EVS27
Barcelona, Spain, November 17-20, 2013

Reducing test duration for EV mileage per charge

- Preparation and evaluation of new testing methodology -

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Abstract

Measuring mileage per charge (range) of Electric Vehicles takes long time in the Japanese type approval test. In order to reduce the test duration, existing test cycle: JC08 mode was modified. “Condensed JC08 mode” was prepared as a modified test cycle. This test cycle has almost the same load or energy consumption as JC08 mode and its testing duration can be reduced to three-quarters of that of JC08. It was validated with two types of Electric Vehicles. The range measured with the condensed JC08 mode almost agreed with the range measured with JC08 mode (error less than 3%). It indicated the potential that the condensed JC08 mode will be used as an option.

Additionally, prospective test procedures, “Worldwide harmonized Light vehicles Test Procedures (WLTP)” were also modified for reducing test duration. The test procedure modification including range estimate method allowed to reduce the number of full depleting tests from two to one. It corresponds to saving one day in the type approval test. The range determined by using range estimate method agreed with the range measured with the original test procedures (error less than 3%).

Keywords: range, BEV (battery electric vehicle), EV (electric vehicle)

1 Introduction

Mileage per charge (range) is recognized as one of the most basic and important factors as well as AC energy consumption in the Electric Vehicle (EV) performance. In fact, AC energy consumption is calculated based on the range. Battery life and endurance which highly relate to EV performance are eventually evaluated by change of range and AC energy consumption. Consumers also show great interest in the range for purchasing vehicles. The range is expected to increase in the future for satisfying consumers’ demand. However, it will cause an issue of increasing test duration. Thus there is an urgent need to update the measurement method according to the technological progress. From the position of national laboratory, we have studied test methods for electrified vehicles including HEV and PHEV, to support creating regulations and test procedures. In this time, we have prepared two methods for responding to the issue of increasing test duration. The first method was test cycle modification. “Condensed JC08 mode was prepared as a test cycle which increased energy consumption per unit time. The second method was test procedure modification based on a range estimate method. The purpose of this study is to examine whether the two methods will allow for measuring the range in a shorter time and also to clarify the margin of errors.

2 Approach to reducing duration of existing test procedure

2.1 Existing test procedure

The Japanese existing test procedure for measuring range is described in "Test Requirements and Instructions for Automobile Standards" (TRIAS)[1]. Figure 1 shows a test schedule of "range and AC energy consumption dynamometer test" in the type approval test for EV. The range is measured by repeat driving on "JC08 mode". JC08 mode is a test cycle with 24.4 km/h of average velocity, which reflects actual traffic conditions in Japan. In the case of EV with mileage of 200 km, it takes over 8 hours for the range test.

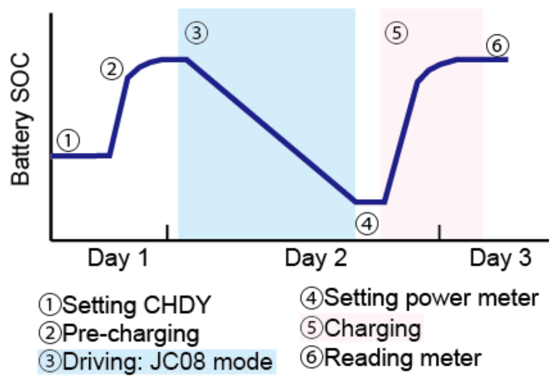

Figure 1: Test schedule based on TRIAS

2.2 Concept of reducing duration and JC08 modification

2.2.1 Concept of reducing duration

The test duration was considered to be reduced by test cycle modification. There were two ideas of test cycle modification which increased energy consumption per unit time to reduce the test duration. One is to add heavy-load part, such as high-speed driving and highly-accelerated driving, to the cycle, and the other is to cut low-load part like idling. In this study, the authors drew attention to the fact that the energy consumption of EVs while idling is smaller than that of while driving, and thus adopted the method to partially cut idling parts to modify the JC08 mode and we named it "condensed JC08 mode (C-JC08 mode)."

2.2.2 Developing new test cycle; condensed JC08 mode

The C-JC08 mode was prepared by modification of JC08 mode. In the C-JC08 mode, the driving loads such as acceleration and deceleration are same as the JC08 mode, and thus the data obtained is expected to be almost same as used in the conventional measurement method. The base JC08 mode consists of three phases (urban, rural and highway) including eleven sections of idling part. The sum of the idling sections in the JC08 mode (total 1204s) is 357 seconds and the minimum section is 6 seconds and the maximum is 77 seconds. This study set all the eleven sections in idling part to 6 seconds. Figure 2 shows each test cycle of JC08 mode and C-JC08 mode. The total length of C-JC08 mode is 913 seconds. It is estimated that 24 % of full depletion time will be reduced.

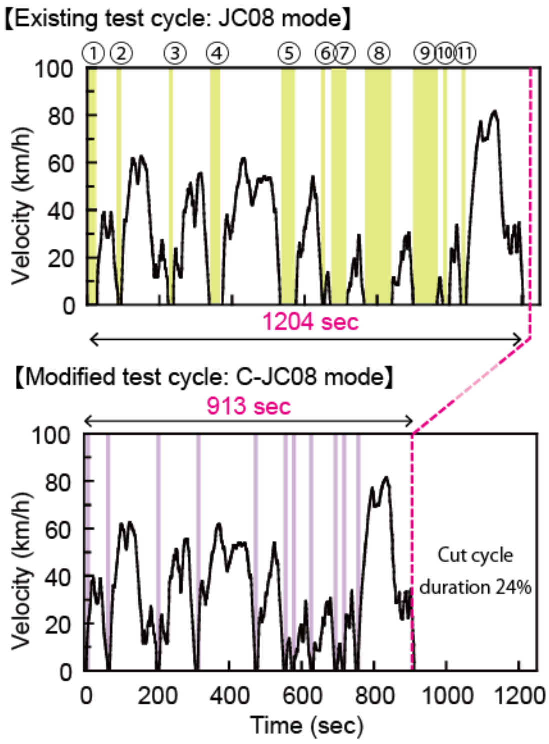

Figure 2: Modification JC08 mode to C-JC08 mode

2.3 Range test results

The range tests using C-JC08 mode were conducted with two types of test vehicles for comparing with JC08 mode. Both range tests using JC08 mode and C-JC08 mode were repeated three times respectively. The average mileages of each three cycles in vehicle A were 185.8 km in JC08 mode and 190.0 km in C-JC08 mode. In the case of vehicle B, they were 117.3 km and 119.2 km respectively (Figure 3). The results of the measurement revealed a tendency that C-JC08 mode had 2% longer range than JC08 mode.

The DC energy while driving was analysed. The DC energy on each cycle of vehicle A is plotted in Figure 4. These on the cycle of C-JC08 were slightly smaller than that of JC08 for all cycles. The average energies except for the first and last cycle were 863.3 Wh in JC08 and 843.9 Wh in C-JC08. The slight gap of 19.4 Wh was assumed to be correspond to the energy in the idle part which we omitted. The relation of energies in the idle part in JC08 and the idle time are plotted in inset of Figure 4. The estimated energy in omitted idle part was 14.8 Wh and almost agreed with the slight gap of energy in JC08 and C-JC08. The longer ranges in C-JC08 were derived from the energy which was not consumed for idle part, but used for extending range.

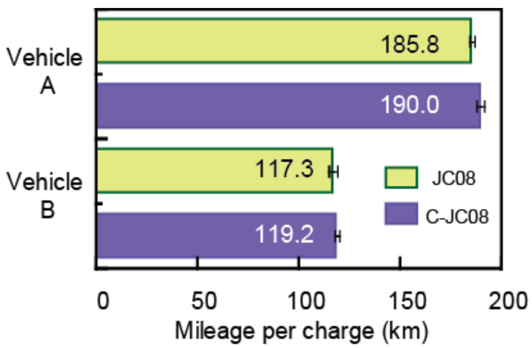

Figure 3: Range test results

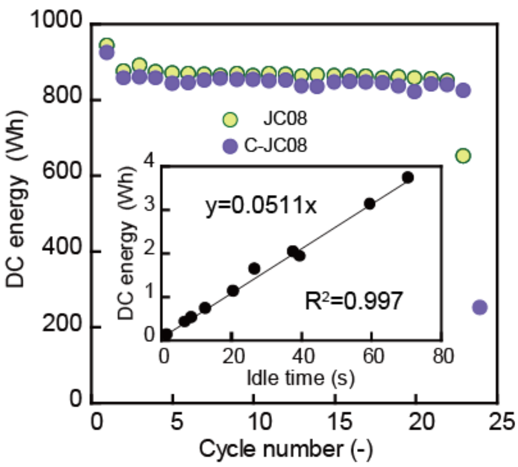

Figure 4: DC energy on cycle

2.4 Test cycle evaluation

The C-JC08 mode contributed to reducing test duration as follows. In the case of vehicle A, the time of full depletion test (except for the time loss of driver change) was reduced to 5 hr and 53 min from 7 hr 35 min, namely 1 hr and 42 min time reduction. The case of vehicle B, the time of full depletion test was reduced to 3 hr and 41 min from 4 hr 47 min, namely 1 hr and 06 min time reduction. The error of range measured in C-JC08 was less than 3% of the range in JC08. The margin of the error mainly depended on the rate of energy while idle part to the total energy. These results indicated the potential that the C-JC08 mode will be used as an optional test cycle for the range test of EVs.

3 Approach to reducing duration of prospective test procedure

3.1 Prospective test procedure

Worldwide harmonized Light vehicles Test Procedures (WLTP)[2] have been developed by United Nations. In case of installation of WLTP to Japan, it will extend the duration of type approval test for EVs due to the increase in the number of test cycles. WLTP contains three test cycles; WLTC-LM, WLTC-LMH and WLTC-LMHexH.[3] Two of them; WLTC-LM and WLTC-LMH will be mainly used because they closely reflect the Japanese actual traffic conditions. Therefore the full depletion test will be essentially conducted twice in the type approval test procedure for measuring range$_{LMH}$ and range$_{LM}$. It expands the test duration for one more day (Figure 5). The extending type approval test duration will become an argument at the time of installation. In this section, we will report the results of the range test with WLTP, the range estimate method and its accuracy.

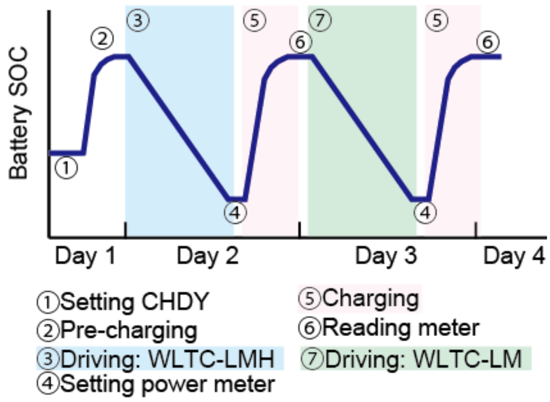

Figure 5: Test schedule based on WLTP

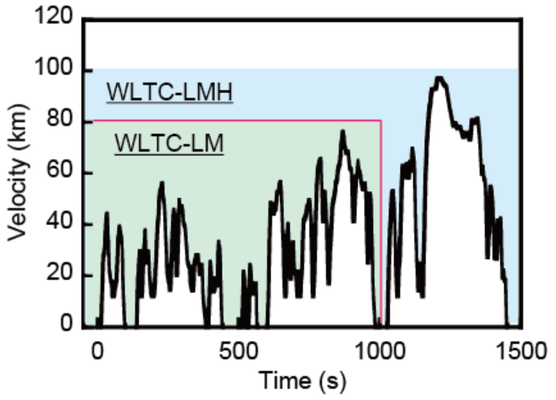

Figure 6: Test cycles in WLTP

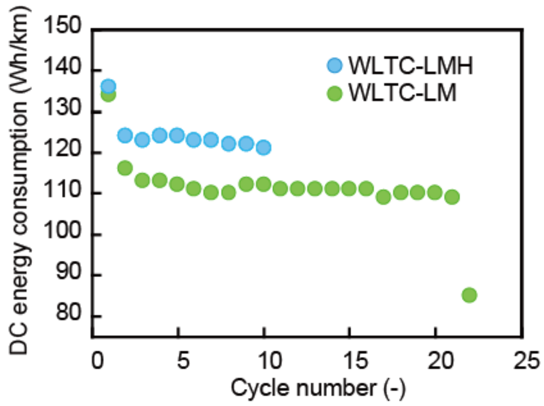

Figure 8: Energy consumption on each cycle

3.2 Range test results using WLTC

Range tests of vehicle A were conducted 3 times each by using WLTC. Vehicle A travelled 149.6 and 168.3 km on average in WLTC-LMH and -LM, respectively (Figure 7). Range$_{LM}$ was ca. 12% longer than range$_{LMH}$. The range$_{LMH}$ and range$_{LM}$ corresponded to 10 times repeat of WLTC-LMH and over 21times repeat of WLTC-LM.

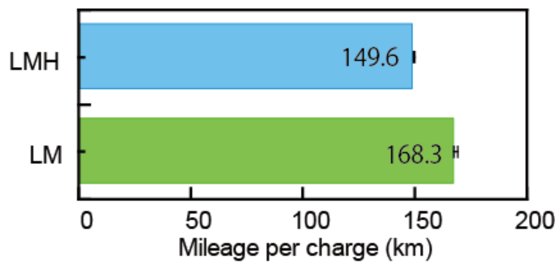

Figure 7: Range test results

DC discharge energy consumptions on each cycle were plotted in Figure 8. Consumption on the first cycle was ca. 135 Wh/km and higher than the energy consumptions on the second and subsequent cycles. It was assumed that Cold-start increased energy consumption. On the second and subsequent cycles (except for 22nd), energy consumptions on average were ca. 123 and 111 Wh/km in WLTC-LMH and -LM.

3.3 Approach to WLTP for reducing test duration; range estimate method

3.3.1 Concept of reducing test duration

The test duration was considered to be reduced by omission of the second range test for measuring range$_{LM}$. Range$_{LM}$ was determined by using the range estimate method. Additionally, the duration of full depletion was considered to be reduced by test sequence modification of the first range test.

3.3.2 Range estimate method and its application for range$_{LM}$

The range estimate method is a range calculation from the relationship Usable battery energy (UBE) and DC discharge energy consumption. The detail of calculation procedure was described in SAE J1634[4]. The range$_{LM}$ estimation is performed as follows. At first, the full depletion test was conducted under condition of WLTC-LMH with collecting data of driving range and DC discharge energy. The total of the DC discharge energy was used as UBE in this calculation. Then the data corresponding to the driving WLTC-LM was extracted from the collected data. The DC discharge energy consumption of each WLTC-LM cycle (ECdc$_{LM}$) and Cycle scaling factor (k$_{LM}$) were calculated from the extracted data. The cycle scaling factor determined the contribution of each cycle's DC discharge energy consumption to the total DC discharge consumption (=UBE). The range$_{LM}$ was calculated using the UBE, Cycle scaling factor of the first cycle (k$_{LM_1}$), DC discharge energy consumption of the first cycle (ECdc$_{LM_1}$) and DC discharge energy consumption of the average of the second and subsequent cycles (ECdc$_{LM_avg}$):

$$\text{Range}_{LM} = \frac{\text{UBE}}{k_{LM\_1}\text{ECdc}_{LM\_1}+(1-k_{LM\_1})\text{ECdc}_{LM\_avg}} \quad (1)$$

3.3.3 Results of range$_{LM}$ estimation

The range$_{LM}$ calculated by the estimate method was 164.9 km which almost agreed with the range$_{LM}$ measured (error 2%). The calculated ECdc$_{LM}$ on the first cycle and the average of ECdc$_{LM}$ on subsequent cycles were 132.7 Wh/km and 111.5 Wh/km (Table 1). They also agreed with measured ECdc$_{LM}$ (Figure 8).

Table 1: Results of range$_{LM}$ estimation

Test No.	UBE (kWh)	k_{LM_1}	ECdc$_{LM}$ (Wh/km) first cycle	ECdc$_{LM}$ (Wh/km) averatge of subsequent cycles	Estimated Range$_{LM}$ (km)	Error
n=1	18.57	0.057	135.7	112.2	163.5	
n=2	18.62	0.055	129.7	111.9	165.0	
n=3	18.57	0.056	132.5	110.5	166.2	
Average	18.59	0.056	132.7	111.5	164.9	-2.0%

3.3.4 Test sequence modification

A test sequence modification was also attempted so as to reduce the duration of the full depletion test. In the case of vehicle A, it took over 4hours for the full depletion test with consequent repeat WLTC-LMH. In this study, the authors focused on the fact that the energy consumptions of EVs except for the first and last cycle were almost constant, and then adopted the method to partially replace WLTC-LMH driving to constant speed driving in the test sequence (Figure 9) .

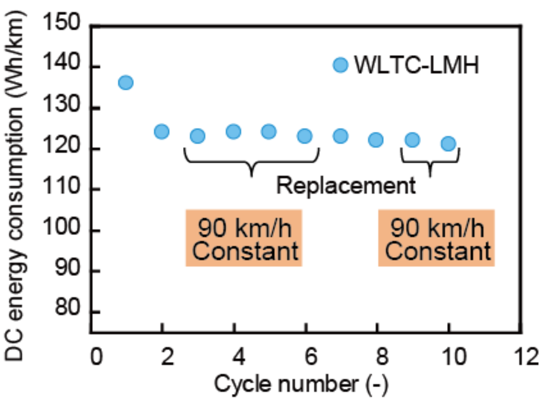

Figure 9: Energy consumption on each cycle

The test sequence was set as Figure 10. The modified test sequence was divided into four parts. In the first part, WLTC-LMH was repeated twice. Second part was composed of a constant speed part of 90 km/h for ca. 30 min, which corresponds to the four times repeat operation of WLTC-LMH. In the third part, WLTC-LMH was repeated twice again. The last part was the constant speed part of 90 km/h until the end of test.

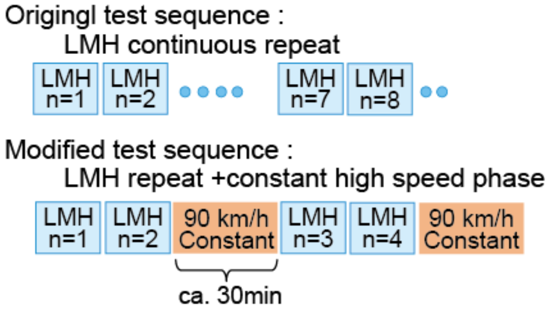

Figure 10: Test sequence modification

3.3.5 Results of range$_{LM}$ and range$_{LMH}$ estimation

Range$_{LM}$ and range$_{LMH}$ were calculated by the range estimate method and each range was 153.4 km and 170.1 km respectively. Both ranges agreed with actual measurement of range$_{LM}$ (error 2.5%) and range$_{LMH}$ (error 1.1%). The calculated ECdc$_{LM}$ and ECdc$_{LMH}$ also agreed with the actual measured ECdc$_{LM}$ and ECdc$_{LMH}$ on the first cycle and the average of following cycles (Table2 and Figure 8).

Table 2: Results of range$_{LM}$ and range$_{LMH}$ estimation

Test cycle	UBE (kWh)	$k_{\_1}$	ECdc (Wh/km) first cycle	ECdc (Wh/km) average of cycles (n=2-4)	Estimated Range (km)	Error
LMH	19.24	0.107	137.4	124.0	153.4	2.5%
LM		0.055	136.0	111.8	170.1	1.1%

3.4 Test procedure evaluation

The modified test procedure with the range estimate method allowed to omit the full depletion test of WLTC-LM. This was because the data of ECdc$_{LM}$ accurately was obtained from the data of the full depletion test of WLTC-LMH. In the case of vehicle A, the error of estimate range was less than 3%. The margin of the error in the range estimate method mainly depended on the repeatability of UBE. These results indicated the potential that the modified test procedure with the range estimate method will be used as an optional test procedure for range tests of EVs.

4 Experimental section

4.1 Test vehicles

Two types of EVs were prepared as test vehicles. Vehicle A was 1520 kg of vehicle weight with a 24 kWh of lithium ion battery pack and has already run ca. 4000 km before the experiment. Vehicle B was 1080 kg of vehicle weight with a 16 kWh of lithium ion battery pack and has already run ca. 10000 km before the experiment.

4.2 DC energy measuring instrument

In the section 3, DC energy was measured by Power analyser 3390, Hioki E.E. Corporation.

5 Conclusion

We have prepared and evaluated the test cycle and test procedure which contribute to reducing the test duration. The modified test cycle of C-JC08 mode allowed to reduce test duration by 24% of the existing test cycle with less than 3% errors. In the case of test vehicle A, the C-JC08 mode shortened the time of full depletion by 1 hr and 42 min. The modified test procedure with the range estimate method allowed to reduce the number of full depleting tests from two to one. It corresponds to saving one day in the type approval test. In the test procedure, the additional test sequence modification also reduced the duration of full depleting test by 2hr and 40 min. The errors were within 3% of range with continuous repeat WLTC-LMH and WLTC-LM. It was demonstrated that the modified test cycle and test procedure reduced the range test duration with error of ca. 3%. These modified test procedures will contribute to solve the issue of increasing test duration.

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