is 100 % at this point. A Direct Drive-system, by which the tires are set on the output terminal of the motor and directly driven, is applied (details are described in the chapter on the motor). A rear 2-wheel drive is applied, since a 2-wheel drive tends to use less input-power than a one-wheel drive, according to studies in the past. [Fujita et al., 2006]

Table 2 shows various resistance values, which are calculated based on the body specifications. As the table shows, acceleration resistance and air resistance are dominant among all of the travel resistance of the car body. Developing a motor with a high efficiency and leeway for output, a body shape with a small air resistance during travel at high speed, and tires with a small rolling resistance is important in order to achieve the targets. Gradient resistance is not added, since climbing a road is not included in this project.

Table 2 Various resistances and all travel resistance applied to the car body (Based on the specifications in Table 1)

Rolling resistance (N)	2.45
Air resistance (N)	21.32
Acceleration resistance (N)	47.22
all running resistance (N)	70.99

A thin, low, long and smooth body shape was applied by referring to the speed-record challenging car, "BERTONE Z.E.R.," which was presented in 1994 by Italy's BERTONE [EV world, 1995; Calliano, 1995]. A vertical tail fin, like an airplane's, is also a feature often seen in many speed-record cars in the past. The vertical tail fin is also used in this project as an important piece of equipment, in order to increase the straight-ahead movement of a light car.

Figure 2 shows the electric power expected to be necessary at each travel speed, according to the body specifications set as a goal. Power consumption (W) increases in proportion to speed increase. (A constant acceleration for 60 seconds is applied up to a speed of 100km/h.)

Figure 3 shows the characteristics after eliminating the acceleration element from the electric power which is expected to be necessary in Figure 2. In the case where the car cruises at the same speed after it has achieved the target speed, electric power is still necessary after eliminating the acceleration element from the required electric-power. Figure 3 shows the power expected. In these figures, *m* represents the rolling resistance coefficient, W is the total weight of the car, DW is the equiva-

Table 1 The specifications of the targeted body

Supply voltage (V)	24-48	Running speed (km/h)	100
Temperature (℃)	20	Air resistance coefficient (Cd)	0.13
Air density (kg/m^3)	1.25	Car frontal projected area (m^2)	0.34
Motor average efficiency (%)	91	Body size (L-W-H mm)	3300-780-510
Drive-train transmittance efficiency (%)	100	Weight of car body (kg)	45
Total weight of car body (kg)	(when one person on board) 100	Tire diameter (cm)	34.0
Road resistance coefficient (μ)	0.002	Motor and drive wheel	DD motor Rear 2-wheel drive

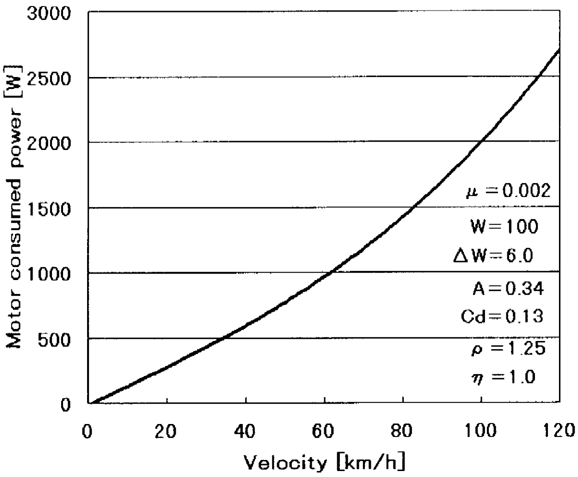

Fig. 2 Expected electric power needed at each travel speed (Electric power at each speed needed to achieve 100 km/h at a constant speed from a stationary position)

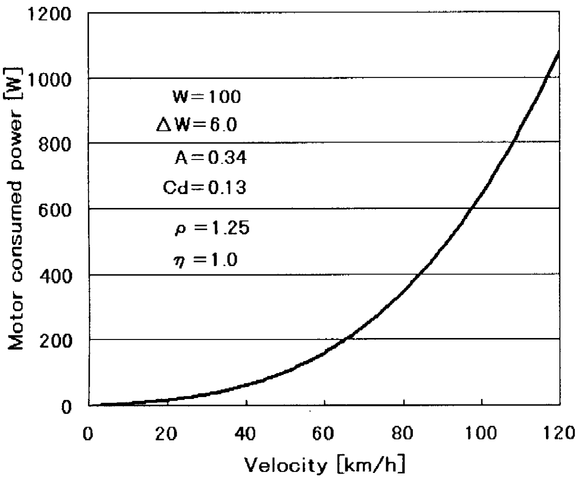

Fig. 3 Electric power needed at a constant speed

lent inertia weight of the rolling part of the driving area, A is the car frontal projected area, Cd is the air resistance coefficient, ρ is the air density, and η is the drive-train transmittance efficiency.

Figure 4 shows 3 1/4-scale models produced experimentally to review the body shape. Three kinds of scale models were made simultaneously in order to shorten the time needed to finalize the shape eventually, the shape of the scale model on the very left was decided on. The 3 kinds of scale models were compared in terms of measurement and experience in order to decide on a shape. The frontal projected area was 0.34 m^2 in all the scale models. The CD value of the air resistance coefficient could be expected to be at the same level, approximately between 0.11 and 0.12. The round nose shape was the reason for deciding on the scale mode on the very left of the Figure. This shape is similar to a droplet shape. The

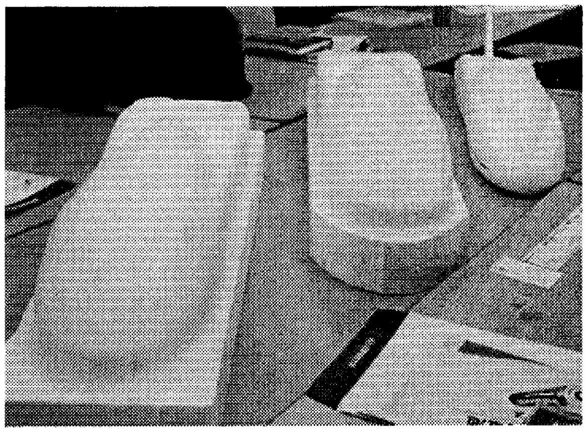

Fig. 4 Three types of scale models.

corner of the scale mode in the center in the Figure seems to swell up a little in comparison to the model on the very left Delamination of air is expected to be generated on the right and left front edges with this kind of shape, according to a basic wind-tunnel study conducted during the production of solar cars by Osaka Sangyo University for a solar-car project. The front edge of the scale mode on the very right is similar to the one on the very left when it is observed at grade level, but it has a cutback between the body and the shelter area, and this area can prevent the smooth flow of air on the body surface. Based on reviews, the body shape on the very left was decided on for use. Basic experiments and experience gained from the production of solar cars were made use of because solar cars travel at high speed.

The relative merits of the body shapes can be studied from this angle. As a result of the study, it was decided to use the shape on the very left.

The drawing shows the size of the driver's seat inside the car, which is big enough for the average Japanese to be able to sit in, and was calculated based on the final-

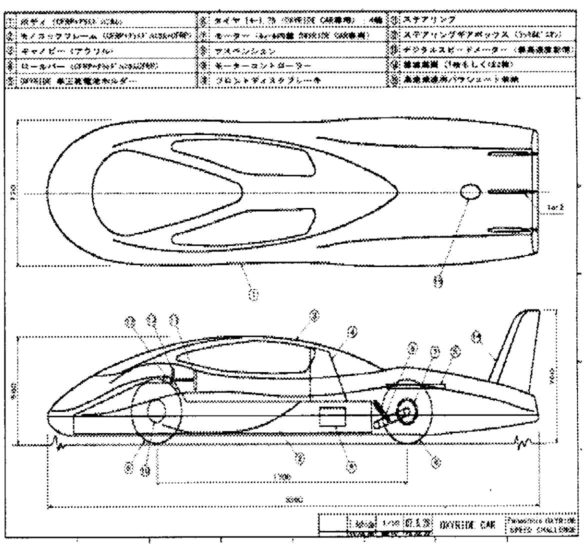

Fig. 5 Body size and layout drawing of device

ized scale model, and the motor, controller, driving device, suspension, and steering gear which were allocated. The frame of the car is a monocoque of CFRP+aramid-honeycomb sandwich-panel combined-material, and the combined shaping of the CFRP and aramid-honeycomb was applied to the body. A heat-shaped acrylic resin-sheet was used for the window screen, and a CFRP rollover-bar was used to secure the safety of the driver's head in a case of a rollover.

As to the brake mechanism, an oil disc-brake was used for the front wheel and the rear wheel used a regenerating brake which uses a drive motor as its generator and retrieves energy of motion. The regenerating brake was operated by a switch mechanism which was built in the brake bar and which controls the oil brake in the front wheel, and it operates together with the brake for the front wheel.

3.2 Production of the car body

3.2.1 Artifice of the master model

Here, the process of manufacturing the car body is discussed. Figure 6 shows a picture of the process of producing the master model, which is the first step in producing the car body. The quality of this master model decides the quality of the completed car. A full-size master model was shaped with low-foam Styrofoam plastic, based on the 1/4-scale model and a drawing of the outer-shapeStrains on the surface were modified in details, and the model was completed to avoid a stagnation flow of air.

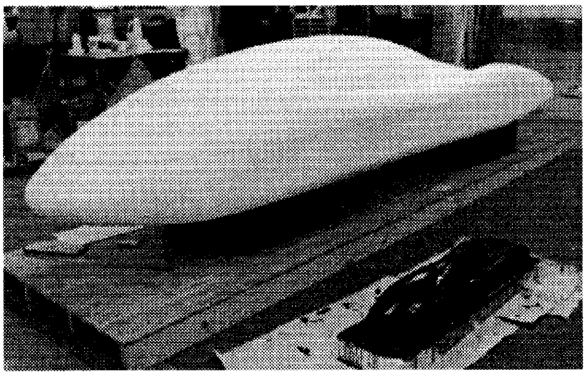

Fig. 6 The master model shaped from low-foam Styrofoam plastic.

The one-fourth scale model, which is painted in black, is at the near side.

Figure 7 is the completed master model. The surface was solidified with epoxy resin in order to assure the strength of a surface made with low-foam Styrofoam plastic. The surface was further polished so that it became smooth, and the model was completed after the bumps, rises and falls and other defects were puttied

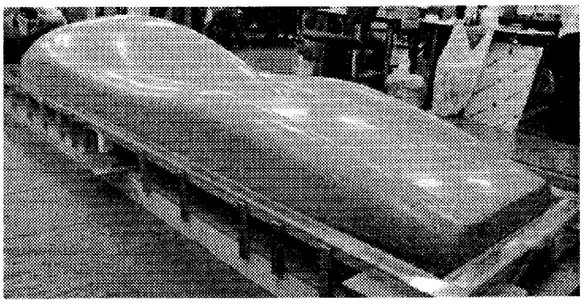

Fig. 7 The 1/1 master model, completed after the surface was solidified with plastic and polished

and polished. The surface was so polished that it showed the reflection of what was around it. It did not have a vertical tail fin at this point yet. It was surrounded with stiffening aluminum square pipes.

3.2.2 Production of a female die

Figure 8 shows a picture of the female die for the upper parts of the car body, which was completed over a painted FRP of epoxy resin and glass fiber after demolding the master model. This is a situation whereby the positive and female dies are reversed. The female die for the lower part of the car body was manufactured in the same way.

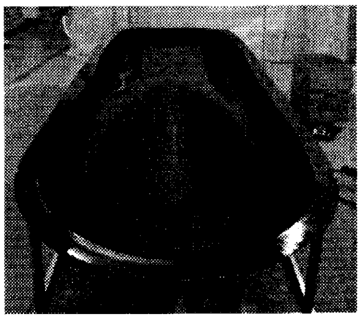

Fig. 8 Completed female die for the upper part of the body

3.2.3 Body molding

Figure 9 shows a picture of the CFRP-made upper part of the body. It was completed with heat hardening after

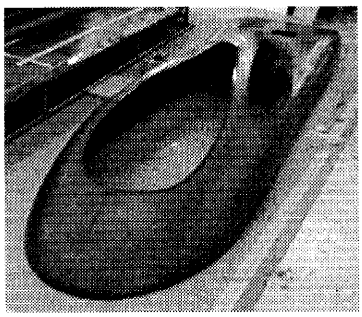

Fig. 9 Completed CFRP-made upper part of the body

lamination of the carbon-prepreg and aramid-honeycomb. The lower part of the body was also molded by the same process.

Figure 10 is a picture confirming the construction situation of the periphery and each part of the body after placing the completed upper body on the completed lower body. The square hole at the rear area is a window to check the battery cells on board.

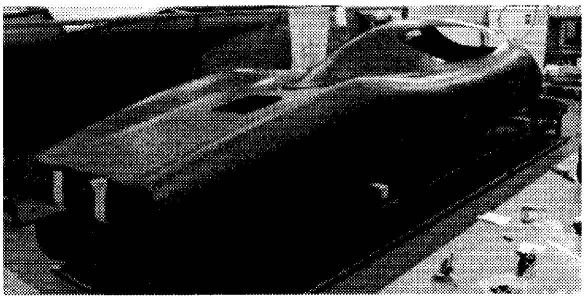

Fig. 10 CFRP-made lower part and upper part of the body

3.2.4 Assembly

Figure 11 is a picture taken when final checks were conducted before the assembly started, to see if there were any problems of interference and matching among the parts. The joint-frame of the CFRP and aramid-honeycomb can be seen before it was adhered and built inside of the lower part of the body.

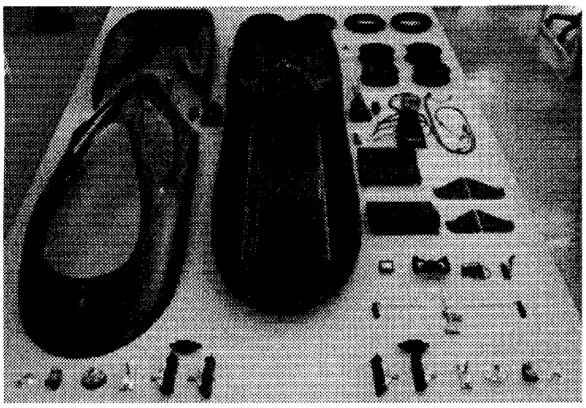

Fig. 11 Each manufactured part before assembly

3.2.5 Field tests

Figure 12 is a picture of a field test with the completed car. The field test was conducted after the car was assembled and before the final coating was done, in order to check if there were problems. The final car-body weight was 38 kg, for reasons including the adoption of a Direct Drive-system motor, and 50 kg of the driver's weight was added, so that in total it was 88 kg. That is 12 kg lighter than when the body was planned at the

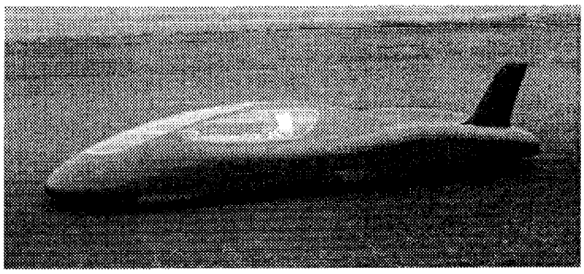

Fig. 12 Photograph of a field test for the car body

beginning, and this means that a weight saving of 12 kg was achieved. This also means about 8 % of energy saving.

4. DESIGN AND PRODUCTION OF THE MOTOR

The motor was designed based on a calculation of necessary electric power during travel, which was examined in 3.1. That is, the total travel resistance, the rolling resistance, the air resistance and acceleration resistance (Table 2) were calculated, based on the specifications of the car body (Table1), which were decided on when designing the car and based on the values of the graph in Figure 2: "Expected electric power needed at each travel speed." The average and peak electric power needed from a stationary position to driving at 100 kn/h were calculated by referring to the graph in Figure 2, and that value became the performance demanded of the motor (Table 3). The number of rotations of the motor was calculated from the number of rotations of the tires at 100km/h.

Table 4 is the output performance of battery cells needed in the motor in development. The specifications are less tight in comparison to the figures in Table 3, which were calculated from the specifications of the car. As to decision making on the performance needed for developing the motor, the parameters were made by referring to catalogue data relating to the characteristics of Oxyride dry battery cells, which are the energy source. The supply voltage was changed from 48 V (Table 3) to 25 V (Table 4), because of the assumption of loaded voltage depression (loaded drooping characteristics). The aim of this project is to travel a 1km-measuring area at an average 100 km/h, and thus sustaining the speed in the measuring area is required even though further acceleration is not necessary. The inner resistance in the battery cells, the source of power, increases because of power consumption, and the speed needs to be maintained even after the voltage depression has increased. In order to accelerate beyond 100 km/h and maintain the speed with commercially-supplied dry battery cells, of which the output is limited, it is important to develop motors which use the energy to a maximum extent in the limited distance. A motor with a larger output was formulated so

Table 3 The performance demanded of the motor based on the car specifications (at 100 km/h)

		After adjustment of the motor efficiency
Number of rotations of motor (rpm)	1560	-
Motor output (W)	2024	2200
Supply voltage (V)	48	-
Power consumption (A)	42.17	45.83

Table 4 The output performance of battery cells needed in the motor in development.

	Motor performance of the entire body	Performance per motor
Number of motor rotations (rpm)	1700	1700
Motor torque (kg·cm)	60.0	30.0
Motor output (W)	2200	1100
Supply voltage (V)	25	25
Power consumption (A)	88	44
Battery output duration (S)	120	120

that the speed could go over 100 km/h, as preparation in a case of headwind. It is important to decide torque so that the number of motor rotations will be appropriate for the desired speed. Drive motors were built in for both of the rear wheels in order to minimize the transmission loss of drive force. The motor was manufactured according to the specifications above.

Table 5 shows the finalized motor specifications. A total efficiency of more than 90% was demanded as the specifications for the necessary motor and transmittance system. The use of a Direct Drive system, which is effective in avoiding deceleration loss and driving loss, is a structural characteristic of the system. The structure serves to minimize the energy transmittance loss of: motor → reduction gears → driving-device → tires. Motor efficiency is equal to the transmittance efficiency of all the driving system, because tires are put in directly to the motor shaft, then activated, and thus it is possible to aim for a high-efficiency system with more than 90% of total efficiency, including motor efficiency.

Motor and controller response to changes of supply voltage is necessary in order to enable smooth acceleration, even with a supply voltage which changes constantly due to the load current at acceleration. The specifica-

Table 5 Finalized motor specifications

Motor specifications	
System voltage	20-40 V
Type	M1048R renewed
Exterior size	φ135 mm×L100 mm
Weight	2.5 kg
Format/drive-system	DC brushless motor/in-wheel DD
Maximum output	approximately 2 kW
Maximum efficiency	more than 90 %
Rated number of load rotations	1700 rpm
Rotation direction	CW (clockwise) · CCW (counter-clockwise)
The number	CW 1 / CCW 1: total of 2

Table 6 The finalized specifications of the controller

Specifications of controller	
Type	M0548C
Exterior size	W130 mm × D147 mm × H58 mm
Weight	0.9 kg
Cooling method	air cooling
Rated input voltage	24 V
Input voltage	18-63 V
Driving system	120-degree square-wave energizing
Regenerating function	boost-regenerating function (with ON/OFF controlling switch)
Control system	
Speed (output) control	PWM+electron angle 16-step (Maximum angle +30°)

tions were made to enable further acceleration after increasing the motor rotation speed, even if the voltage decreased, by widening the power-distribution angle and having field weakening in stages, according to voltage depression. The effect was checked by the field tests. Table 6 shows the specifications of the finalized controller based on the results above. A characteristic of the controller is that a manual 16-step electron-spark was equipped, in addition to the traditional PWM-system, as a means of controlling speed. In the case of an ordinary DC brushless-motor, generally the timing for energizing is fixed, or vector-control field weakening is used when speed control is necessary. This controller enables the driver to widen the electric angle by 2 degrees per step over 16 steps, with the maximum angle being 30 degrees. This makes it possible to change the torque and the characteristics of the rotating speed (T-N characteristics) without sacrificing efficiency characteristics, and this becomes an effective method to control the speed degradation caused by voltage depression (loaded drooping characteristics) of Oxyride dry-battery cells.

As to the rear wheels equipped with a DD motor (because of structural space), it is difficult to load a mechanical brake in relation to the structural space, and a boost-regenerating function was adopted as a brake sys-

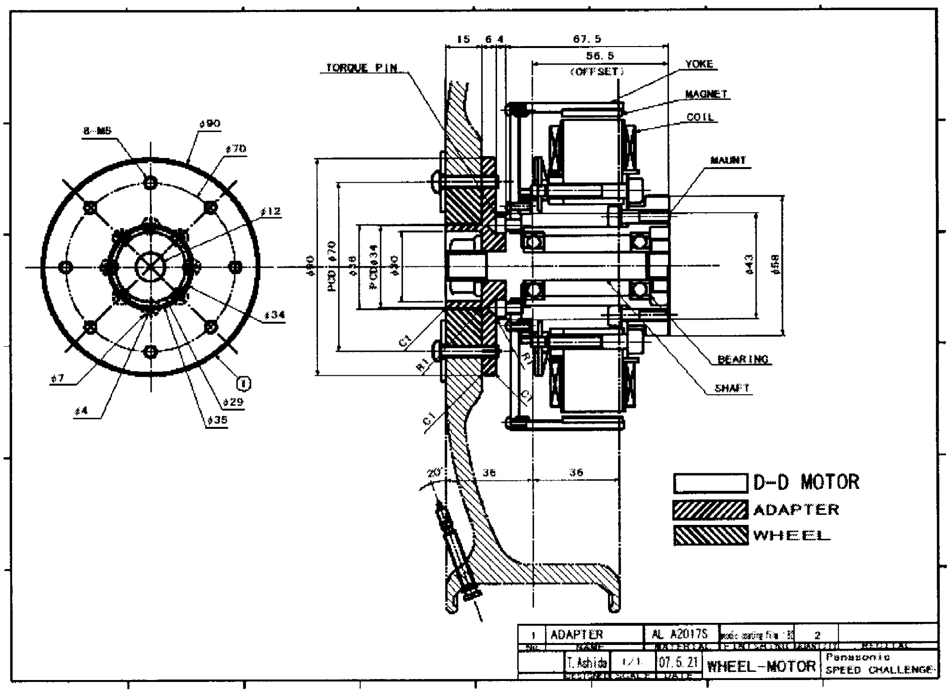

Fig. 13 Construction drawing indicates the motor layout inside the wheel

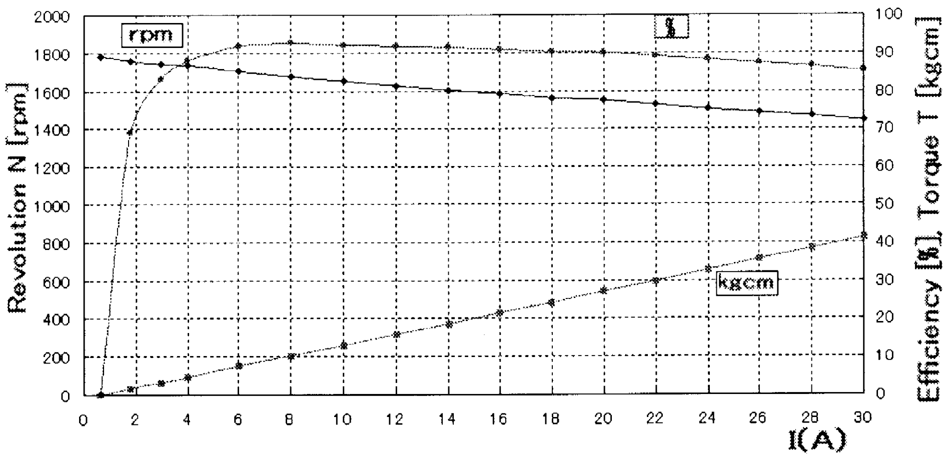

Fig. 14 Characteristics of the motor (at input-voltage 24 V)

tem for the rear wheels. The effect of this regenerative braking was checked in the field tests. Figures 20 and 22 show the increase of battery voltage caused by the regenerative braking. The input voltage range of the controller was decided on as 18-63 V, in order to respond to the voltage depression at acceleration and changes of input voltage caused by boost regenerating at deceleration. Figure 13 is a construction drawing which shows the layout of the motor inside the wheel.
Figure 14 shows the characteristics of the motor at controller input-voltage DC24 V which were obtained from the experiment. It was confirmed that more than 85 % of efficiency in the wide range of electric current can be maintained.
Figure 15 is a picture of the completed DD motor (for the left- and right-sides). The picture on the left shows a view from the back of the motor for the left side. The stator of the coil is fixed in the case of this DD motor, which is different from ordinary motors, and the magnet-attached rotor around the motor rotates. The motor shaft in the right picture and the rotor around it rotate together.

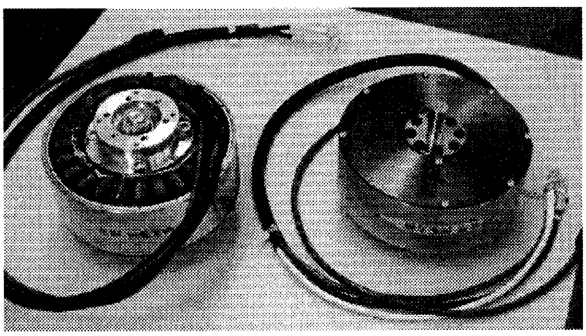

Fig. 15 Completed DD motor (for left and right sides)

Figure 16 shows the DD motor (for the right) which is attached to the body mediated by a swing-arm suspension.

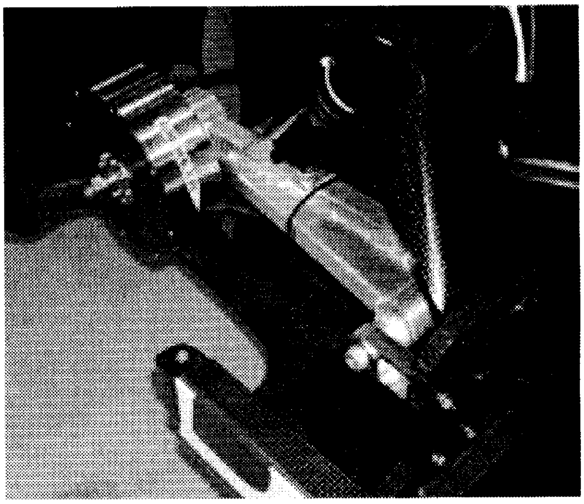

Fig. 16 DD motor attached to the body (for the right-rear wheel) (The wheel has been removed for the photo to be taken.)

5. DEVELOPPING SPECIFIC TIRES

5.1 Development of tires

Reducing rolling resistance is an extremely important element in this project. Thus importance was placed on the quality of puncture-resistance in the development of exclusive tires, based on experiences with eco-run sports-specific and cycling-specific tires. The targets for developing tires were: the quality of puncture-resistance should be more than 2-times stronger than for eco-run tires, the tire should be 20% lighter than the same size of cycling tire, and there should be a 50% reduction of rolling resistance in comparison to cycling tires.
As Figure 17 shows in the left-hand drawing, the structure of the traditional cycling-specific tire is a 3-ply structure, that is, a 1-ply tire-cord winds round both beat-parts and in the middle of the tread area they are stacked together. Hysteresisloss increases as the number of plies of tire-cord increases, and thus the tire developed in this

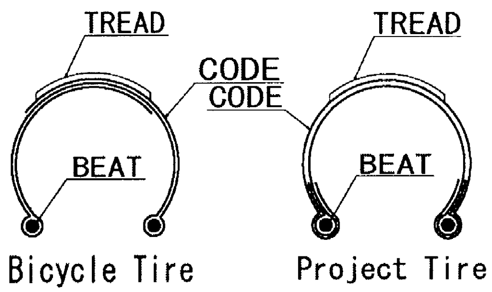

Fig. 17 Comparative figure of cross-section structures of a tire (Left: normal cycle-specific tire; Right: developed specific-tire)

project was completed with a tire-cord divided into 2 plies, with a 2-ply tire cord on the tread area and 4-ply on the beat area, as the right-hand drawing. Figure 17 shows experiments confirmed that the energy consumption of the developed tire in this project is about 50% less than for a cycle-specified tire (Table 8).
Table 7 shows the specifications of the completed specific tire. The size is indicated by inch, according to the codes and standards used for cycle-tires, since the specific tire was developed in accordance with the standard used for cycle-specific tires.

Table 7 Specifications of specific-tires

Name of tire	14-1.75sd4
External diameter of tire (inch)	14
Width of tire (inch)	1.75
Thickness of tread (mm)	2.5
Number of ply (PLY)	Tread: 2, Hooked Edge: 4
Recommended air-pressure (kPa)	500
Tube material	Urethane resin
Style of valve	Presta valve
Weight of finished tire (g)	157
Weight of urethane tube (g)	90
Recommended width of rim (mm)	55

5.2 Results

Figure 18 is a picture of the finished specific-tire, 14-1.75sd4, loaded on the car. Figure 19 is a picture of measurement of the consumption energy using a manufactured rolling-resistance testing machine.
Table 8 shows the measured results of consumption energy, using a testing machine for tire rolling resistance. As is shown in the table—load: 35 kgf, power consumption 10.47 W at travel speed 15 km/h, power consumption 19.00 W at 25 km/h and 29.49 W at 35 km/h—though the puncture-resistance was increased, the power consumption was about 50 % less than for the same-size cycle-specific tire in each speed-testing area. This means that the consumption energy of the developed tire is small.

Fig. 18 14-1.75sd4 tire

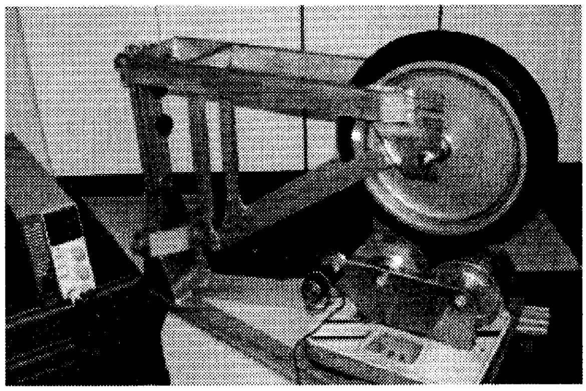

Fig. 19 A photograph of measurement of the consumption energy of the manufactured specific tire

6. DRIVING TEST

A driving test was conducted at the runway of the old Shirahama Airport, in order to check the performance of the completed car and to create the basic data for achieving the desired speed record. But the runway was not long enough to satisfy the specified measurement method for testing, "the average speed of a return trip in the1km of measurement area within 1 hour," and thus the test only checked the performance of the car.
Figure 20 shows the data for voltage, current and speed obtained during the driving test at Shirahama Airport. The speed was reduced after the car managed to increase its speed to over 100 km/h, because the runway was too short to travel at a constant speed after it had accelerated till 100 km/h. As expected from the start, the car accelerated and reached 100 km/h within about 60 seconds. The graph shows that the voltage increased and the current direction reversed at the speed-reducing area at around the 60-second point. This tells us that the boost-regenerative braking operated effectively because of the decrease in speed. The data shows that the dura-

Table 8 Comparative results of tire consumption energy

Tire air-pressure: 500kPa; Testing load: 35kgf								
	Speed	Voltage	14-1.75sd4 testing tire		14-1.75sd4 specific tire		Reference: Circle-specific tire	
			Current	Power consumption	Current	Power consumption	Current	Power consumption
1	15 km/h	6.5 V	1.66 A	10.79 W	1.61 A	10.47 W	3.28 A	21.32 W
2	25 km/h	10.8 V	1.8 5A	19.01 W	1.76 A	19.00 W	3.58 A	38.66 W
3	35 km/h	15.2 V	2.05 A	31.16 W	1.94 A	29.49 W	3.80 A	57.76 W

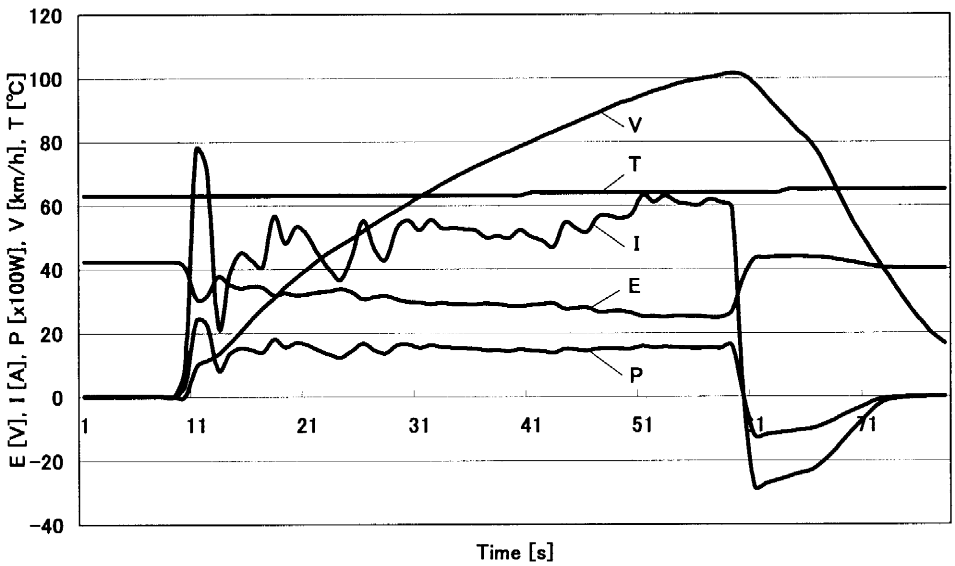

Fig. 20 Data of driving tests at old Shirahama Airport

tion at over 100 km/h is about 5 seconds, a maximum 2,374 W of output electric power was recorded, and an average speed of 100km/h was maintained on the 1km-measuring area because the output power above 1,300 W output-power was sustained for 45 seconds. For speed to accelerate by keeping the output constant is ideal, but the graph shows that power consumption increased up to 2,374 W and electric current to 80 A. This happened because the driver was not accustomed to controlling the output volume.

Although at the beginning it was assumed that inner resistance would increase due to power consumption and there would be a large voltage depression, the degree of voltage depression was not significant. One consideration is that the inner resistance was reduced because the high-load electric-discharge generated heat and voltage depression was controlled.

Figure 21 shows the Photograph of the driving tests. The car was driven with string attached to the rear part of the body in order to examine the aerodynamic performance, and in this way the air flow was observed. Separation and turbulence of the flow cannot be seen, and this indicates that the aerodynamic characteristics are excellent. Figure 22 shows data taken during the driving tests conduced in the morning of the driving-record event at Shirosato Test Course, at the Japan Automobile Research Institute, where the targeted speed was to be achieved. In order to reach the targeted average speed of 100 km, the 1km-measuring area has to be driven across in less than 36 seconds. Because of this, the aim was to main-

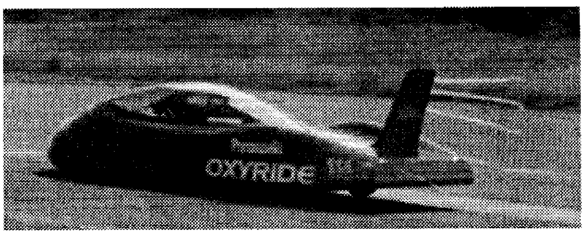

Fig. 21 A photograph of the running tests at old Shirahama Airport

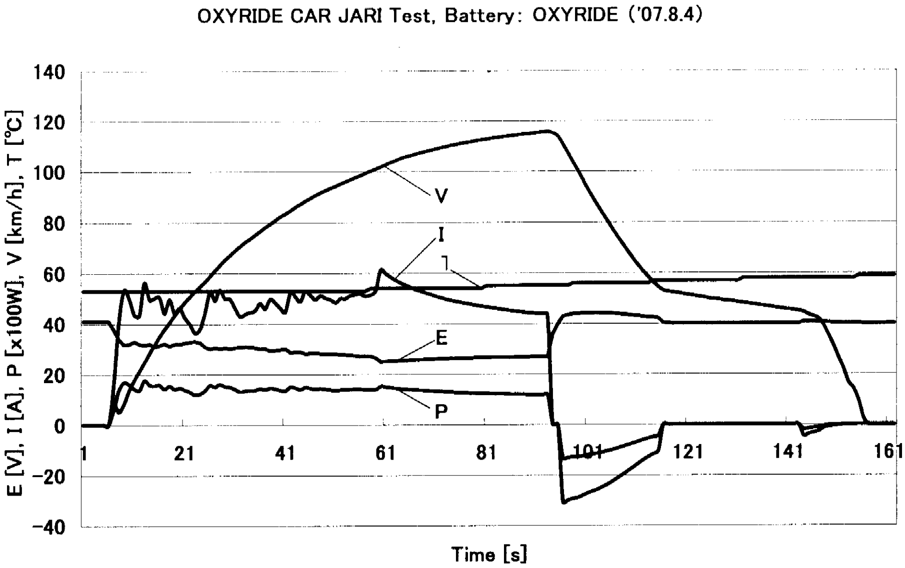

Fig. 22 Data from driving tests at Shirosato Test-course

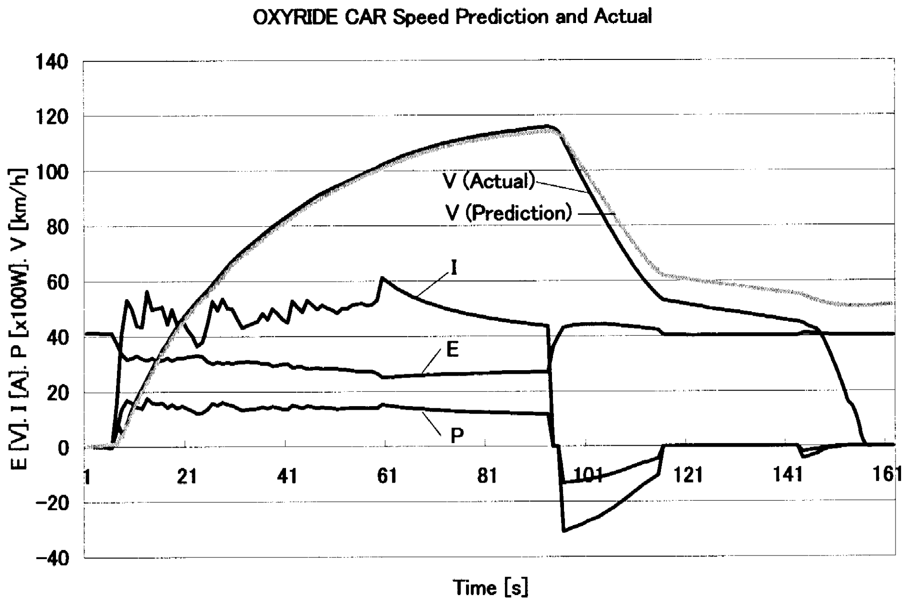

Fig. 23 A diagram indicating the relation between the forecasted curve of the speed calculated, based on the actual electric power used and the measured curve.

tain a speed of 100 km/h for 40 seconds, after the car reached the speed in the driving test. The results confirmed that Oxyride dry-cell batteries enable more than 1100 W output even after maintaining a speed of more than 100 km/h for 41 seconds. The maximum output in this driving test was recorded at 1770 W, and after that, more than 1200 W output was maintained for 80 seconds, and the speed reached 115.9 km/h at maximum. Figure 23 shows the expected velocity characteristic obtained from the calculation of resistance while driving, based on the power consumption shown in Figure 22 and the sequential measurement of speed. It matches with the measured speed very well. The results of these driving data and numeric calculations confirmed that the planned car, its specifications and the design of the power systems were correct.

7. CONCLUSION AND DISCUSSION

This paper describes the research results of a project where aims were to demonstrate the possibility of reaching a speed of 100 km/h with size-AA dry-cell batteries and to make a case for the high-efficiency of electric cars. For these purposes, a compact electric car was manufactured which can be ridden by a person and which uses commercially-sold Oxyride dry-cell batteries as its source of power. Importance was attached to weight-saving and low resistance in order to obtain the performance needed for achieving the goal. Thus the car was developed by keeping the car's weight to 38 kg and the air-resistance coefficient to about 0.12. It was found that the air-resistance coefficient is under 1/2 of an ordinary car, of which the coefficient is 0.23-0.3. A Direct Drive system was applied to the motor to maximize the energy-delivery efficiency, and the motor was designed so that more then 90 % of motor efficiency could be obtained in a wide current range. As a result, the drive force was delivered to the wheels without any loss. Light and low rolling-resistance tires were developed, and they were completed with about 1/2 of energy consumption compared to cycle-specific tires of the same size. This efficient performance made it possible to drive while maintaining a speed of more than 100 km/h with a car using 192 Oxyride dry battery-cells. The car drove at an average speed of 105.95 km/h on the specified 1km-measuring area at the record-attempt held in Shirosato Test Course, with The Guinness Book of World Records approval checkers in attendance. This record has been accepted for appearance in The Guinness Book of World Records for 2008.

Effective use of energy is important from the standpoint of managing environmental issues. The aim of this project is to use energy in a highly effective way over a short period of time, but this design technique for car bodies, motors, tires and so on can be applied to the designing of compact cars for which the aim is to drive over a long period of time. For such use, an examination of power supply and interior comfort becomes important. This paper describes only the optimization of power systems, and does not describe the maximization of output of dry-cell batteries and the number of dry batteries required. This is described in another paper: "Designing Compact Battery-car for Which the Target Speed is 100 km/h Using Nickel-system Primary-cells (Oxyride dry-cell Batteries) Part 2: Battery System Optimization."

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