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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Abstract

Among transportation-related issues, the most effective measure for resolving the problem of oil resources is the electric car. The key to the practical use of electric cars is cell batteries, which are the source of power for such cars. From this point of view, we have conducted experiments to prove that a speed of 100 km/h can be achieved by using size-AA dry-cell batteries [JIS,2006], in order to promote the efficiency of electric cars among the general public. This paper describes the results obtained from studies conducted into the optimization of the battery-cell system, which is an important parameter for this project. In this study, Oxyride dry-cell batteries, developed by Matsushita Battery Industry Co., Ltd, were selected and used, since they are higher in output power and energy, and content than traditional alkaline dry-cells. The study results indicate that, when using these batteries in an area of large current discharge, safety and the highest efficiency are achieved when they are heated to 60°C. Based on these results, an optimal battery system using size-AA battery-cells was examined in order to achieve a speed of 100 km/h with a person on board a car, and the outcomes of this examination are described in this paper.

Keywords

electric vehicles, optimum battery design, oxyride battery, 100 km/h project, AA battery car, velocity profile

1. INTRODUCTION

As a measure to prevent the exhaustion of fossil fuels and to control global warming, the value of electric cars has come under review, and the development of these cars has been conducted at a global level. But the performance of cars powered by electricity is inferior to cars powered by gasoline, and thus electric cars have not yet been widely used. Electric trains are better than steam-engines or Diesel train in various aspects, and this fact shows that electric cars, if their characteristically high-efficiency motors can be applied, can produce a better performance than traditional gasoline-powered cars. But the use of electric cars lags far behind because there are problems with the battery system. The purpose of this study is to demonstrate that cars powered by electricity are extremely high in efficiency. As a way of doing so, we have considered a method of demonstrating that a car powered by dry-cell batteries can run at a high speed with a person on board.

As a start, we developed a compact electric car with a person on board in 2004, as shown in Figure 1 shows, by using 2 size-AA Oxyride dry-cell batteries from Matsushita Battery Industry Co., Ltd. And in the same year, an electric car for children, shown in Figure 2, was developed which was powered by 2 size-AA Oxyride dry-cell batteries. In the same year again, we developed a compact electric-motorbike, shown in Figure 3, powered by 8 size-AA Oxyride dry-cell batteries. Advancing on these developments, we have considered a project to produce a car which is powered by size-AA dry-cell

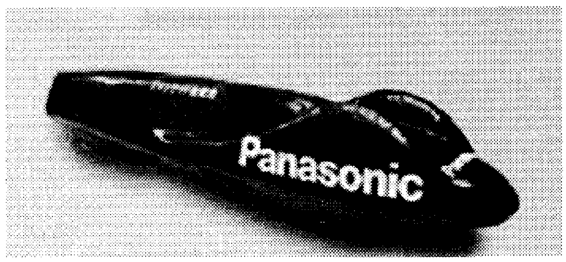

Fig. 1 A compact electric car run by 2 size-AA Oxyride dry-cell batteries (2004)

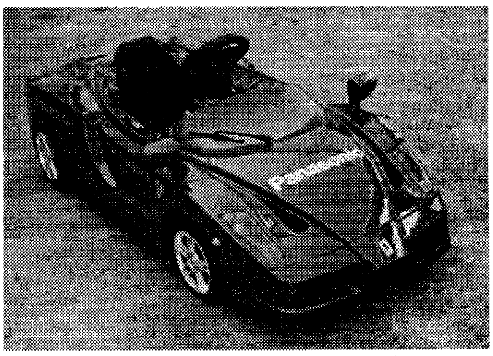

Fig. 2 Children's electric cart run by 2 size-AA dry-cell batteries (2004)

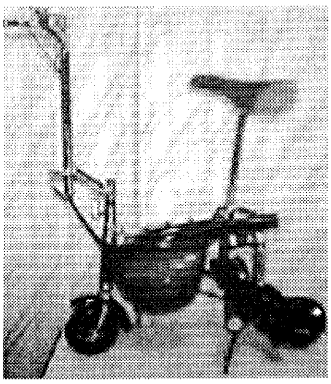

Fig. 3 A compact electric motor bike run by 8 size-AA dry-cell batteries (2004)

batteries and runs at a speed of 100 km/h with a person on board, and we have began studies in order to realize this project. This paper describes the results of study into the optimization of an electric-power system for achieving this goal. We also aim to have a speed record placed in The Guinness Book of World Records in order to spread the results of this study widely. A high-efficiency and low-resistance electric-power system and the optimization of outcome of battery cells are essential for developing compact electric cars which can use dry-cell batteries with a limited output performance.

To use dry-cell batteries for a car which people can ride, the first step is to understand the characteristics of batteries in certain conditions that are significantly different from the environment where the batteries are normally used. Thus at first, high-output power characteristics and the temperature dependence of Oxyride dry-cell batteries are to be obtained from experiments in this study. As described in another paper [Ashida et al., 2007], the four points listed below are the important features for achieving a target speed of 100 km/h with a compact electric car.

(1) Development of a light and safe car body with excellent performance.
(2) Development of a light, compact and high-efficiency motor and drive-train.
(3) Development of specific-tires with little rolling resistance.
(4) Optimization of the number of dry-cells which are loaded and the temperature and the types of batteries used.

This paper describes only no.4 above. Items from no.1 to 3 above are discussed in paper [Ashida et al., 2007]. Figure 4 shows a compact electric car which was developed and manufactured for this project, also shown in paper [Ashida et al., 2007]. This paper describes the results of developing a battery-system for the car.

2. THE TARGET PERFORMANCE FOR OXYRIDE DRY-CELL BATTERIES

We consider that Oxyride dry-cell batteries manufactured by Matsushita Battery Industry Co., Ltd. are the most suited in respect of energy density, and therefore in this project mainly these batteries were used.

2.1 Optimization of the number of Oxyride dry-cell batteries on board

Minimum use of Oxyride dry-cell batteries as a power source is important not only to prevent an increase of weight for the car but also to keep to the technical-research purpose, which is to examine the possibility of low-energy driving. First, we needed to assess the characteristics of Oxyride dry-cell batteries in the extreme conditions we aim for, according to the published performance for Oxyride dry-cell batteries. In order to bring out the performance of Oxyride dry-cell batteries effectively and to realize high-speed driving with a compact electric car, it is important to find the optimal condition for battery-energy discharge and to understand the electric energy needed to achieve the goal, while optimizing the number of batteries used in order to use the electric energy effectively. It is important to examine conditions so that the Oxyride dry-cell batteries will not fall into dangerous conditions caused by heat from a high load while driving.

Size-AA Oxyride dry-cell batteries were used, manufactured by Matsushita Battery Industry Co., Ltd. At first, the electric power needed for high-speed driving will be discussed based on the car body shown in Figure 4, designed for achieving the goal of this project. Then the high-output performance of Oxyride dry-cell batteries will be optimized so that the minimum number of Oxyride dry-cell batteries is sufficient as electric power.

2.2 Necessary electric power

The general rules and the guidelines for the measurement method for recording speed in the "Record Breaker's Pack" of The Guinness Book of World Records determines that a speed can be approved as a record when the average speed is calculated from the transit time in a 1km-measuring area, after the car has succeeded in making a return trip in the measuring area

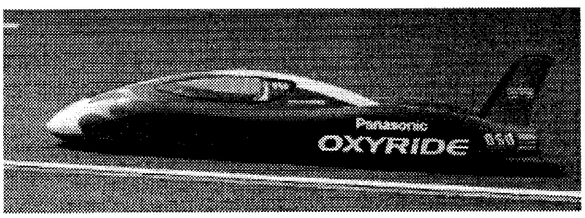

Fig. 4 A compact electric car which was developed and manufactured to load the battery system for this project, as discussed [Ashida et al., 2007]

within 1 hour. Thus in this project, when the total driving time is expected to be 120 seconds according to the calculation of the acceleration time—(60 seconds) + transit time in the measuring area (36 seconds) + deceleration time (24 seconds)—the necessary electric power is a maximum of 2000 W at acceleration. 1000 W for about 60 seconds is also needed in order to maintain a speed of 100km/h after acceleration ends, according to Table 4 in paper [Ashida et al., 2007], which is described on related to the designing of the drive-train for this project.

Performance evaluations of dry-cell batteries were conducted in order to use the Oxyride dry-cell batteries' capability heavily. First, the number of batteries necessary was calculated according to the performance nominal values published by the makers. According to the information about temperature characteristics of Oxyride dry-cell batteries at a constant electric-power continuous discharge indicated by the makers, which are shown in Figure 5, the output duration increases as temperature increases in a condition with a constant output of electric power. [Panasonic, 2007] And as the temperature of battery cells becomes higher, greater electric power is put out in relation to the constant output time. The number of batteries needed for driving was estimated by referring to this information [Panasonic, 2007]: the standard electric discharge performance during a constant current discharge of Oxyride dry-cell batteries, as indicated by the makers and shown in Figure 6. The graph in Figure 5 does not show the short duration of 120 seconds, and thus the figure at 120 seconds at 20 °C was estimated based on the extrapolation of mono-

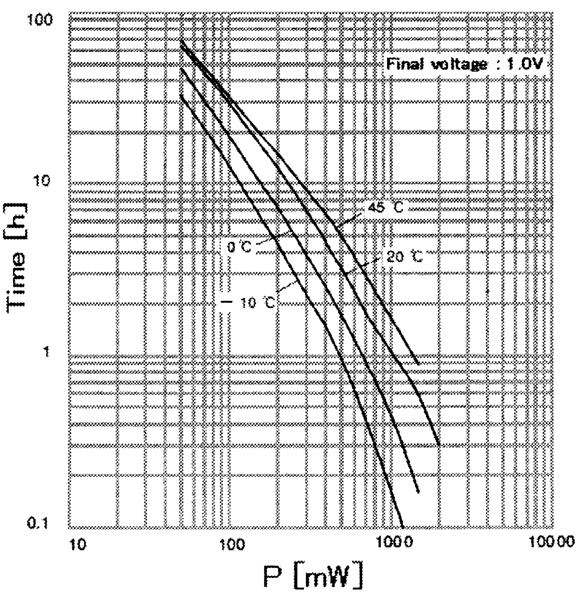

Fig. 5 Temperature characteristics during the constant current continuous discharge of Oxyride dry-cell batteries according to paper [Panasonic, 2007]

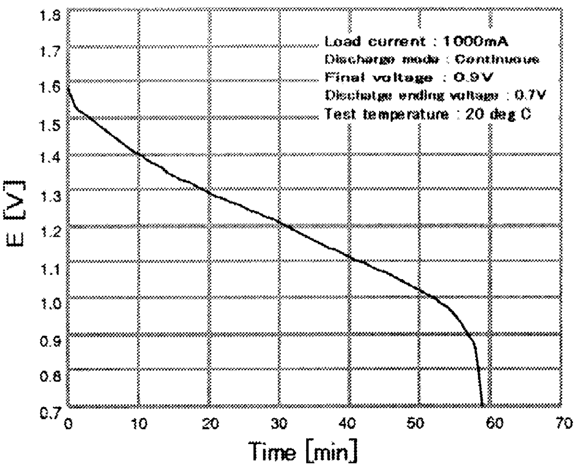

Fig. 6 Characteristics of standard discharge during the constantcurrent continuous electric discharge of Oxyride dry-cell batteries according to paper [Panasonic, 2007]

tonic decrease graph. It is estimated that the constant electric power per Oxyride dry-cell battery at 20 °C is more than 2500 mW. Based on this estimation, it was calculated that the approximate number of Oxyride dry-cell batteries needed to assure 1000 W-output at a point after 120 seconds is 400.

2.3 Affirming the capability of battery cells and the system of electric power

The capacity of Oxyride dry-cell batteries for use in normal conditions has been published. But in order to realize high-speed driving by an electric car with a person on board, as in this project, it is necessary to conduct an evaluation of performance under conditions of a large discharge and to establish a method to bring out the energy of Oxyride dry-cell batteries in a short period of time. Battery cells, and any other objects which bring about chemical reactions, generally react quickly when the temperature is high. It is assumed that with dry-cell batteries a high temperature reduces the internal resistance, making it easy to bring out their power. But if the temperature is raised without any limit, the inner pressure of the dry-cell batteries will increase, and this is highly risky to cause emergency situations, including the leak of electrolyte or an outburst of gas, because the safety valve is activated. Furthermore, in the case of batteries, a large output of current causes self-heating. Thus it is important to check the heating conditions at high-output, to set up a safe temperature for the beginning of use and to control the heat. Based on data obtained from experiments into current discharge under various conditions of use, a decision on the number of Oxride dry-cell batteries to be loaded will be determined.

3. EXPERIMENTS

3.1 Procedures for checking the current-discharge characteristics of Oxyride dry-cell batteries

Experiments for obtaining data on the characteristics of Oxyride dry-cell batteries were conducted according to the following procedures:

(1) It was decided to use 24 size-AA dry-cell batteries in series as a basic unit, because of ease of system control, which includes the motor when new Oxyride dry-cell batteries are used for a compact electric car.

(2) Oxyride dry-cell batteries used for obtaining their characteristics were kept at heat for 12 hours, in a heating box set at a temperature for the experiment in advance.

(3) Changes of total power voltage and inner resistance were measured in each step of pre-warming, post-warming, and after the experiment, for current discharge when placing 24 batteries in series.

(4) Slide resistance, which was set to become 5 A when 24 V is applied, was connected as a load.

(5) Voltage power, electric current and characteristics of temperature changes at a current discharge for 120 seconds, which is equivalent to the driving duration of the car, were recorded in a data logger. Table 1 shows the measuring instruments used in the discharge test for Oxyride dry-cell batteries.

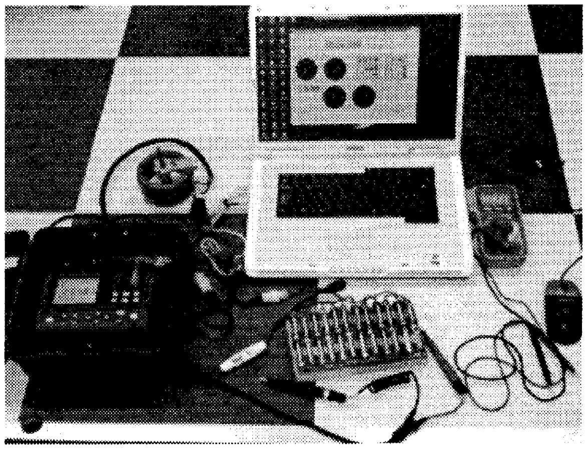

Fig. 7 Photograph of discharge tests (The battery unit is seen in the lower-center of the picture.)

A discharge test was conducted using 24 Oxyride dry-cell batteries in series under different conditions of tem-

Table 1 List of instruments used in the discharge test

Name	Maker	Style/specification
Battery tester	HIOKI	Battery HIGHTESTER 3554
Circuit tester	Sanwa Electric Instrument	Digital multi-meter CD731
Data logger	EAGLE TREE SYSTEMS	E-Logger MPR-02
Load resistance	DTO	11 Ω 200 W

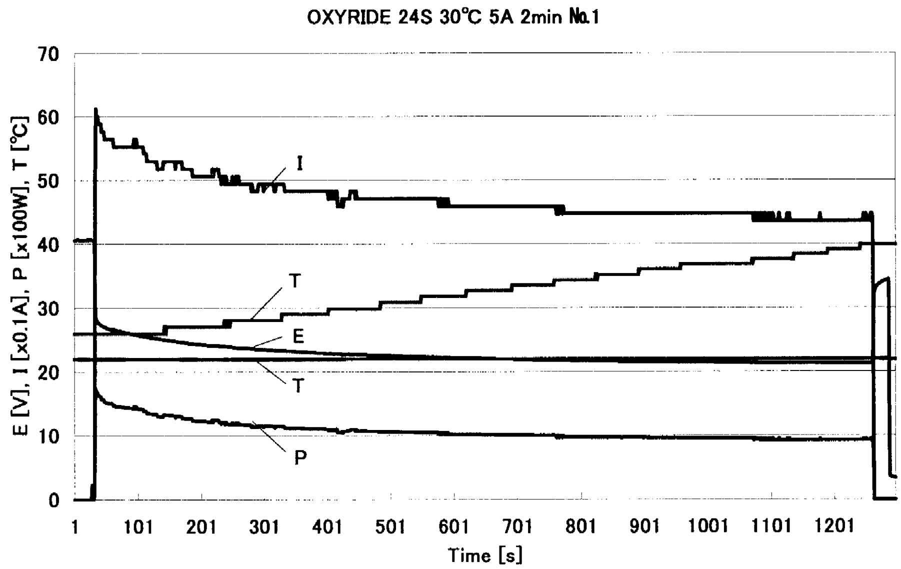

Fig. 8 Oxyride dry-cell batteries, 24 in series, two-minute discharge test at room temperature (Output of 173 W, 25.9 °C at the beginning of discharge, output of 93 W, 39.8 °C at the end of 120-second discharge.)

Table 2 Changes of power voltage, inner resistance and temperature at load-open before and after the current discharge in the experiment with the 24 batteries in series shown in Figure 8.

24 batteries in series, power voltage (V), internal resistance (mΩ), temperature (℃)	
Before discharge	10 minutes after discharge
41.3 V 2.241 Ω	39.0 V 1.43 Ω

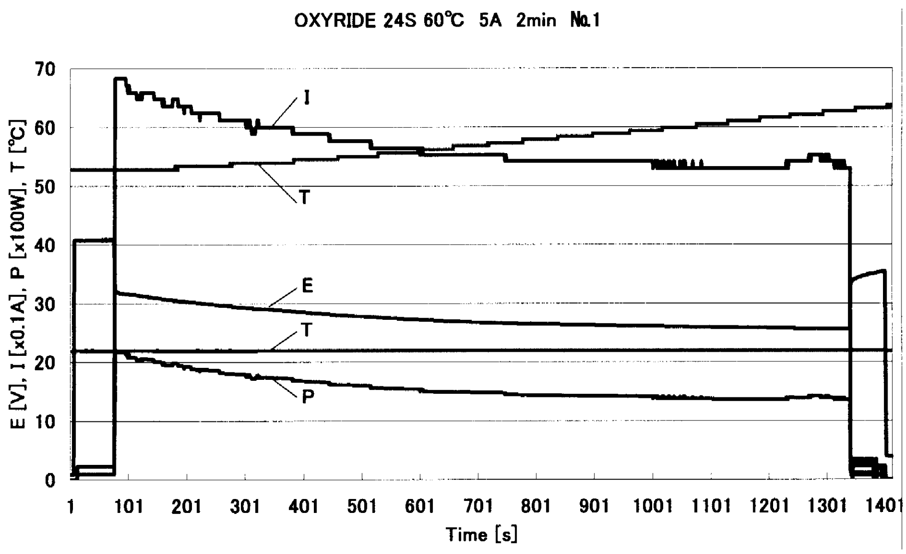

Fig. 9 Oxyride dry-cell batteries, 24 in series, kept at 60 °C for 12 hours, 2-minute discharge test at room temperature (Output of 219 W, 52.8 °C at the beginning of discharge, output of 139 W, 62.7 °C at the end of 120-second discharge)

Table 3 Changes of power voltage, inner resistance and temperature at load-open before and after the current discharge in the experiment with the 24 batteries in series shown in Figure 9.

24 batteries in series, power voltage (V), internal resistance (mΩ), temperature (℃)	
Before heating	After heating/before discharge
41.3 V, 2.280 Ω	41.27 V, 1.695 Ω, 52.8 ℃

perature with the procedures described above (Figure 7). Battery units kept at a heat of 60 °C (Figure 9, Table 3) produced more than 127 % output in comparison to units kept at a room temperature of 25 °C (Figure 8, Table 3). In these figures, the voltage of the batteries is E, current is I, power consumption is P and the temperature is T. When they were heated up to 70 °C (Figure 10, Table 4), more than 147 % of output was obtained in comparison to the case of units at a room temperature of 25 °C. These results proved that, as estimated, when the battery temperature is high at the beginning of current discharge, the output is also high. In an experiment at 70 °C shown in Figure 10, one of the batteries of which the temperature went over 80 °C during discharge had a leak of electrolyte, because the activation of the safety valve was caused by the increase of pressure inside the battery. This battery caused an increase in the inner resistance of the entire battery unit. Based on this, it was decided to conduct the study under 80 °C as a safety standard for the battery unit.

The batteries were charged for 1.5 hours at 48 V 0.5 A after heating at 60 °C for 12 hours. Then they were further heated up to 70 °C and then discharged at room temperature. (Output of 254 W, 71.2 °C at the beginning of discharge, output of 140 W, 78.6 °C at the end of 120-second discharge.)

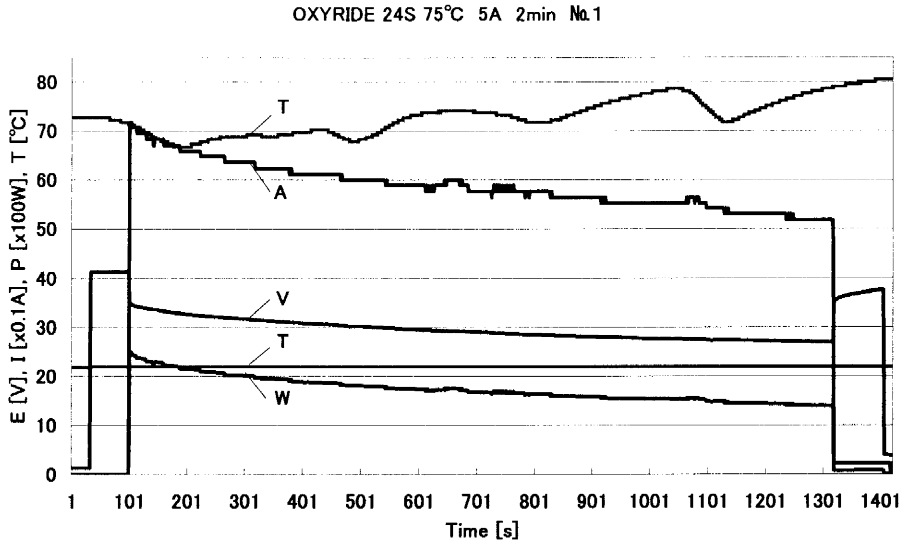

Fig. 10 Oxyride dry-cell batteries, 24 in series, kept at 60 °C for 12 hours +70 °C for 1.5 hours, 2-minute discharge test at room temperature.

Table 4 Changes of power voltage, inner resistance and temperature at load-open before and after the current discharge in the experiment with the 24 batteries in series shown in Figure 10.

24 batteries in series, power voltage (V), internal resistance (mΩ), temperature (℃)	
Before heating	After heating/before discharge
41.46 V, 2.440 Ω, 28 ℃	41.58 V, 0.752 Ω, 69.7 ℃

3.2 Impact resistance test

To use Oxyride dry-cell batteries as a power source for a compact electric car, it is important to check the changed capabilities of Oxyride dry-cell batteries when they undergo an impact. The batteries were dropped to create an impact and they were checked to see if there were any changes in their performance. The manner of falling for the batteries was decided on and they were dropped from a height of 1 meter to a concrete-floor. Then measurements were conducted to see if there were any changes in power voltage and internal resistance. The results show that internal resistance increases when batteries have some impact added. Table 5 shows the changes of power voltage and internal resistance of Oxyride dry-cell batteries in the drop tests. According to a piezo sensor measurement the peek of the impact was about 1000 G and the duration was about 0.5 ms. Output voltage did not change before and after the fall, and the internal resistance increased by under 10 % in all cases.

Table 5 Changes in internal resistance and average rate of change of Oxyride dry-cell batteries as caused by drop impact (1m in height)

Manner of fall	Test 1	Test 2	Test 3	Test 4	Test 5	Changes in internal resistance	
						Average value	Range of changes
(+) pole downside	+9.6 mΩ	+8.1 mΩ	+4.0 mΩ	+2.6 mΩ	+11.7 mΩ	+7.2 mΩ	+7.6 %
(-) pole downside	+7.7 mΩ	+2.7 mΩ	+11.8 mΩ	+7.6 mΩ	+5.7 mΩ	+7.1 mΩ	+7.1 %
Side	+4.7 mΩ	+7.9 mΩ	+2.7 mΩ	+6.3 mΩ	+7.3 mΩ	+5.9 mΩ	+6.0 %

3.3 Design of power supply unit

The results of the discharge test confirmed that a large output can be obtained when the temperature of batteries is kept high in comparison to a situation where the batteries are not heated, in the case of a discharge in a short period discharge time. For batteries kept at a temperature of 60 °C, the output of 24 batteries in series was 139 W after 120 seconds. Therefore, in a situation using dry-cell batteries with no internal resistance changes caused by impact, the power voltage needed if the car runs at 120 km/h after the end of acceleration to the final point in the measuring area, is 1105 W, according to Figure 3 in paper [Ashida et al., 2007], This means that 8-parallels of the basic power-supply unit of 24-batteries in series are sufficient for the performance of 100 km/h. According to this result, the number of Oxyride dry-cell batteries loaded on the compact electric car was decided as a total of 192 batteries, (24-batteries in series × 8-parallels.) It was also decided to use the power-supply unit by heating it to 60 °C. By this method, it was possible to keep the number of batteries to be loaded at less than half of 400, which was the estimation made in the beginning. Because of the space in the car, a power-supply unit was put together with 2 units of 96 batteries of 24 in series × 4-parallels, where one unit was placed on the top of another to make 2 layers of units (Figure 11 and Figure 12).

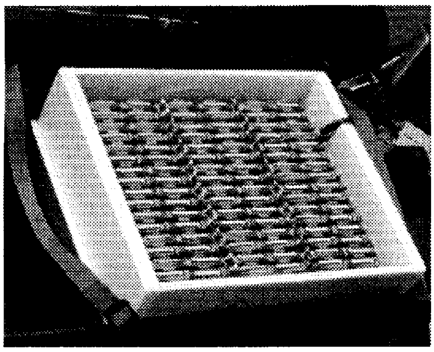

Fig. 11 Battery holder (24-inline × 4-parallels total 96, 2 layers)

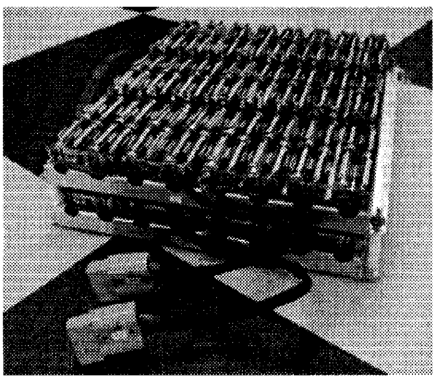

Fig. 12 Heat-retention box for oxyride dry-cell batteries (Using heat insulating agent for housing)

As to the connection of the batteries, in order to prevent a situation whereby all of the one-line of inline wired batteries would become non-effective if an abnormality occurred to any batteries, or a bad fit or other problems occurred during driving, back-up wiring was used so that the 96-battery power-unit was in the form of 2-inline × 4-parallels × 12-inline, rather than 24-inline × 4-parallels (Figure 13). This method will prevent a significant electric power shortage in the case of some troubles happening to a part of the loaded batteries, because other batteries, which are connected in parallel, will share the burden. Needless to say, self-discharge occurs in the parallel connection of batteries, because of the difference of inner electromotive force of each battery placed in parallel. They should not be kept in that way for a long time.

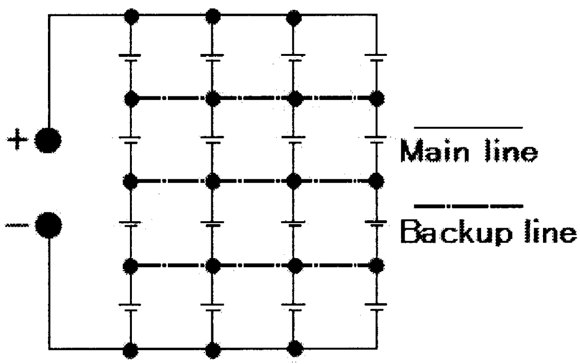

Fig. 13 Backup wiring method in a case of 4-inline x 4-parallels

4. TEST RUN

4.1 Test run

A test run was conducted on the runway of the old Shirahama Airport in order to obtain the basic data needed to achieve the desired speed record, as well as to check the capacity, safety and reliability of the finished power-supply unit. The car and motion-system described in paper [Ashida et al., 2007] were used in this test. As Figure 14, the actual duration of time at a speed over 100km/h was 5 seconds, and the maximum output was 2374 W. The output voltage, after an output of more than 1300 W was maintained for 45 seconds, was over 1500 W. This confirmed that an average speed of 100 km/h could be maintained in the 1-km measuring area.

As Figure 15, a test run was conducted on the morning of the challenge for the record at the Shirosato Test-course of the Japan Automobile Research Institute, which was the place prepared for the record run for The Guinness Book of World Records. According to the

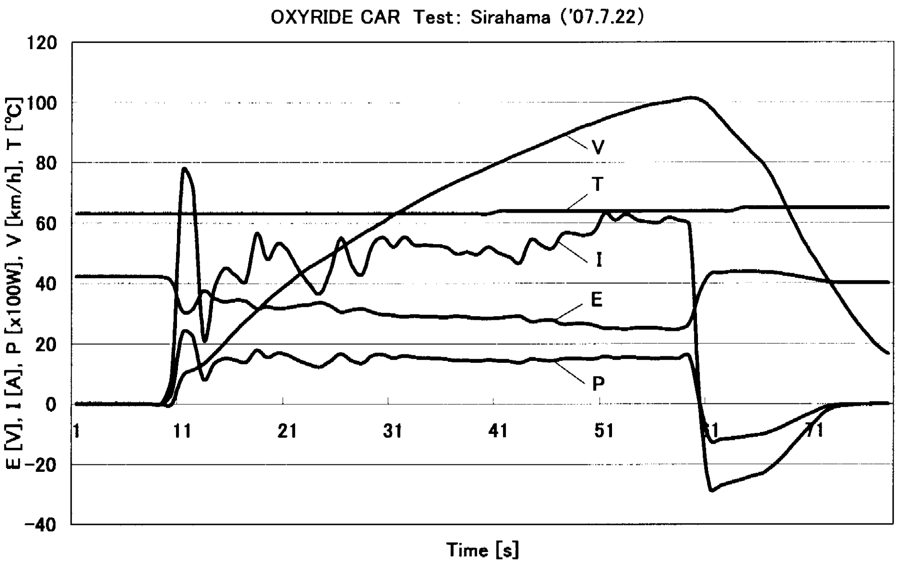

Fig. 14 Data from test run at old Shirahama Airport

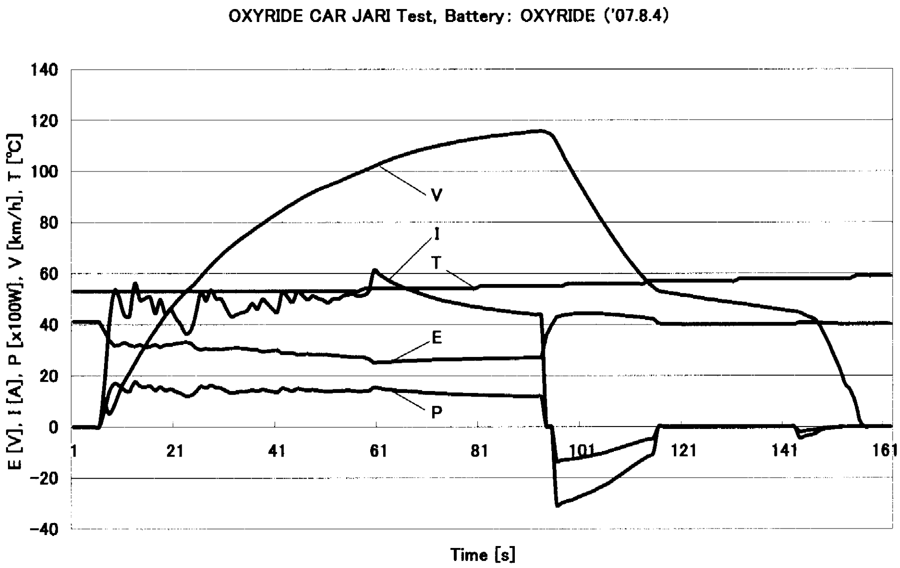

Fig. 15 Test run with (192) oxyride dry-cell batteries, Shirosato Test course 07-8-4

results, it was confirmed in the test run that oxyride dry-cell batteries could produce an output of more than 1100 W after maintaining a speed of more than 100 km/h for 41 seconds. In this test run, a maximum output of 1770 W was recorded, and, after that, an output of more than 1200 W was kept up for 80 seconds and the maximum speed reached 115.9 km/h.

Figure 16 shows the data from the test run, in which alkaline dry-cell batteries were used in the same conditions as for Oxyride batteries for comparison. It shows that the maximum output of oxyride dry-cell batteries is higher by 130 % than for alkaline dry-cell batteries. But the maximum temperature of the alkaline dry-cell batteries was lower by 15 °C.

4.2 Speed record

On August 4, 2007, a Guinness Book of World Records challenge run was conducted at the Shirosato Test-course of the Japan Automobile Research Institute, in Ibaraki-prefecture (Figure 17). Though the details are described in paper [Ashida et al., 2007] , an average speed of 105.95km/h at the outward and homeward routes in a 1-km area was recorded as a Guinness Book world record on that day, and the aim of the project was achieved. (Figure 18) (Table 6). Figure 19 shows the battery parameter and speed record obtained at that time. This data includes the interval needed for the change of direction from the outward to the homeward routes and for changing the power supply units of the oxyride dry-cell batteries. New 2-sets of power-supply units of

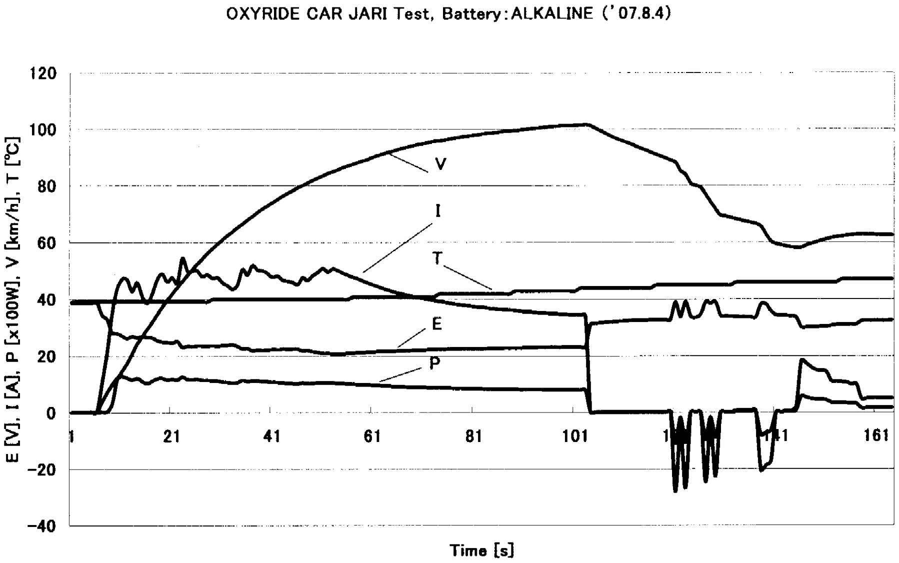

Fig. 16 Comparative test-run with (192) alkaline dry-cell batteries, Shirosato Test-course 07-8-4

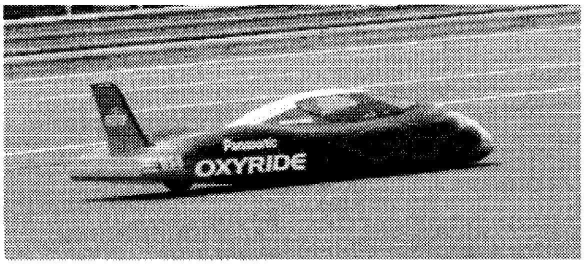

Fig. 17 Photograph of the run on the homeward route at Shirosato Test-course for Guinness Book world record run

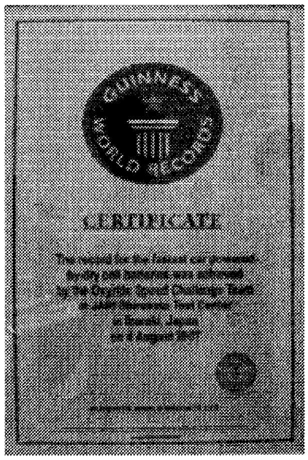

Fig. 18 Guinness Book of world records certification

Table 6 Results of measurements on outward and homeward routes

Parameter	Course: direction	1km transit time	Average speed in 1km measuring area
1	Outward: north ⇒south	32.96 s	109.22 km/h
2	Homeward: south ⇒north	35.06 s	102.68km/h
3	Average on return trip	34.01 s	105.95km/h

oxyride dry-cell batteries were used on outward and homeward routes.

4.3 Temperature of batteries and internal resistance

Table 7 shows measured results of the temperature of Oxyride dry-cell batteries and the internal resistance before the run, during the run and just after the run. Though it was assumed that the internal resistance would increase because of the power consumption of the batteries, the source of power, the measured results show that the resistance decreased to 58.8%- 59.0 % just after the run. It is assumed that this happened because the increase of temperature which was caused by the high load reduced the internal resistance. Furthermore, the power voltage just after stopping was slightly higher than 3 minutes after stopping, and this was because the car

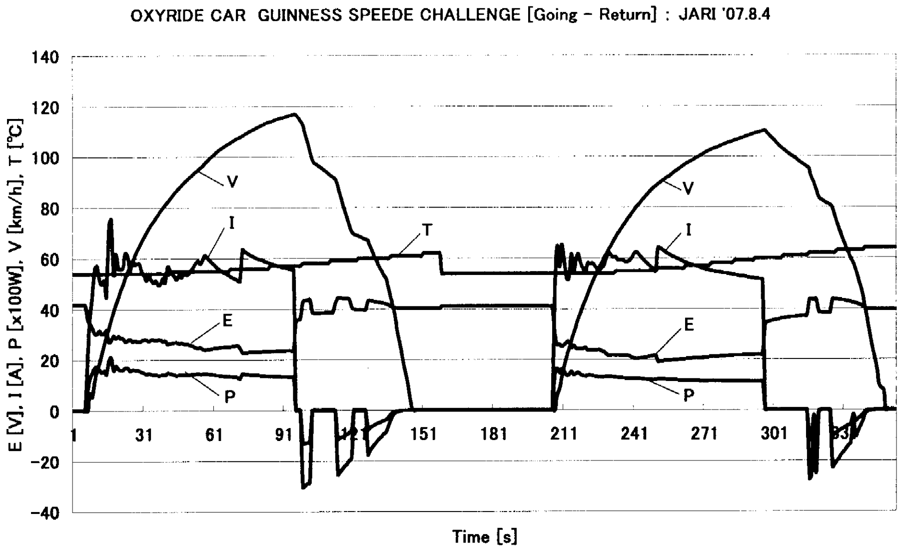

Fig. 19 Record–run at Shirosato Test-course at Guinness Book of World Records run 07-8-4

Table 7 Oxyride dry-cell batteries: temperature of batteries and internal resistance

	Temperature	Voltage unit: B1/2			Voltage unit: B2/2		
		Voltage	Inner resistance	Battery temperature	Voltage	Inner resistance	Battery temperature
At battery charge	29 ℃	41.39 V	0.439 Ω	28.6 ℃	41.39 V	0.448 Ω	28.6 ℃
After heating	27 ℃	41.35 V	0.343 Ω	55.0 ℃	41.35 V	0.352 Ω	55.0 ℃
Before run	27 ℃	40.99 V	0.345 Ω	53.0 ℃	40.99 V	0.354 Ω	53.0 ℃
At maximum speed	27 ℃	27.0 V	—	55.0 ℃	27.0 V	—	55.0 ℃
Just after the run ended	27 ℃	40.41 V	0.203 Ω	60.0 ℃	40.42 V	0.209 Ω	60.0 ℃
3-min. after the run ended	27 ℃	40.17 V	0.232 Ω	67.0 ℃	40.18 V	0.236 Ω	67.0 ℃

stopped in a charging condition with 44.3V at maximum, which was caused by regenerative braking.

5. CONCLUSION AND DISVUSSION

This project describes the development results of a power-supply system which aims for a compact electric car with dry-cell batteries as its power source to be able to drive at 100 km/hWe examined the capability of commercially-sold Oxyride dry-cell batteries as a drive source and demonstrated the optimal conditions in experiments. It was found that the electric-power output of Oxyride dry-cell batteries increases as the temperature increases, but also it was discovered that when the temperature goes over 80 °C, the safety valve is activated and this causes a leak of electrolyte. Thus it was decided to use the batteries setting the target temperature at 60 °C.

When Oxyride dry-cell batteries are used at 60 °C, output increase becomes possible by 27 % in comparison with use at room temperature. Thus, in order to run at the targeted average speed of 100km/h in a 1km area, 192 batteries are sufficient. Since the estimated number of batteries needed based on information published by the maker was 400, a total of 5.3 kg (5.3 %) in weight was saved as a result.

Because of the combination of a light body and the efficiency of the drive-train of the car, as described in another paper [Ashida et al., 2007], and the battery efficiency as a result of this study, an electric car was developed in this project which succeeded in running at an average speed of 105.95 km/h in a 1km measuring area. Moreover, it was confirmed that this will be recorded in The Guinness Book of World Records for 2008.

In this study, Oxyride dry-cell batteries were examined and were compared to alkaline dry-cell batteries, but examinations of the possibilities for using other types of compact energy were not conducted. Such examinations are also important for discussing energy saving.The Oxyride dry-cell batteries used in this research recovered their voltage up to 1.715-1.718 V, which is closest to 1.72 V of initial voltage, after they were left to stand for a while. If the relations among power consumption, recovery of voltage and recovery time become clear in the future, the results are likely to bring more efficiency to the energy saving of electric cars. In this study, primary batteries were used as an energy resource for an electric car, and this car does not have the disadvantage of a long charging time, which is the greatest problem in the spread of traditional electric cars. Thus the results of this project demonstrate possibilities for the development of new electric-car systems for the future. As Figures 14, 15, 16 and 19 show, charging was conducted by regenerating electric power in the primary batteries during driving. In this sense, the charging-discharging characteristics of primary batteries in high-load conditions are also an interesting research theme for the future.

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