Technical Report on the Shikoku EV Rally and Ekiden 2003 in Tokushima

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Abstract

To promote environmentally friendly Electric Vehicles (EV's), we have entered an EV converted from a gasoline automobile in the Shikoku EV Rally (since 1999) and collected data for the purpose of improving technical performance. Also, since 2002 we have participated in the Shikoku Ishu Ekiden , a long distance rally around the island of Shikoku and thus have acquired more data for analysis. Using the analysis of the past data, in the 2003 Ekiden a method simulating rally performance was established to modify clearer, and the actual rally results with that of the rally simulation were similar. Our EV received first position in the class competition as well as in the energy efficiency category.

Keywords

electric vehicle, environment

1. INTRODUCTION

Since the Kyoto Global Climate Conference (December 12, 1997), social consciousness for environmental problems caused by emission gases has risen. Toyota and Honda started retailing fuel cell electric vehicles (FCEV) since December 2002, and from that time experimentation on the use of new energy in automobiles for the purpose of environmental conservation has become a major agenda.

In August 1998, Shikoku EV Rally 2000 Committee announced its proposal for promoting the use of low pollution EV's (Electric Vehicles) by sponsoring the Shikoku EV Rally. This rally, conducted on public roads, is the first in Japan for EV's and is open to educational institutions, companies and private parties involved in developing or making electrically run cars. The Osaka Sangyo University (OSU) EV Project Team, which includes our students, first entered this rally held in Tokushima prefecture in 1999 [Nakahira et al., 2000]. This two-day rally is a competition requiring the participating parties to complete within designated time, the courses the participants choose in advance, from nine or ten courses designed by the organizers. The courses must be run as indicated on the official rally map, and the participants must take photographs at various checkpoints. Performance is evaluated on the number of points gained by completing these courses.

Another rally, Shikoku Ishu Ekiden featuring a round trip of Shikoku Island was commenced in 2002. We entered this rally first held in Ehime prefecture, receiving assistance and support from former graduates and students of OSU's Junior College and undergraduate departments. Last year, the team entering the Shikoku EV Week 2003, that hosted both the Shikoku Ishu Ekiden (August 19-21) and Shikoku EV Rally (August 23-24), included three students from the Faculty of Human Environment, three students from the Junior College of Automotive Engineering, and the three instructors and authors of this paper. This paper reports the data and analysis gained from these rallies and discusses the possibilities for enhancing the characteristics of EV's, and ways to enhance their performance in terms of economy and environmentally friendly use.

2. EV SPECIFICS

Since the conversion of our EV from a gasoline vehicle, we have developed and improved it every year. (See Figure 1 for photograph of 2003EV.) The improvements made were:

Fig. 1 Photograph of 2003EV

(1) Enhancing battery capacity from 36Ah to 52 Ah for longer running distance.

(2) Installation of carbon fiber wheel foils and a full undercover for lower resistance and lighter weight.
(3) Total rewiring of the vehicle to reduce weight.
(4) Installation of Solar panels in front, top and back for recharging auxiliary battery during the operation.
(5) Installation of HID headlights and LED brake light and blinkers, to display for better electric efficiency.

Usually in Japan synchronous motors are used in EV's and FCEV, because of their compact size. But we chose to use an USA built induction motor, because as proven in North America and Europe, these motors generally have higher endurance and are cost efficient. The gearbox is a single gear type correlated to 1/10 of the motors revolutions and covers from start to a top speed of 100km/h. Because of the nature of this powerful motor in low-speed, acceleration rates higher than a 1500cc gasoline vehicle is possible. The acceleration-braking (0-40m) test results at the rally showed our EV to accelerate to 46.67km/h.

Table 1 Specifics of 2003EV

Manufacturer	Toyota
Body Type	E-ST190 (conversion)
Body Style	Passenger Car
Energy Type	Electricity
Motor (Maximum Power)	U.S.A-Solectria AC42 78kw 150Nm DC312V 0~10000^-1(rpm)
Gear Box	10:01
Battery Charger in Vehicle	Solectria BC6600 3φ200V6.6Kw
Length x Width x Height	4450 x 1690 x 1390(mm)
Battery	Lead-acid Battery Nominal Capacity 52Ah(5HR)
Wheel Base	2580mm
Axial Space (Track)	1465mm
Vehicle Weight	1365kgf
Maximum Speed	100(km/h)
Tire Size	185/50-14
Wheel Disc	5.5J Aluminum-Wheel

(Table 1 shows specifics of 2003 EV). The motor is positioned for FF drive and secured with a strut bar over the top and cross members below. (Figure 2 shows layout of devices in front)

The axial shaft for power transmission is connected to the output shaft (USA-GM) from the gearbox, which is welded to the Toyota original drive shaft. The power steering hydraulic pump (Toyota 4432-42040) and the brake vacuum pump (Nissei Obaru NR-3220DSK) are installed in the front. A circuit breaker (Mitsubishi Electric NF225-SP175A600VDC), which is required for all vehicles in the rally as a safety device, is positioned under the hood so that it can be accessed directly or operated manually by the driver. There are 24 batteries connected linearly for powering the vehicle, 6 are located in the front and back seat space and 12 are in the rear trunk space. (Figure 3 shows layout of devices for 2003EV)

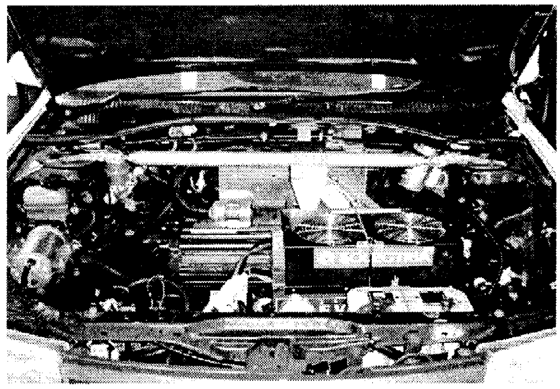


Fig. 2 Layout of devices in front

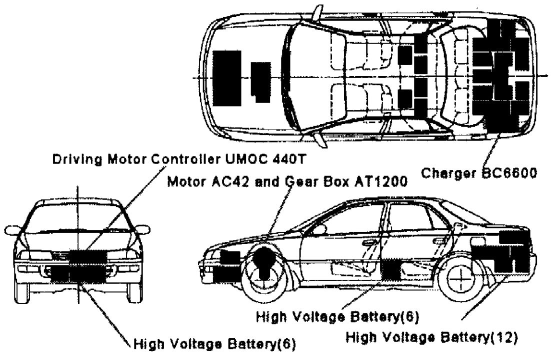


Fig. 3 Layout of devices for 2003EV

Placing more weight on the front axis of a FF drive is necessary for increasing the efficiency. With the motor, controller and other heat sources located under the hood, it is necessary to allow for sufficient cooling. However, unless we challenge the extreme tests such as "acceleration-braking," it is possible to reach higher levels of low energy performance for EV's if operating in this weight distribution.

Instrument panel and displays (Figure 4) includes an analogue ampere meter (Yokokawa Electric) that the driver can see easily at the top right of the display and a digital E-Meter (Namikoshi-Electric AH703) to monitor voltage, electric current, remaining battery capacity, vehicle speed and distance at the bottom.

There are on/off switches for the regeneration brakes and power steering, LED display for the controller operation, and forward/reverse direction switch. When the regeneration brakes are ON and the driver pushes the accelerator past the halfway position, the flow of elec-

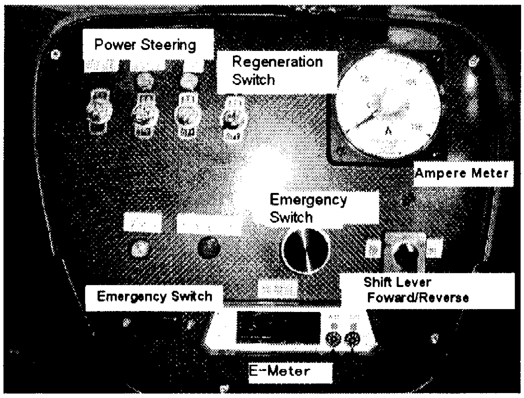


Fig. 4 Design of control panel

tricity driving the vehicle is controlled and if the accelerator is released back past the halfway position, the regeneration brakes are engaged.

This allows the driver to accelerate or decelerate by using only the accelerator pedal. The driver uses the Power Save Control Volume to adjust electric current in accordance with road conditions.

3. HYBRID RAPID GENERATIONS AND OPERATIONAL INSTRUMENTATION

3.1 Hybrid rapid generation system

Figure 5 shows the hybrid rapid generation system (Yata Electric) installed and in use since 2002.

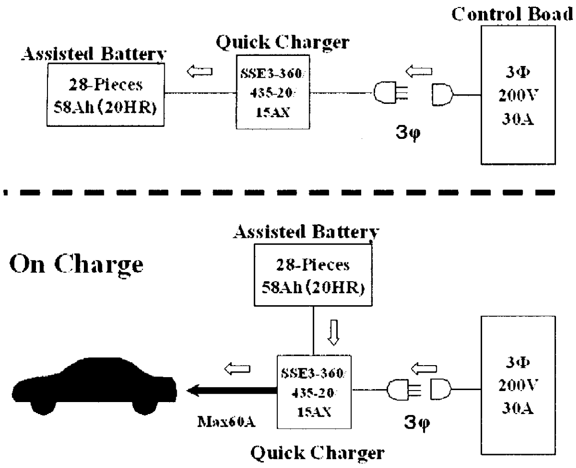


Fig. 5 System diagram of hybrid charging method

The rally course provided 3-phase 200V30A plug-ins in the battery recharging areas and while the EV was running the course, a series of twenty-eight 56Ah/20hr batteries were recharged. When the car entered the recharging area, its batteries were charged with the 3-phase electricity and the charged set of batteries.

This system is used to reduce the charging time. For this, it is necessary to use suitable batteries, so Optima Deep Cycle batteries were installed instead of using the Japanese batteries in 2002. While using the system, the batteries recharge in about one hour from the DOD 100% condition, but the recharging gets closer to completion, saturation occurs and as shown in Figure 6, charging efficiency decreases. Because of this, it is necessary to complete the recharging as soon as possible in accordance with the distance to be run in the following leg of the rally. Figure 7shows the Electrical Wiring.

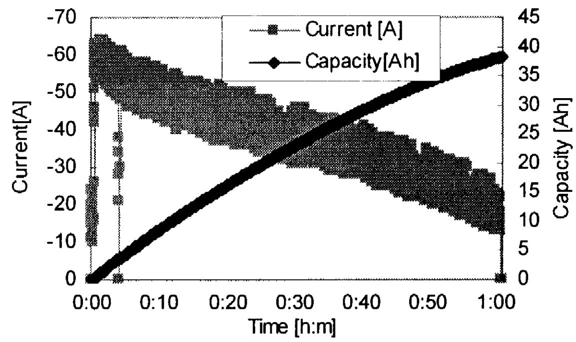


Fig. 6 Charging curves of the battery

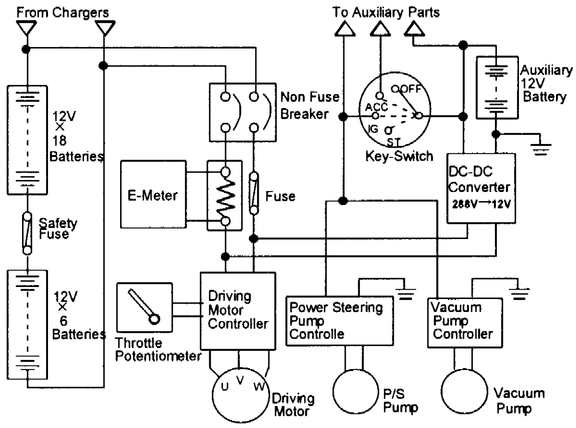


Fig. 7 Circuit diagram of 2003EV

3.2 Sensors and instrument system

Figure 8 shows the Sensors and Instrument system.

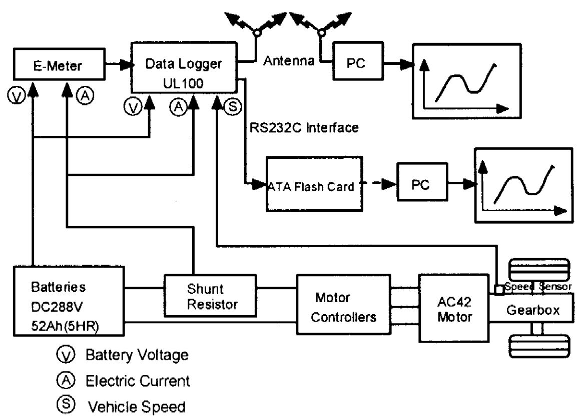


Fig. 8 Diagram of measurement system for 2003EV

The system uses a voltage divider (Asahi Keiki ADV-501-15, 1000:1) for battery voltage, and a shunt resistor (200A60mV) for electric current for digital panel instrumentation. Vehicle speed is measured by digital signals produced by a magnet attached to the lead switch and shaft that sends 1 pulse signal with every rotation of the shaft as it does the D/A conversion. A pressure semiconductor sensor (Fujikura XFPM-115KPA) is used to collect data on course undulation. All the analogue signals from the above are recorded on data logger (Unipulse UL100). There is a compact flash memory card that constantly records the data every second for memory in the data logger. The data is sent by wireless telemeter system to the PC located in the support car. During the rally, this data is analyzed and instructions on speed and other information are communicated from the support car to the EV driver by a FM wireless radio.

4. THE SHIKOKU EV WEEK 2003

4.1 The Shikoku Ishu Ekiden

The Shikoku Ishu Ekiden is a long distance demonstration rally around the Island of Shikoku. Each team presents its plan in which several places for charging battery are selected along the running course. The purpose is to collect the basic data for future use when electric vehicles come into regular use.

It is not a race as such, but if the vehicle successfully completes the course the team receives a certificate of completion from the Shikoku EV Challenge 2000 Committee.

On August 19, we started our rally from the designated starting point at Tokushima College of Technology. The route is shown in Table 2, and our convoy was lead by a maintenance car, carrying the charging equipment and followed by the EV, carrier car and support car.

Figure 9 shows on the map of Shikoku, the eight charging points of the course. The EV's use these points to recharge and complete the 800km course in three days. The plug-ins used for charging is for electric power supply from 20A or 30A. It was necessary for the maintenance car to drive ahead and prepare for efficiently recharging the EV by confirming the type of plug-ins (some were older types that were incompatible for our use). By preparing ahead of time, the EV could be given a longer period to recharge and reach the final charging point as fast as possible.

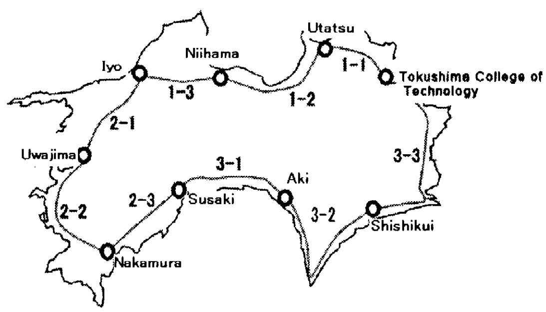


Fig. 9 Charging points and Ekiden course

Figure 10 shows the remaining battery capacity at the points where charging was done on the second day of

Table 2 Driving schedules for Ekiden

First Day(Aug.19)					
1. From Tokushima College of Technology – to UTATSU	2.Marugame -City Charge (@30A)	3.From UTATSU office of Toyota – to Sumitomo company of Niihama	4.Niihama – City Charge (@30A)	5.From Sumitomo Company of Niihama – to Ai Auto of Iyo	6. Iyo – City Charge at all night (@20A)
(Takamatu High Way) 77km		Takamatu and Matuyama High Way 88km		(Matuyama High Way)78km	
2nd Day (Aug.20)					
1.From AI Auto – to Tsurushima Auto of Uwajima	2.Uwajima – City Charge (@20A)	3.From Tsurushima Auto of Uwajima – to Kochi Suzuki of Nakamura	4.Nakamura – City Charge (@30A)	5.From Kochi Suzuki Dealer of Nakamura - to Takahashi Motores of Susaki	6.Susaki - City Charge at all night (@20A)
(Matuyama High Way and Interstate(Interstate No.56) 95km				(Interstate No.56) 78km	
3rd Day (Aug.21)					
1.From Takahashi Motors of Susaki – to Aki Auto Industry	2.Aki-City Charge (@20A)	3.From Aki Auto Industry - to Kawata Auto of Shishikui	4.Shishikui -Town Charge (@30A)	5.From Kawata Auto of Sihshikui – to Tokushima College of Technology	
(Interstate No.56,No.55) 80km		(Interstate No.55) 87km		(Interstate No.55) 112km	

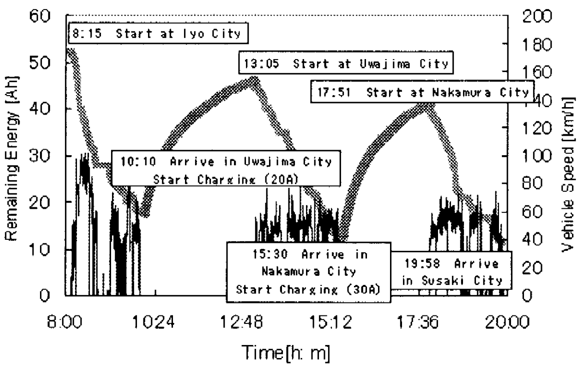


Fig. 10 Transition of the remaining battery energy on 2nd day

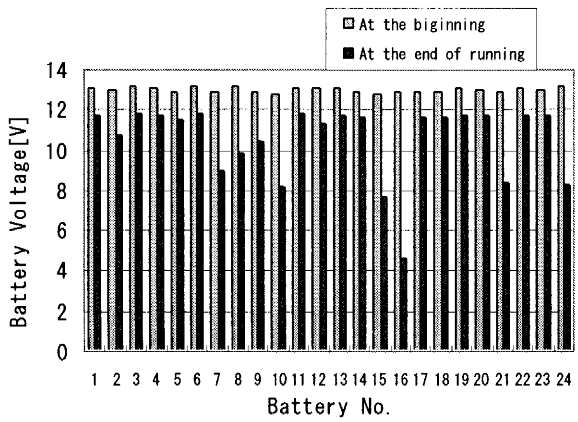


Fig. 11 Electricity remaining in the twenty-four batteries

the Ekiden. Although the EV was recharged for three hours using the 20A plug-in, it was not possible to regain the consumed electrical capacity recorded at the previous charging point. It is necessary to run the course so that 10Ah remains in the batteries when the last leg of the day is completed. Figure 11 shows the variations of voltage in the twenty-four batteries serially connected at the end of the running with their levels at the beginning. As the figure shows, when DOD is deep, the levels of each batteries vary in voltage and this raises the possibility of not being able to run the vehicle. Because of this, our experience and data from the 2002 rally, it is necessary to keep the battery minimum level at 10Ah. This fact along with our previous experience and the analysis of data from the 2002 rally, it seems it is necessary to keep the battery level at 10Ah.

Table 3 shows the total data collected after completing the entire course. The total distance was 762.6km that were run in 20hours 33minutes. The total power consumption was 302.86Ah. Two drivers (college students) took turns driving to learn efficient driving skills and reduce fatigue levels.

The results of their driving are shown in Figure 12. The rally is run on public roads that vary in condition.

The data indicates that at the beginning of the rally, the drivers were not used to driving with the necessary skills but towards the end they attained the same level as the drivers in the 2002 rally. As an example, Figure 13 shows the data collected during the Nakamura-Susaki leg of

Table 3 All the data collected after completing the entire course

		1-1		1-2		1-3		2-1		2-2		2-3	
	Section(Start)	Tokushima	Utatsu	Utatsu	Niihama	Niihama	Iyo	Iyo	Uwajima	Uwajima	Nakamura	Nakamura	Susaki
	Section(Goal)	Utatsu		Niihama		Iyo		Uwajima		Nakamura		Susaki	
	Stiation	Run	Charge	Run	Charge	Run	Charge	Run	Charge	Run	Charge	Run	Charge
Time	Start	10:57	12:41	14:24	16:10	18:14	20:03	8:15	10:10	13:05	15:30	17:51	19:58
Time	Goal	12:41	14:24	16:10	18:14	20:03	8:15	10:10	13:05	15:30	17:51	19:58	7:30
Time	Driving Time	1:44	1:43	1:46	2:04	1:49	12:12	1:55	2:55	2:25	2:21	2:07	11:32
Drive	Distance[km]	76.9		82.0		74.7		77.9		94.9		77.9	
Drive	Average Speed	44.4		55.9		41.1		40.6		39.3		36.8	
Battery	Energy at Start[Ah]	52.0	17.4	40.3	1.3	32.9	1.0	52.0	17.2	45.7	11.8	40.1	10.4
Battery	Consumption Energy[Ah]	34.6	-22.9	39.0	-31.6	31.9	-51.0	34.8	-28.5	33.9	-28.3	29.8	-41.7
Battery	Remaining Energy[Ah]	17.4	40.3	1.3	32.9	1.0	52.0	17.2	45.7	11.8	40.1	10.4	52.0
Coefficient	Mileage[km/Ah]	2.223		2.035		2.230		2.239		2.799		2.614	
Coefficient	Mileage of 2002	2.518		2.544		2.589		2.511		2.546		2.735	
Coefficient	Coefficient of charge[Ah/min]		-0.222		-0.255		-0.070		-0.163		-0.201		-0.060
Others	Voltage at Start[v]	317	290	317.8	285	308.5	249.3	317.7	285.7	313.9	266	311.8	280.4
Others	Voltage at Goal[v]	290	317.8	285	308.5	249.3	317.7	285.7	313.9	266	311.8	280.4	320
Others	Driver	A		A		B		B		A/B		A	

		3-1		3-2		3-3
	Section(Start)	Susaki	Aki	Aki	Shishikui	Shishikui
	Section(Goal)	Aki		Shishikui		Tokushima
	Stiation	Run	Charge	Run	Charge	Run
Time	Start	7:30	11:02	13:30	15:30	17:25
Time	Goal	11:02	13:30	15:30	17:25	20:40
Time	Driving Time	3:32	2:28	2:00	1:55	3:15
Drive	Distance[km]	80.0		86.8		111.6
Drive	Average Speed	22.6		43.41		28.3
Battery	Volume of Energy[AH]	52.0	24.3	46.1	11.6	48.0
Battery	Volume of Consumption[AH]	27.7	-21.8	34.5	-36.4	36.8
Battery	Remaining Energy[AH]	24.3	46.1	11.6	48.0	11.2
Coefficie	Mileage[km/AH]	2.888		2.516		3.033
Coefficie	Mileage of 2002	2.781		2.685		2.649
Coefficie	Coefficient of charge[AH/min]		-0.147		-0.317	
Others	Voltage at Start[v]	320	303	326	290.5	320.3
Others	Voltage at Goal[v]	303	326	290.5	320.3	290.6
Others	Driver	B		A		B

Total Time [h:m]	57:43
Driving Time[h:m]	20:33
Charging Time[h:m]	37:10
Driving Distance[km]	762.6
Average Mileage[km/Ah]	2.52
Average Speed[km/h]	37.2
Total Consumption Energy[Ah]	302.86

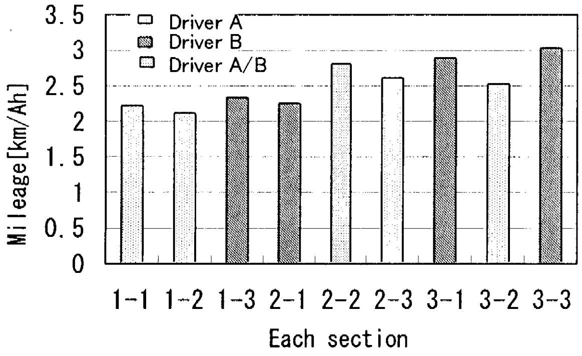


Fig. 12 The result of their driving

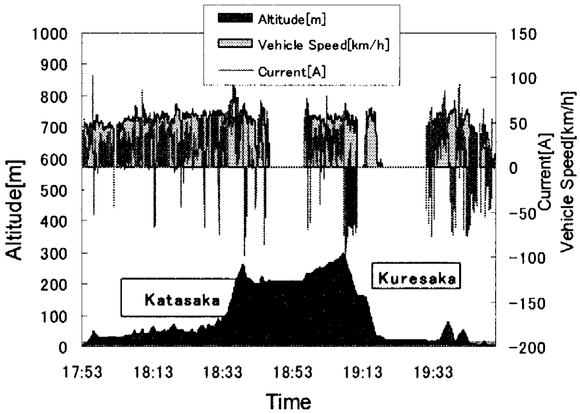


Fig. 13 The data gathered during the Nakamura-Susaki the rally.

The Nakamura checkpoint is located at the mouth of the Shimanto River with an elevation of 5m. The No. 56 Highway used between the checkpoints runs along the Pacific Ocean, but just before Kubokawa city the road takes a steep climb at Katasaka. From Kubokaw to Nanako Toge the elevation is 292.7m and from there at Kurezaka there is a sudden drop in elevation. No.56 is a single lane, no passing road and because we ran on it during commuting time, the traffic was heavy and the average speed attained was 50km/h. Before reaching Susaki, the fluctuation of the electric current is sharply.

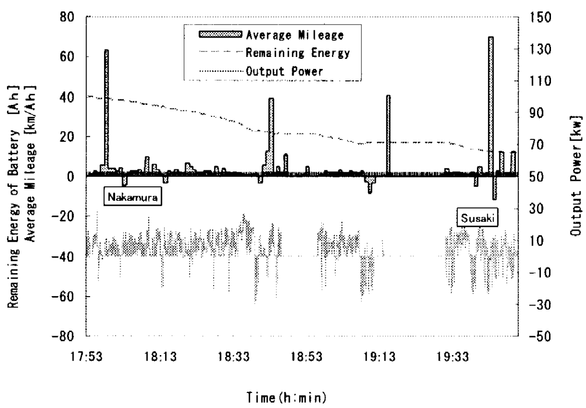


Fig. 14 The average power consumption per minute and remaining energy

This can be attributed to the driver's fatigue, as his operation of the accelerator was not very smooth. Figure 14 shows the average power consumption per minute and battery charge level in this part of the route. The average power consumption attained between these two checkpoints was 2.33km/Ah. The four points recording the highest averages indicates where the force of inertia drove the vehicle and where the average recorded is negative the regeneration system was operating. As a result, the battery level at the start in Nakamura was 40.1Ah and at goal in Susaki it recorded 10.4Ah.

4.2 Shikoku EV rally

The Shikoku EV Rally is a two-day competitive rally that requires the participants to run 9 or 10 designated public road courses and score points according to the difficulty of the course. If the battery levels become too low the vehicle is required to return to the starting point for recharging. The competition awards vehicles in four areas, namely, long distance that tests the vehicle and driver's skills, average power consumption, acceleration and braking, and a time trail on unpaved road conditions.

The rally started on August 23 with forty-seven vehicles participating. Our EV was allowed in the lead-acid battery normal vehicle category, which is the most competitive technical category. The categories were divided, correctly, according to the battery type, motor type and size of the vehicle. After completing the car inspection the day before we started with the long distance event at 9am. The competition requires the completion of the nine courses (Leg 1-Leg 9) within ten hours, six hours on the first day (a Saturday, 9:20 to 15:20) and four hours on the second (a Sunday, 6:30 to 10:30). The Legs traveled and the order they are run, are chosen and registered before the rally begins. Table 4 shows the courses we ran with distance and road conditions.

Table 4 Distances of each legs and road conditions

Leg No.	Points	Distance[km]	High way[km]	Coment for Traffic Condition
1	110	67.78	18.8	Single lane on each side
2	60	41.24	10.5	Naruto Uchino Sea Park
3	15	9.52		Periphery of Univ. of Tokushima
4	65	38.03	9.1	Periphery of Tokushima-Station etc.
5	110	70.28		Longest rout through Tokushima Downtown
6	65	35.1		Kamiyama Forest Park as Hill Climb rout
7	55	35.4		Periphery of Tokushima Air-Port
8	50	36.41		Non Heavy Traffic
9	40	28.9		Non Heavy Traffic
Total		362.66		

These routes run on expressways, mountain roads and city roads, and care must be taken in deciding the time of day to run the legs on city roads where traffic congestion is expected. Distances range from 29km to 71km so that the EV's performance can be taken into consideration when choosing courses. The courses were inspected with the drivers earlier, and road condition data was collected. Figure 15 shows the average speeds and time for completion of the nine legs with no traffic congestion.

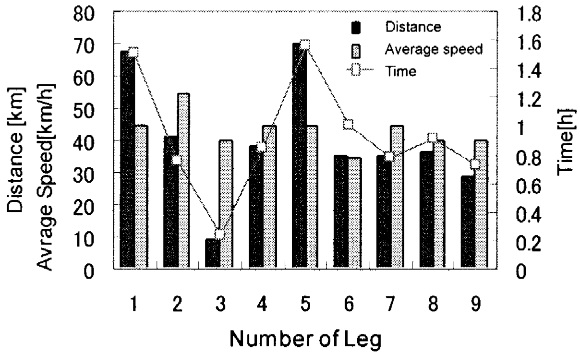


Fig. 15 The average speed and time for completion nine legs

As a result, the total times reach 8 hours and 55 minutes for actual running time only, and further it is necessary for charging time of batteries except them. Therefore we should consider as running and charging time in limits total ten hours of first day 6 hours and second day 4 hours. Course simulation carried out providing the coefficients for road conditions according to time of day (see Table 5).

Table 5 Coefficient for road conditions according to time of day

	Time Zone	Time Zone	Time Zone	Time Zone	Time Zone	Time Zone
Leg No.	9:30-10:30	10:30-11:30	11:30-12:30	12:30-13:30	13:30-14:30	14:30-15:30
1	0.9	0.9	0.85	0.85	0.85	0.85
2	1	0.95	0.95	0.95	0.9	0.9
3	1	1	1	1	1	1
4	0.95	0.9	0.9	0.85	0.85	0.8
5	0.9	0.85	0.8	0.8	0.75	0.75
6	0.95	0.95	0.9	0.9	0.9	0.85
7	1	0.95	0.95	0.9	0.9	0.85
8	1	1	1	1	1	1
9	1	1	1	1	1	1

August 24, 2003

	Time Zone	Time Zone	Time Zone	Time Zone
Leg No.	6:30-7:30	7:30-8:30	8:30-9:30	9:30-10:30
1	1	1	0.9	0.9
2	1	1	1	1
3	1	1	1	0.95
4	1	0.9	0.9	0.8
5	1	0.95	0.9	0.85
6	1	1	1	0.95
7	1	1	1	0.95
8	1	1	1	1
9	1	1	1	1

August 24, 2003

Figure 16 is a comparison of the average speed and power consumption for the Rally and Ekiden in 2002 and Ekiden in 2003. In the rally type competition, with time limits to clear, the average power consumption at all speeds was 0.5km/Ah lower than the events without time limits. This is because of the need to drive at higher speeds and also the frequency of higher acceleration rates results in higher power expenditure. However, the hybrid charging system installed the year before made it possible for shorter recharging time and when the battery charges are lower, the charging efficiency (Ah/min) is higher, so raising speeds to shorten running time and increasing charging time was possible.

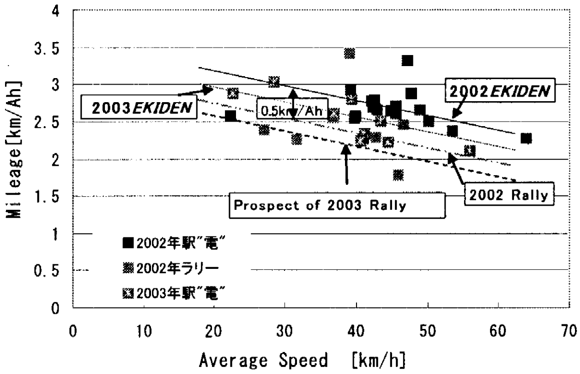


Fig. 16 Comparison of the average speed and power consumption

Also, comparing results from the previous year's Ekiden, the power consumption was higher although the route conditions were almost the same. This was because the drivers for the 2002 events were relatively experienced drivers in comparison to the drivers in 2003. In order to estimate power consumption for the 2003 Rally, a calculation is possible by subtracting 0.5km/Ah from the 2003 Ekiden results. V represents velocity; Fv km/Ah represents estimated power consumption.

$$Fv\ [km/Ah] = (-0.0254) \times v + 3.2 \qquad (1)$$

Next the first day's six-hour time limit is T1, the second day's four-hour time limit is T2, and the leg distances are represented as l1, l2 ... l9. The average speeds in Figure 15 and the road congestion variables of Table 5 give the actual average speeds and these are represented as v1, v2, ... and v9.

$$T1 > \Sigma\ li/vi \ .... \qquad (2)$$

$$T2 > \Sigma\ lj/vj \ .... \qquad (3)$$

However, $i \neq j$.

The charge capacities over the first and second days are respectively Ch1 and Ch2. Since the charging coefficients is dependant on DOD, although integral calculus is used to calculate charge capacity exactly, but here the average coefficient of 0.66Ah/min. is used for the product of charging times.

$$Ch1 = \text{Charging coefficients X } (T1\text{-}X1) \ldots. \quad (4)$$

$$Ch2 = \text{Charging coefficients X } (T2\text{-}X2) \ldots. \quad (5)$$

X1 represents the total running time of the first day and X2 the second day.

Battery capacities for the two days is represented by 52+Ch1 and 52+Ch2 and the power consumption which substituted and asked the estimated power consumption formulas 1 for the average speed (v) run in the various legs are set to F1, F2, ... and F9.

$$52 + Ch1 > (\Sigma\ li/Fi) + y \ldots. \quad (6)$$

$$52 + Ch2 > (\Sigma\ lj/Fj) + y \ldots. \quad (7)$$

However, $i \neq j$.

They Ah in formulas 6 and 7 were given the value of 10Ah in the Ekiden, because the difference in electric discharge between individual batteries was such. But for the Rally and its time requirements the value was set at 0Ah.

From this formulas 2, 3, 6, and 7 were used to decide on the order the chosen legs would be run and the charging times were decided. Table 6 shows the final data collected from this simulation. From this data the estimated charge and discharge of the batteries was calculated, as seen in Figure 17 and the actual charge and discharge is shown in Figure 18.

Comparing this data, it shows that there was time left over on the first day. Running another leg planned for the next day instead of Leg 3 was considered, but these courses were over 30km and the average speed required to complete was 40km/h. In the case of the actual rally,

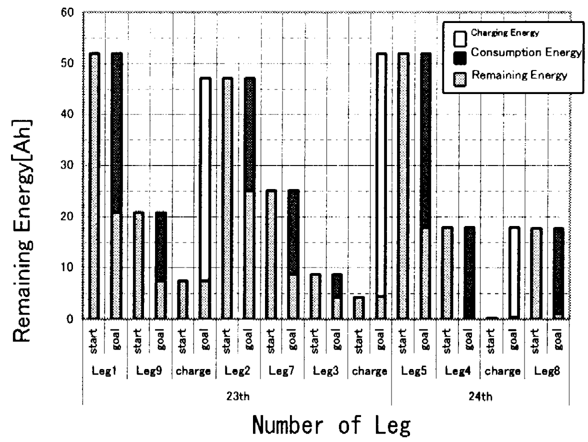


Fig. 17 Driving simulation

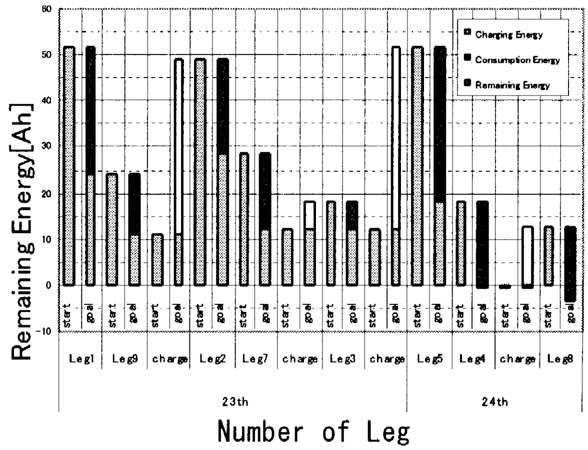


Fig. 18 Data of actual drive

Leg 5 on the second day was the longest distance to be attempted and the remaining charge of the batteries was less than 20.1Ah, which according to the simulation data, required for what, I think it is not complete. Leg 4 ran on an expressway and the electrical charge for that was also slightly under the requirement as well. However, if charging the batteries before running Leg 4 would have

Table 6 The final data gained from this simulation

	Order	Leg. No.	Distance[km]	Remaining Energy[Ah]	Consumption Energy[Ah]	Charged Energy[Ah]	Run/Charge Time[h:m]	Passage Time[h:m]	Average Speed[km/h]	Mileage[km/Ah]	Coefficient of Charge[Ah/min]	note
1st Day	1	1	67.78	52.0	31.2		1:40	1:40	40.5	2.17		With High Way
	2	9	28.9	20.8	13.3		0:43	2:23	40	2.18		
	3	Charge		7.5		39.6	1:00	3:23			0.66	
	4	2	41.24	47.1	22.1		0:47	4:10	52.25	1.87		With High Way
	5	7	35.4	25.1	16.3		0:53	5:03	40.5	2.17		
	6	3	9.52	8.7	4.4		0:14	5:17	40	2.18		
				4.4								
2nd Day	7	5	70.28	52.0	34.1		1:45	1:45	45	2.06		
	8	4	38.03	17.9	17.5		0:53	2:38	40.5	2.17		With High Way
	9	Charge		0.4		17.5	0:25	3:03			0.7	
	10		36.41	17.9	16.7		0:55	3:58	40	2.18		
				1.2								

Leg No.	Distance	Average Speed	Time
1	67.78	45	1.51
2	41.24	55	0.75
3	9.52	40	0.24
4	38.03	45	0.85
5	70.28	45	1.56
6	35.1	35	1.00
7	35.4	45	0.79
8	36.41	40	0.91
9	28.9	40	0.72
Total	362.66	------	8.32

been attempted, the remaining time needed to run Leg 4 and Leg 8 would not be within time limits, since the charge efficiency falls under the influence of DOD. As a result the remaining battery capacity was -0.8Ah. Also, some of the batteries did not have enough voltage to discharge anymore. At the final charging before running Leg 8, the intention was to give the batteries enough charging time, but again it was necessary to reduce risks such as traffic congestion to complete the course in the required time limit, and so charging time was shortened with one hour remaining for running time. With 5km remaining to reach the goal, battery voltage had dropped to the lowest level for running the vehicle.

The accelerator was pushed to the limit but the EV would not run over 20km/h. With 5 minutes of time remaining, the vehicle crossed the goal line Leg 6 had with remaining battery capacity at -3.2Ah. Originally, been the intended course, but it runs on mountain roads so the Ah/min. energy consumption rate is high.

Instead Leg 4 was chosen because it has the higher distance efficiency potential (remaining battery capacity/running time). The choice proved to be a correct one as the result showed in terms of points collected. Table 7 shows the data of our EV for the long distance competition. Also, Figure 19 shows power consumption rates, regeneration rates and average speeds for all the legs. Our EV has a regeneration braking system, but as seen in Figure 19 it is better to take advantage of the effective use of vehicle inertia rather than using the regeneration system for the economical driving.

It is always important to be aware of the traffic and road conditions and constantly react early to avoid sudden acceleration or deceleration. Figure 20 shows the data from the Ekiden section 3-3 and Figure 21 (1) to (8) show the motor output power in relation to speed traveled. Figure 21 (1) shows the distribution of in the high-speed and high output power range indicating a suddenly acceleration. In the same series of figures, (2) and (6) show similar distribution patterns even though (2) runs on an expressway and (6) runs on public roads only.

Table 7 Data of actual drive on long-distance category

	Aug.23,2003									
	①Leg 1	②Leg 9	③1st Char	④Leg 2	⑤Leg 7	⑥2nd Cha	⑦Leg 3	⑧All nigh	Subtotal-1	Reserved Time
Driver	A	B		C	B		D			
Start Time[h:m:s]	9:21	11:09	11:47	12:49	13:49	14:50	14:57			
Goal Time[h:m:s]	11:09	11:47	12:48	13:49	14:50	14:57	15:15			
Expense Time[h:m:s]	1:48	0:38	1:01	1:00	1:00	0:07	0:18		5:53	6:00
Remaining Time [h:m:s]	4:12	3:33	2:32	1:32	0:32	0:24	0:06			
Distance[km]	68.6	27.1		41.5	35.8		9.8		182.8	
Average Speed[km/h]	38.1	42.5		41.4	35.7		31.7			
Max Power[kw]	45.5	39.8	-18.8	43.3	41.0	-20.1	45.0			
Remaining Energy at Start[Ah]	52.0	24.3	11.0	49.1	28.5	12.1	17.9	12.2		
Remaining Energy at Goal[Ah]	24.3	11.0	49.1	28.5	12.1	17.9	12.2	52.0		
Total Consumption Energy[Ah]	27.7	13.3	-38.2	20.7	16.4	-5.8	5.7			
Volume of Consumption Energy[Ah]	33.9	16.3	0.0	24.5	21.4	0.0	7.8			
Volume of Regeneration Energy[Ah]	6.2	2.9	38.2	3.8	5.0	5.8	2.2			
Mileage[km/Ah]	2.48	2.03		2.68	2.50		1.72			
Coefficient of Regeneration Energy	0.18	0.18		0.16	0.23		0.27			
Volume of Charging Energy[Ah]			38.2			5.8				
Coefficient of Charging Energy[Ah/min]			0.621			0.798				
Battery Voltage at Start[V]	316	293	293	298	292	283	294			
Battery Voltage at GoalV]	293	279	293	291	283	290	283			
Vmax [V]	299	295	293	298	293	291	294			
Vmin[V]	265	252	280	282	257	283	249			

	Aug.24,2003						
	⑨Leg5	⑩Leg4	⑪3rd Cha	⑫Leg8	Subtotal-2	Reserved T	Total
Driver	D	B		C			
Start Time[h:m:s]	6:27	8:03	9:10	9:27			
Goal Time[h:m:s]	8:03	9:10	9:27	10:21			
Expense Time[h:m:s]	1:35	1:07	0:16	0:54	3:54	4:00	9:47
Remaining Time [h:m:s]	2:24	1:17	1:00	0:05			
Distance[km]	71.5	40.1		38.0	149.6		322.5
Average Speed[km/h]	45.0	35.6		39.7			
Max Power[kw]	44.7	38.7		21.4			
Remaining Energy at Start[Ah]	52.0	18.2	-0.8	12.6			
Remaining Energy at Goal[Ah]	18.2	-0.8	12.6	-3.2			
Total Consumption Energy[Ah]	33.8	19.0	-13.3	15.7			152.4
Volume of Consumption Energy[Ah]	40.5	23.0	0.0	18.6			185.9
Volume of Regeneration Energy[Ah]	6.7	3.9	13.4	2.8			33.5
Mileage[km/Ah]	2.12	2.11		2.41			2.12
Coefficient of Regeneration Energy	0.17	0.17		0.15			0.18
Volume of Charging Energy[Ah]			13.4				57.3
Coefficient of Charging Energy[Ah/min]			0.813				
Battery Voltage at Start[V]	306	289	236	291			
Battery Voltage at GoalV]	289	225	291	232			
Vmax [V]	306	300	294	295			
Vmin[V]	266	195	236	200			

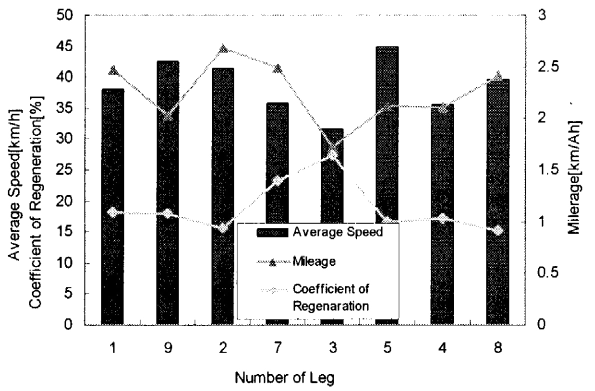


Fig. 19 Average speed, mileage, and coefficient of regeneration

The drivers are different as well. Driver A drove Leg 7, which recorded a power consumption efficiency rate of 2.50km/Ah, and this type of driving, proves to be most effective. The vehicle's best power consumption rate was on Leg 8 where it gained 2.83km/Ah and the distribution seen in (7) shows that the output was under 15kw. The reason for this was that the driver adjusted the Power Save Volume in accordance to road conditions. In Figure 20 Driver B had the highest power consumption rate of 3.03km/Ah for the Ekiden in section 3-3 of the course. Gaining driving skills during the competitions ultimately resulted in the good ranking received in the power consumption category. Figure 21 (4) shows the difference between expressway and regular public roads with two clear clusters. Figure 21(5) shows the power consumption and average speed for the leg run on early Sunday morning when the traffic was relatively light allowing for very little acceleration and constant speeds between 50-80km/h. This contributes to the relatively high average speeds along with efficient power consumption. The dirt road trails held at the Tokushima College of Technology campus. We had two chances to attempt to race, but the suspension of our EV's was too hard and was not suitable due to the road surface had unpaved conditions.

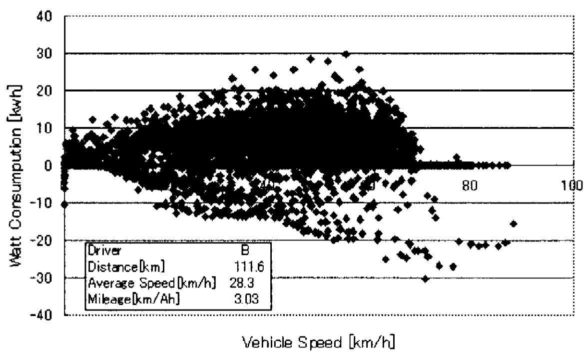
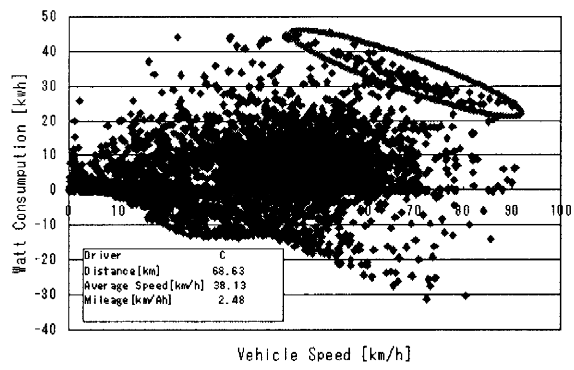
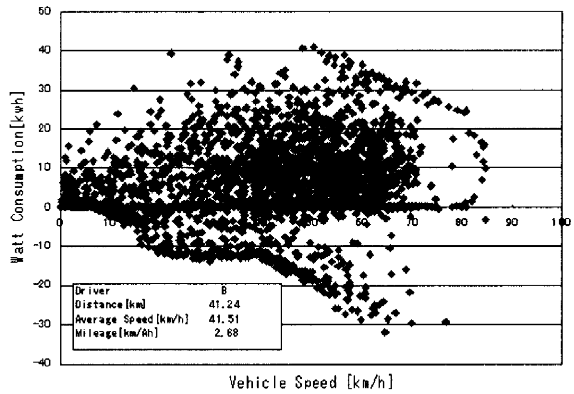


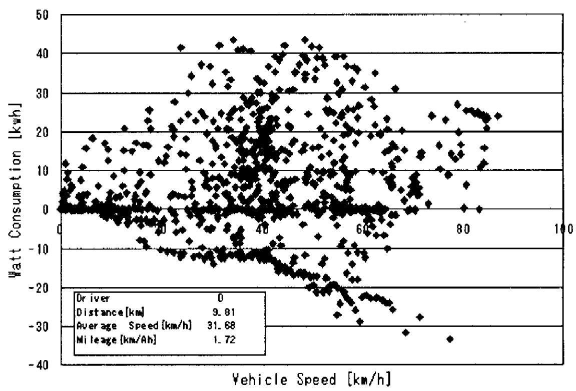
Fig. 20 Driving points in Ekiden (3-3)



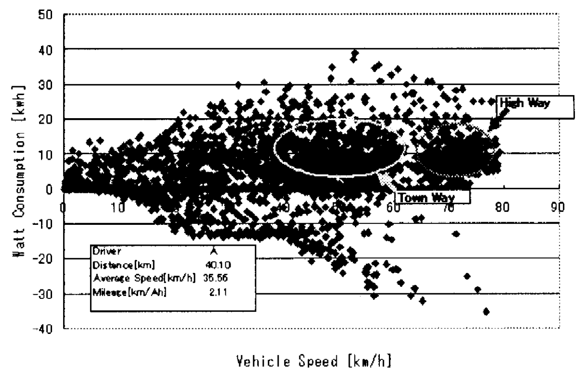
(1) Driving Points in Leg-1



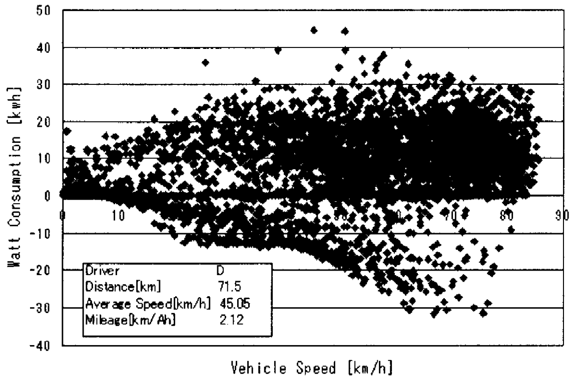
(2) Driving Points in Leg-2



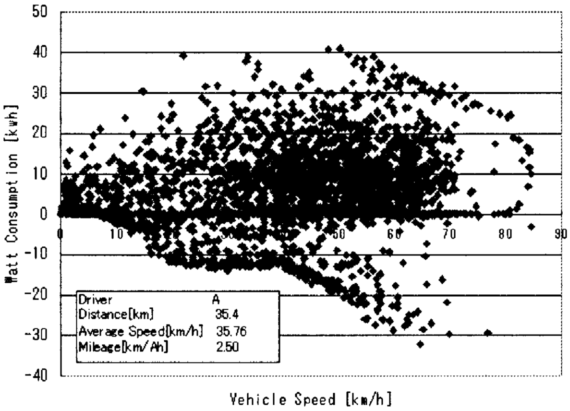
(3) Driving Points in Leg-3



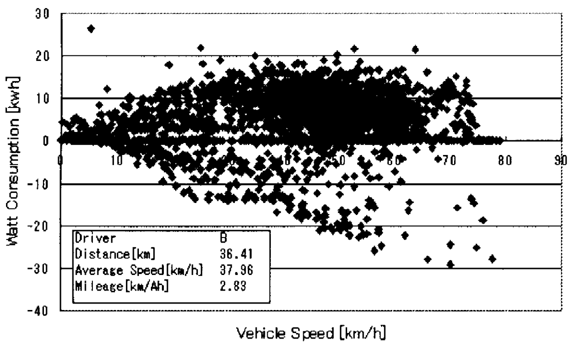
(4) Driving Points in Leg-4



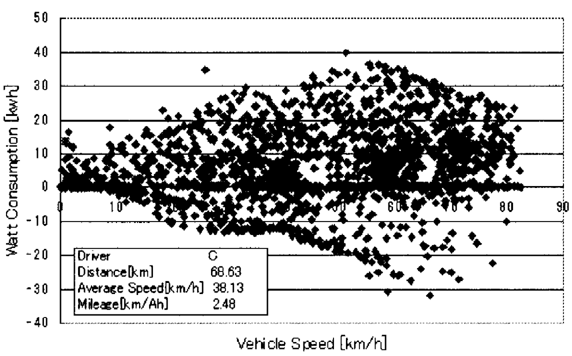
(5) Driving Points in Leg-5



(6) Driving Points in Leg-6



(7) Driving Points in Leg-8



(8) Driving Points in Leg-9

Fig. 21 Driving Points in leg-1-9

Table 8 The results of our EV in Shikoku EV rally

Year	Name of The Competition	Result
1999	*Shikoku EV Rally* in TOKUSHIMA Long-distance category	9 place
	Time trial category	total 3 place
2000	*Shikoku EV Rally* in KOCHI Long-distance category	2 place
	Energy consumption(km/kwh)category	4 place
2001	*Shikoku EV Rally* in KOTOHIRA Long-distance category	total 6 place
	1 – 2 category	3 place
2002	*Shikoku EV Rally* in NIIHAMA Long-distance category	win
	Energy consumption(km/kwh)category	4 place
	Acceleration brake category	win
2003	*Shikoku EV Rally* in TOKUSHIMA Long-distance category	win
	Energy consumption(km/kwh)category	win
	Dirt trial category	5 place

In the evening of the first day in the energy efficiency category, the EV recorded 24.1071km/kwh and won the first prize. Table 8 [Saihara et al., 2001], shows the results of participation by OSU in these EV events.

5. CONCLUSIONS

The following conclusions were made as the result from our participation in the Shikoku EV Week 2003.

(1) At the Ekiden 2002 event, the vehicle traveled 728km in 16 hours 44minutes; average energy efficiency was 2.65km/Ah, average speed 43.6km/h, and total power consumption at 274.81Ah. In 2003 the running time was 20hours 33minutes. The average energy efficiency was 2.567km/Ah; average speed 37.2km/h and total power consumption was 302.86Ah.

(2) The use of student drivers was successful in the two events as they gradually learned how to drive efficiently.

(3) In the EV Rally distance category, the data from previous races and looking over the road conditions ahead of time and simulating the race were important in planning for battery charging, and rally leg selection. One of the legs was canceled but we were able to run the vehicle quite closely to the simulation.

(4) By being able to adjust electrical output power we were able to reach 4.1071km/kwh and win the energy efficiency category.

(5) By participating in this event the students gained insights into environmental issues in relation to auto-

mobiles. It was a good educational experience for them.

Acknowledgements

A problem that needs to be worked on in the future is the reduction in discharge levels between batteries. Although we set the lowest level at 10Ah, it is necessary to use the battery manager, now under development, to monitor the batteries more closely.

We would like to thank all of those who provided assistance as we participated in the events described. In particular we thank Mr. Tsutsui Kenichi of Banzai Automobile who provided maintenance at the checkpoints of the Ekiden.

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