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TESTING OF THE ELECTRIC VEHICLE IN DRIVING CYCLES

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Abstract

The energy consumption of the car depends on traffic conditions and the car characteristics, speed and motion resistance such as rolling resistance, the slope angle, wind speed, etc. Vehicle speed determines the energy consumption in the vehicle in the comparable moving conditions. It is necessary to perform the research in a number of tests corresponding to the different traffic conditions to widen the knowledge beyond that from type-approval tests.

The article presents energy consumption studies of electric passenger car in both approval tests: European – NEDC, American – FTP as well as special tests, for example Stop and Go. The tests were repeated several times, i.e. for different initial levels of battery charge. In addition, tests under real traffic conditions on the big city streets have been conducted. The measurements were made on a Zilent Courant passenger car, produced by Chinese company Shandong Baoya New Energy Vehicle Co. ltd. This is a pure electric vehicle, which meets the conditions for qualifying it as a "pure electric vehicle" in accordance with section 2 of the ECE Regulation no. 101. Courant is a 4-seat vehicle, based on the version of the spark ignition engine. The vehicle is equipped with an electric, brushless engine of 8.5 kW power. Acid-lead batteries provide a nominal voltage of 120 V.

***Keywords**: electric vehicles, road transport, environmental protection, FTP, NEDC, Stop&Go*

1. Object of the tests

The desire to reduce pollutant emissions from vehicles with combustion engines has increased the interest in electric vehicles. In the majority of the developed countries at the present time, there are intensive studies under way on the electric vehicles and the fleets of electric vehicles are being introduced. To enter this stream of research, the Motor Transport institute has conducted studies on the electric vehicle. This paper presents selected results of these studies.

The measurements were made on a Zilent Courant passenger car, produced by a Chinese company Shandong Baoya New Energy Vehicle Co., LTD. This is an electric car, and it is only power source are rechargeable batteries, thus it meets the conditions to qualify it as a "pure electric vehicle" in accordance with section 2 of the UN ECE 101 Regulation.

Courant is the vehicle 4-passenger, based on the version of the engine ignition. The vehicle is equipped with an electric brushless motor, of 8.5 kW power. Lead-acid batteries provide a nominal voltage of 120V. The range of the vehicle, as specified by the manufacturer, is 150 km. Battery charging time is 12-14 hours. The car is shown in the Fig. 1.

Fig. 1. Zilent Courant electric car

Table 1 shows the specifications of the Zilent Courant car being tested.

Tab. 1. Zilent Courant vehicle technical data

Dimensions (length x width x height)	3618 x 1563 x 1533 mm
Kerb weight (without battery)	831 kg
Vehicle's weight ready for driving	1170 kg
Ground clearance	150 mm
Number of passengers	4
Wheelbase	2335 mm
Brakes	Front: Disc / Rear Drum
Maximum speed	85 km/h
Economical speed	40 km/h
The stopping distance from 50 km/h - 0 km/h	≤ 20 m with full load
Slope gradability	slope 36% (20°)
Range	≥ 150 km*
Motor power	8.5 kW
Type of motor	Electric, brushless, three-phase
Battery rated voltage	120V battery = 10 batteries 12V-100Ah
Battery Type	Lead-acid, maintenance-free
Charger	External Power Charging: 220V/50-60Hz, power 1500W
Charging time	12 – 14h
Turning circle diameter	9.6 m
Wheels	5.0 x 13"
Tyres	155/65 R13 – 73T

2. The measuring equipment used in the studies

In the course of the tests, the following equipment was used:

- single roller chassis dynamometer with adjustable curve resistance from AVL Zoellner,
- fifth wheel from Peiseler,
- a measuring device with the recorder of charging process and the course of driving cycle.

The measuring system for the energy consumption and speed.

The device used for the purpose of the measurements had the following functions:

- measurement of the rotational speed of the chassis dynamometer roller, using the signal from the chassis dynamometer,
- voltage measurement of the battery pack with the 150V range,
- measurement of current on the battery pack terminals by using a shunt system incorporated into the vehicle electrical system and a voltmeter, with 60mA range. Range of current measured, up to 150 A,
- recorder for recording the above parameters.

The recorder can record signals from all three measuring circuits with a frequency of 1 Hz.

Fig. 2. Electrical power measuring and recording device

3. The measuring procedure

The measuring procedure has been based on the UN-ECE Regulations 101 and within the scope requiring it to be detailed according to EN 1821-1:1996, "Electrically driven vehicles, the measurement of performance in road conditions, only vehicles with electric drive".

3.1. Studies on the bench in driving tests

The tests were conducted on a chassis dynamometer adjusted to reproduce the total driving resistance of the test vehicle. Before the test, the vehicle was charged until the full charge indicator came on. After the driving cycles, the repeated charging took place.

Because the registration of current and voltage enables the measurement of energy flow to and from battery, and does not specify the flow of the energy from the charger, the values of the energy obtained to drive the vehicle were adjusted based on energy efficiency of the battery and the battery charger. Efficiency of the batteries was determined from the ratio of energy expended by batteries in the driving test and the amount of energy supplied during charging. The rectifier efficiency was assumed at 85%.

The measured value of the energy taken from the batteries, per 100 km travelled, as well as the corrected value was placed in the tables.

3.2. Limitations of the devices used and the corrections introduced of the measured values

The measuring system enables the evaluation of the energy flow to and from battery, so the results of the dyno-tests represent the value of the energy taken from battery. For this reason, the measuring system does not meet the requirements of ECE Regulations 101 for energy measurement, because it has no measuring function of energy between the vehicle power socket and the vehicle power supply during charging, Annex 7, paragraph 2.4.3.

Sampling frequency ratio of 1 Hz, the maximum for the given device is sufficient for the registration of the vehicle speed, but too small for the characteristics of recorded current.

4. The course and results of the measurements

4.1. Limitations of the devices used and the corrections introduced of the values measured

Measurements of the total resistances were carried out on the road with the vehicle of 1170 kg including the driver. Measurements were carried out in traffic, having selected the section of the road with a profile as flat as possible. During the measurements the road was dry, the temperature was 14°C, ambient pressure 1006.8 hPa and wind speed did not exceed 0.2 m/s Before measurement the vehicle batteries were fully charged. The vehicle was towed to the measuring section. During the measurements, the vehicle accelerated using electrical energy. 10 coast down tests were performed involving the registration of the vehicle speed from the speed around 80 km/h. The results are shown in the Tab. 2

Tab. 2. The strength and power of the corrected set of measured road

Speed	Force measured (corrected)	Total resistance power
[km/h]	[N]	[kW]
20	204	1.13
30	240	2.00
40	256	2.84
50	295	4.10
60	337	5.62
70	377	7.33

Based on the results, the setting was made of the chassis dynamometer using absorbed power curve defined by a third-degree polynomial with coefficients given in the Tab. 3.

Tab. 3. Second-degree polynomial coefficients of the total road resistance curve of the tested vehicle

R_W [kg]	1360
F_0 [N]	169.6
F_1 [Ns/m]	5.12
F_2 [Ns^2/m^2]	0.2869

Tab. 4. Second-degree polynomial coefficients of the road resistance curve (power absorbed)

R_W [kg]	1360
F_0 [N]	0.705681
F_1 [Ns/m]	2.49111
F_2 [Ns^2/m^2]	0.376571

4.2. Relation between the energy consumption at steady speeds real road

The study was performed on a chassis dynamometer adjusted to reproduce the actual resistance. The current and voltage on the battery terminals were registered. The test was repeated for each gearshift in accordance with their use while operating a vehicle (Tab. 10). Because at the speed of 100 km/h the amperage exceeded the device's range, the current intensity used for further calculations was 160 A.

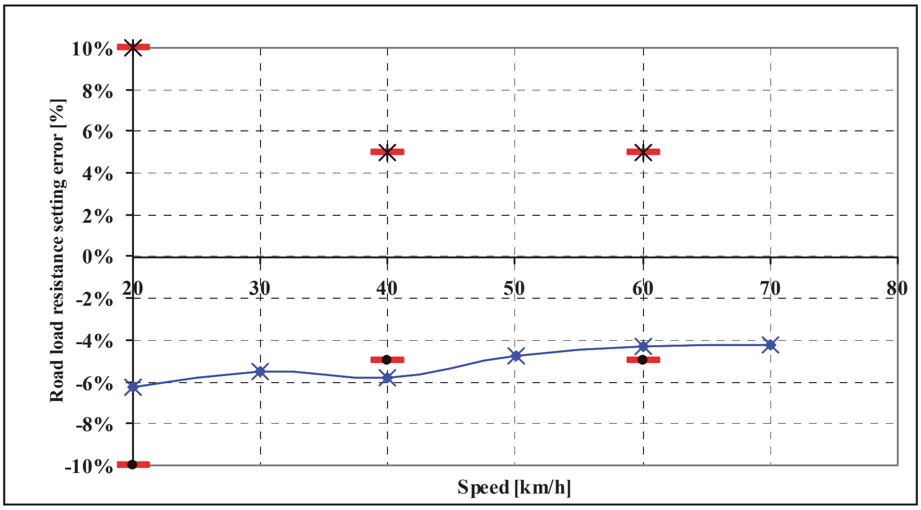


Fig. 3 The verification results of the total resistance

Tab. 5. Measurement of battery voltage and current for an electric car while driving at fixed speeds

Speed	Gear I	Gear II	Gear III	Gear IV	Gear V
10	U= 128.0 V	U= 127.3 V	U=127.1 V	U=127.7 V	U=127.6 V
	I= 4.8 A	I=2.1 A	I=2.5 A	I=1.8 A	I=2.2 A
20	U=125.7 V	U=125.8 V	U=125.6 V	U=125.7 V	U=125.7 V
	I=12.6 A	I=9.6 A	I=7.2 A	I=5.2 A	I=6.1 A
30	-	U=123.4 V	U=124.9 V	U=124.6 V	U=124.7 V
	-	I=14.0 A	I=13.5 A	I=12.1 A	I=11.4 A
40	-	U=122.5 V	U=123.6 V	U=124.4 V	U=124.7 V
	-	I=22.2 A	I=22.0 A	I=22.9 A	I=19.7 A
50	-	-	U=122.9 V	U=123.2 V	U=123.6 V
	-	-	I=31.8 A	I=33.8 A	I=29.5 A
60	-	-	U=121.5 V	U=121.8 V	U=122.4 V
	-	-	I=43.0 A	I=44.9 A	I=41.6 A
70	-	-	-	U=120.7 V	U=120.8 V
	-	-	-	I=59.2 A	I=61.0 A
80	-	-	-	U=118.9 V	U=118.9 V
	-	-	-	I=82.2 A	I=81.3 A
90	-	-	-	-	U=115.7 V
	-	-	-	-	I=115.4 A
100	-	-	-	-	U=113.2 V
	-	-	-	-	I=HI

Based on the measurements, the electrical power taken from the traction batteries in each gear and speeds was calculated.

Tab. 6. Power consumption from the battery while replicating the constant speeds [kW]

Speed	Gear I	Gear II	Gear III	Gear IV	Gear V	Average
10	0.61	0.27	0.32	0.23	0.28	0.34
20	1.58	1.21	0.90	0.65	0.77	1.02
30	-	1.73	1.69	1.51	1.42	1.59
40	-	2.72	2.72	2.85	2.46	2.69
50	-	-	3.91	4.16	3.65	3.91
60	-	-	5.22	5.47	5.09	5.26
70	-	-	-	7.15	7.37	7.26
80	-	-	-	9.77	9.67	9.72
90	-	-	-	-	13.35	13.35
100	-	-	-	-	18.11*	18.11

** Assuming a current of 160 A*

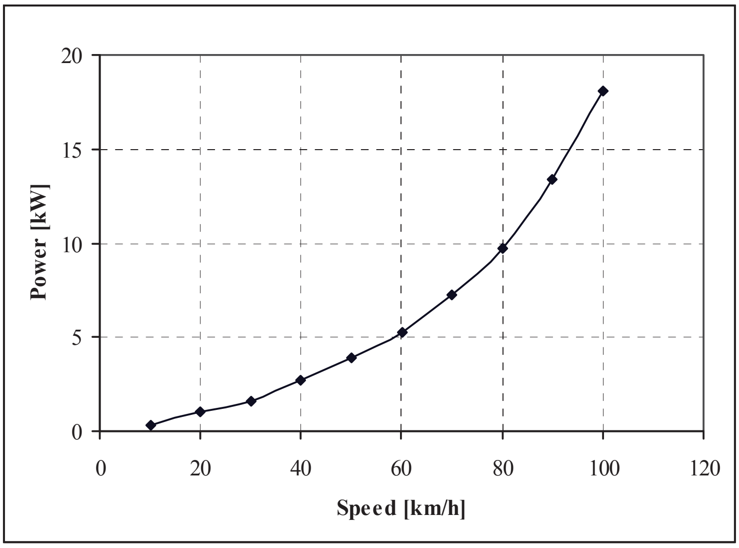


Fig. 4. The average electric power versus vehicle

4.3. The procedure of preparing the vehicle for tests

4.3.1. Determining 30 minute speed

One of the requirements of the type approval procedure of ECE 101 Regulations is the procedure of preparing the vehicle for tests. The basic parameter is the 30-minute speed, which should be declared by the vehicle manufacturer. In the case of the tested vehicle, this value was not known.

The 30-minute speed is defined in EN 1821-1:1996 standard – "Electrically driven vehicles, the measurement of performance in road conditions, only vehicles with electric drive", as the highest average speed that the vehicle can maintain for 30 minutes in accordance with section 9 of that standard.

The provisions of the standards do not clearly state whether the vehicle is to accelerate to the given speed using its own or a external power. Because, the according to the standard the measurement can be performed on the road and the vehicle acceleration procedure is not described, it was assumed that the vehicle is to accelerate using the energy stored in the batteries, and only then continue driving with constant given speed.

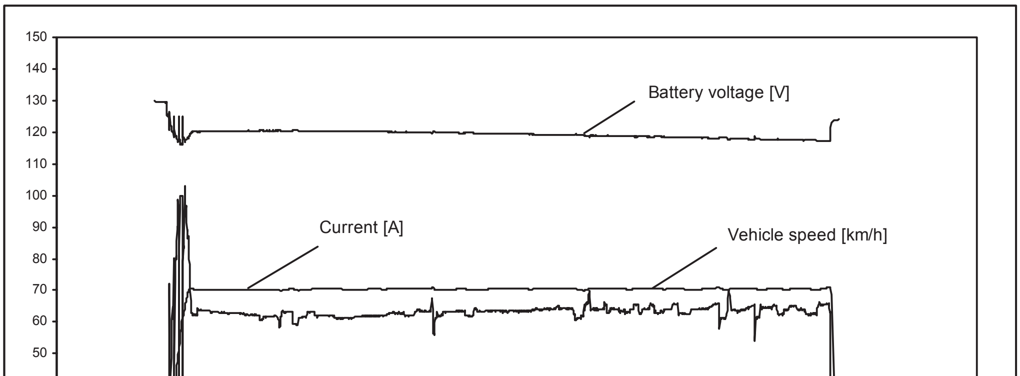


Fig. 5. The test at a speed of 70 km/h

Tab. 7. Parameters of the test at a speed of 70km/h

Work	3.94 [kWh]
Charge	33.0 [Ah]
Average current	63.6 [A]
Driving time	32 [min]
Average speed	70.1 [km/h]
Distance	36225 [m]
Energy consumption	10.87 [kWh/100km]

We could initially assume that the thirty-minute speed was the speed at which the current drawn discharges the battery in 30 minutes. Since the declared capacity of the battery was 60 Ah, the thirty-minute current should be around 120 A. Based on these considerations and Fig. 4 the speed of 90 km/h was selected as the test speed.

As it can be seen in the chart documenting the course of the test (Fig. 4), while cruising at the constant speed, the voltage on the battery terminals of batteries dropped from 118 to 104 V. This decrease was compensated by the driver, resulting in increasing current. Power supplied from the battery was constant and averaged 12.8 kW until the battery discharging and the no possibility to maintain the set speed, which happened in the 1971 second of the cycle.

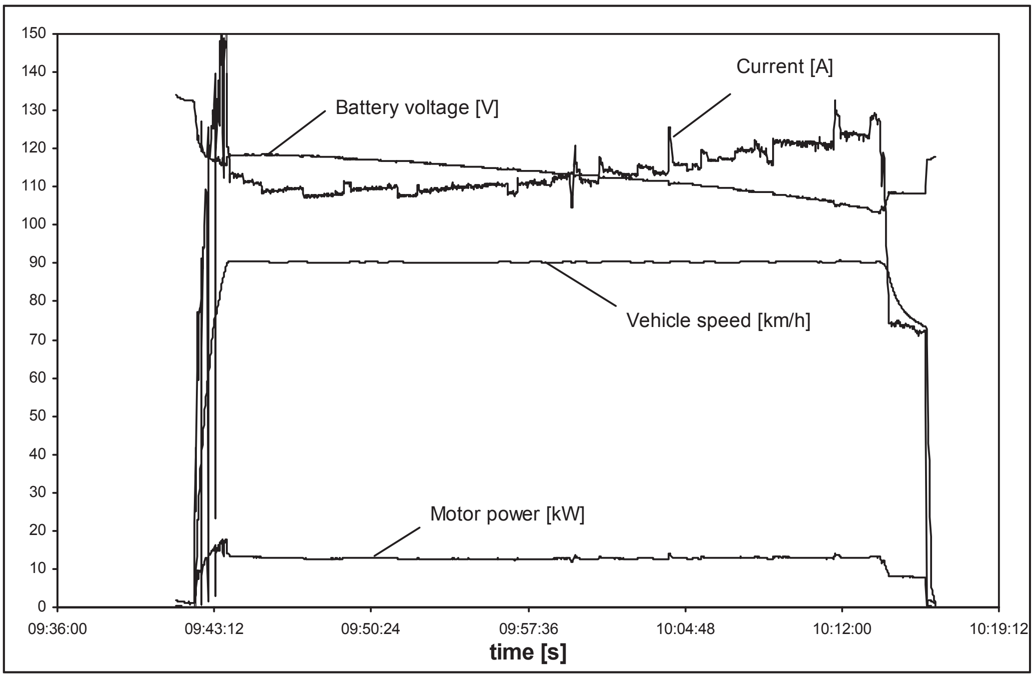


Fig. 6. The test at a speed of 90 km/h

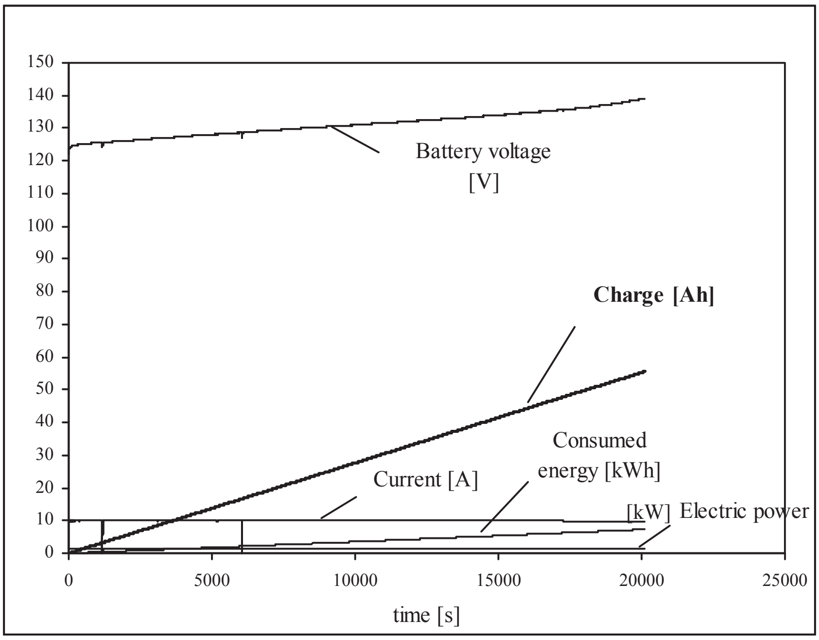
Tab. 8. Parameters of the test at a speed of 90km/h

Energy	7.04 [kWh]
Charge	62.4 [Ah]
Average current	107.6 [A]
Cycle time	35 [min]
Average speed	85.5 [km/h]
Route	49554 [m]
Energy consumption	14.2 [kWh/100km]
Energy consumption cor.	22.0 [kWh/100km]

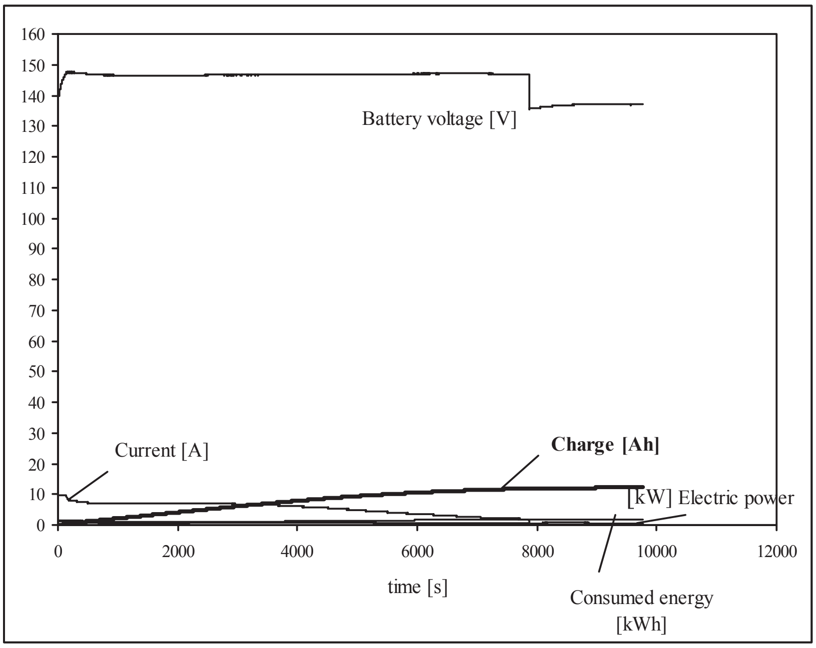
The tested vehicle reached a speed of 90 km/h in 145 second of the cycle, while the speed dropped below 95% of set speed in the 1826 second of the cycle. So time of maintaining the desired speed of 90 km/h was 30 minutes and 26 seconds, while the actual average vehicle speed in this interval of time was 90.35 km/h. Therefore, in accordance with paragraph 9 of standard EN 1821-1:1996 the speed of 90 km/h was regarded as the thirty-minute speed of the vehicle.

Tab. 9. Battery charging measurements after driving at a speed of 90km/h

File		AR205_0_2011-01-13_11-38-09	AR205_0_2011-01-16_07-38-43	Total
Energy	[kWh]	7.28	1.79	9.1
Charge	[Ah]	55.48	12.22	67.7
Average current	[A]	9.94	4.50	-
Cycle time	[min]	334.83	162.77	498



The record file AR205_0_2011-01-13_11-38-09



The record file AR205_0_2011-01-16_07-38-43

Fig. 7. Battery charging after driving at a speed of 90km/h

4.3.2. Measurements in the FTP test

Measurements in the FTP test began with a full battery charged. Then six cycles were performed. As one can see from the chart, the current values were above 150 A, indicating the need for the use full power to reproduce acceleration in the given cycle.

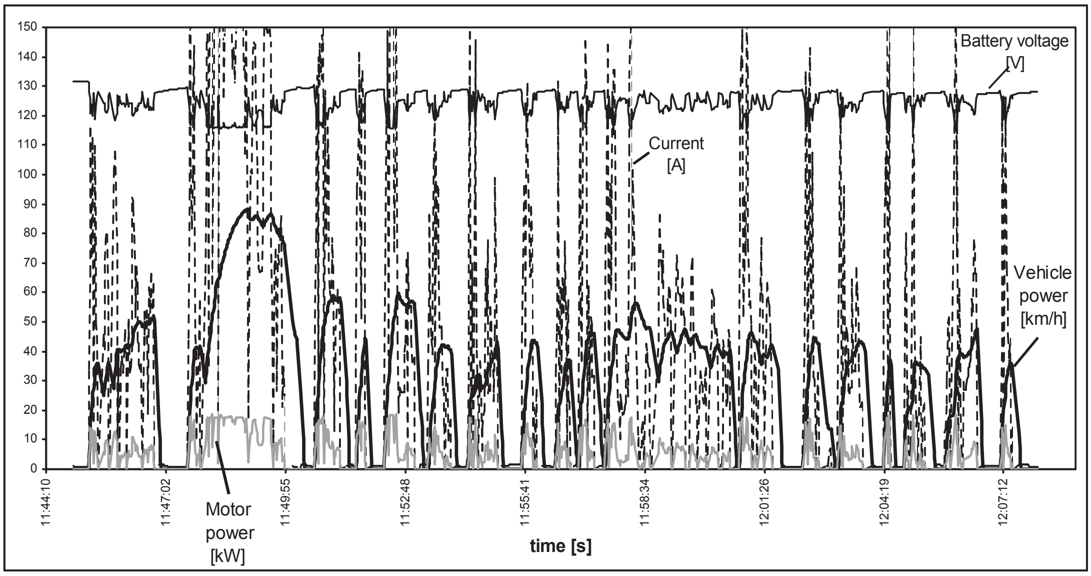


Fig. 8. FTP test parameters after charging the batteries. The record file AR205_0_2011-01-17_11-44-49

In the last, sixth test; the battery charge status prevented the proper completion of the test causing a drop in the motor power and a decrease in vehicle performance, which allowed to achieve a top speed of 70 km/h. Thus, the distance the vehicle travelled, is clearly shorter than the others.

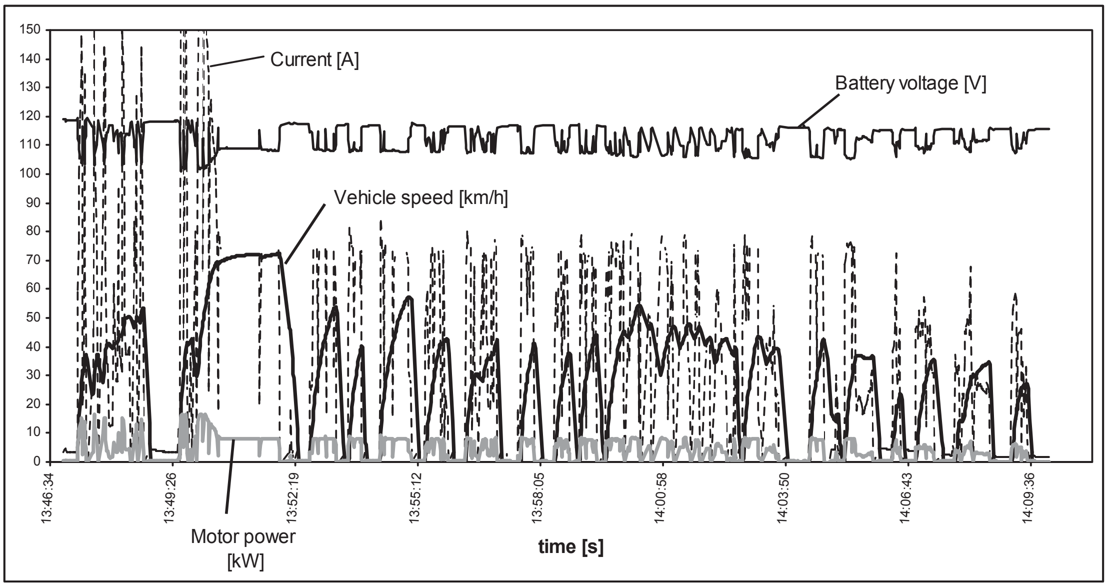


Fig. 9. FTP test parameters with a significant discharge of the vehicle battery. The record file AR205_0_2011-01-17_13-46-53

During the FTP test, the vehicle travelled 70 km consuming 9.4 kWh of energy. Until the repeated charging of the batteries, it consumed 11.4 kWh. Thus, on average of 100 km of the road the specified energy-adjusted consumption was 19 kWh/100 km.

Tab. 10. Measurements of the energy consumption by the electric vehicle in the driving FTP cycle

File		AR205_0_2011-01-17_11-44-49	AR205_0_2011-01-17_12-08-39	AR205_0_2011-01-17_12-33-17	AR205_0_2011-01-17_12-59-04	AR205_0_2011-01-17_13-23-03	AR205_0_2011-01-17_13-46-53	Average	Total
Test	-	FTP	FTP	FTP	FTP	FTP	FTP	-	-
Energy	[kWh]	1.71	1.57	1.57	1.56	1.58	1.40	1.60	9.4
Charge	[Ah]	14.3	13.3	13.5	13.8	14.4	12.9	13.8	82.2
Average current	[A]	44.0	41.5	43.3	45.2	49.4	39.1	44.67	-
Cycle time	[min]	23.2	23.2	23.2	23.2	23.2	23.2	23.20	-
Average speed	[km/h]	30.5	30.9	30.9	30.7	30.6	28.0	30.7	-
Route	[m]	11 797	11 956	11 957	11 887	11 838	10814	11 887	70249
Energy consumption	[kWh/100km]	14.5	13.1	13.2	13.1	13.3	13.0	13.4	-
Energy consumption cor.	[kWh/100km]	20.6	18.7	18.7	18.7	19.0	18.4	19.1	-

Tab. 11. Battery charging measurements, following the a series of FTP driving tests

File		AR205_0_2011-01-17_14-33-08	AR205_0_2011-01-18_07-02-22	Total
Energy	[kWh]	11.25	0.10	11.4
Charge	[Ah]	85.84	0.67	86.5
Average current	[A]	9.18	2.77	-
Cycle time	[min]	561	15	576

4.3.3. Measurements in the Stop & Go test

Measurements in the Stop & Go test began with a full battery charge. Then the driving took place until the batteries were exhausted. As it can be seen from the chart, the current intensity occasionally exceeds 50 A. So this is a test where the vehicle reached expected speeds without the need for full power.

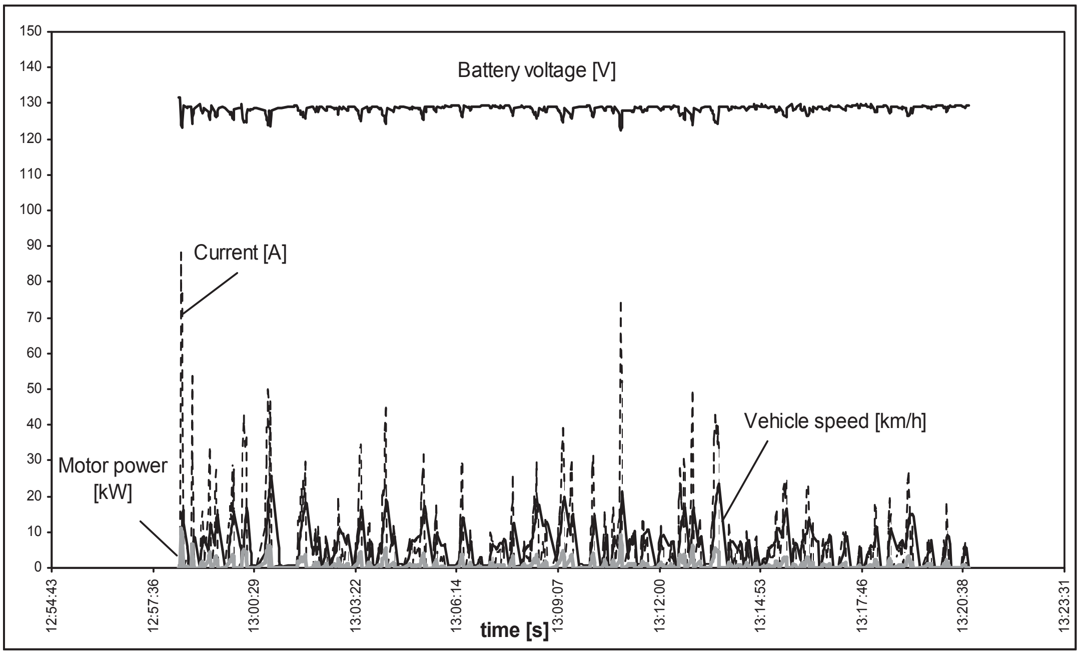


Fig. 10. Stop & go test parameters

Tab. 12. Measurements of the energy consumption by the electric car in the Stop & Go driving tests

File		Average	Total
Energy	[kWh]	0.24	10.4
Charge	[Ah]	1.95	85.6
Average current	[A]	8.7	-
Cycle time	[min]	22.8	1004.9
Average speed	[km/h]	5.8	-
Route	[m]	2168	95407
Energy consumption	[kWh/100km]	11.1	-
Energy consumption cor.	[kWh/100km]	17.9	-

Tab. 13. Charging measurements following the series of Stop & Go driving tests

Energy	[kWh]	14.26
Charge	[Ah]	107.56
Average current	[A]	7.38
Cycle time	[min]	874

The 44 test cycles were performed at an average speed of 5.8 km/h, until a full discharge, which is characteristic to the vehicle use in the traffic jam. The vehicle travelled 95 km until a full battery discharge, consuming 10.4 kWh of energy. To recharge the batteries, the 14.3 kWh were used. Thus, for an average of 100 km of the road, the specified energy-adjusted consumption was 17.9 kWh/100 km.

4.3.4. Measurements in the NEDC cycle

Measurements in the NEDC cycle began with a full battery charge. Then the test was repeated five times. As can be seen from the graph (Fig. 10) current occasionally exceeds 50 A. So this is a test where the vehicle reached the expected speeds without having to use full power.

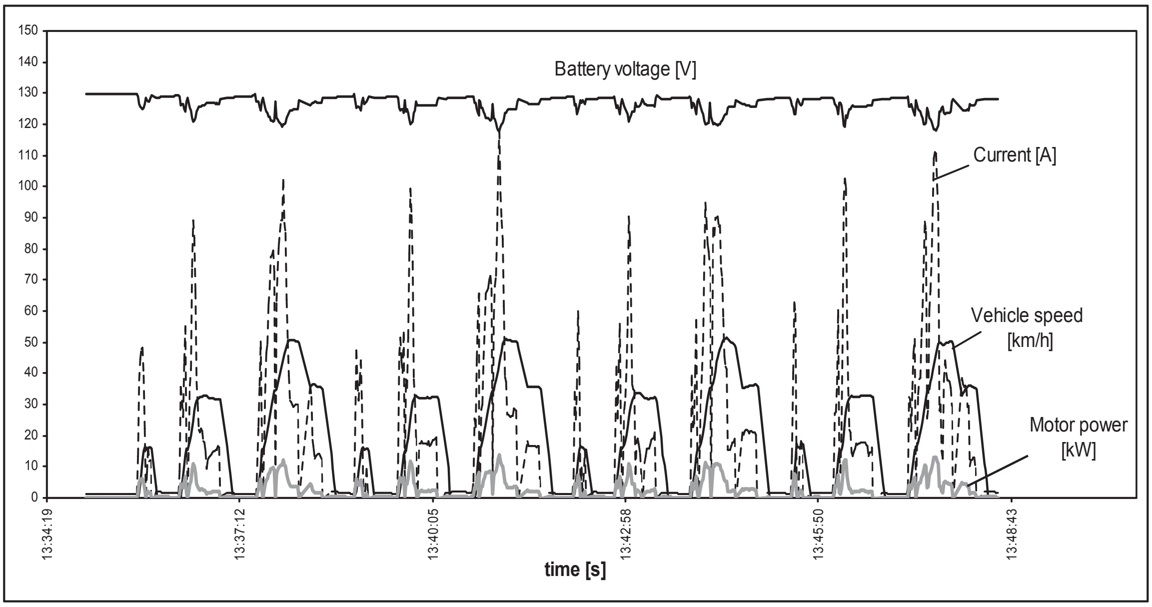


Fig. 11. The parameters of the selected NEDC test

The vehicle travelled 20.2 kilometres at an average speed 17.9 km/h using about 2.4 kWh of energy. For charging batteries was used 3.3 kWh of energy. Given the efficiency of the rectifier, for the 100 km of the road, the vehicle consumed an average of 19.4 kWh.

Tab. 14. Measurements of the energy consumption by an electric car in the NEDC driving tests

Test No.		1	2	3	4	5	Total
Energy	[kWh]	0.506	0.482	0.463	0.459	0.455	2.4
Charge	[Ah]	4.0	3.9	3.8	3.8	3.7	19.2
Average current	[A]	20.9	19.8	19.3	19.8	20.1	-
Cycle time	[min]	13.6	13.6	13.6	13.6	13.6	68
Average speed	[km/h]	17.9	17.9	17.9	16.8	17.9	-
Route	[m]	4056	4054	4047	4058	4047	20262
Energy consumption	[kWh/100km]	12.5	11.9	11.4	11.3	11.2	-
Energy consumption cor.	[kWh/100km]	20.8	19.8	19.1	18.8	18.7	-

Tab. 15. Charging measurements following a series of NEDC driving tests

File		AR205_0_2011-01-16_14-45-27	AR205_0_2011-01-17_07-07-17	Total
Energy	[kWh]	3.31	0.04	3.3
Charge	[Ah]	23.73	0.27	24.0
Average current	[A]	5.3	6.6	-
Cycle time	[min]	267	2	269

4.3.5. The vehicle's range tests

The tests were performed in accordance with the procedure described in Annex 9 to UN-ECE Regulations 101. After the charging cycle, the discharging cycle was performed at 60 km/h. As the test end criterion was adopted the speed decrease by 5% below the set average speed.

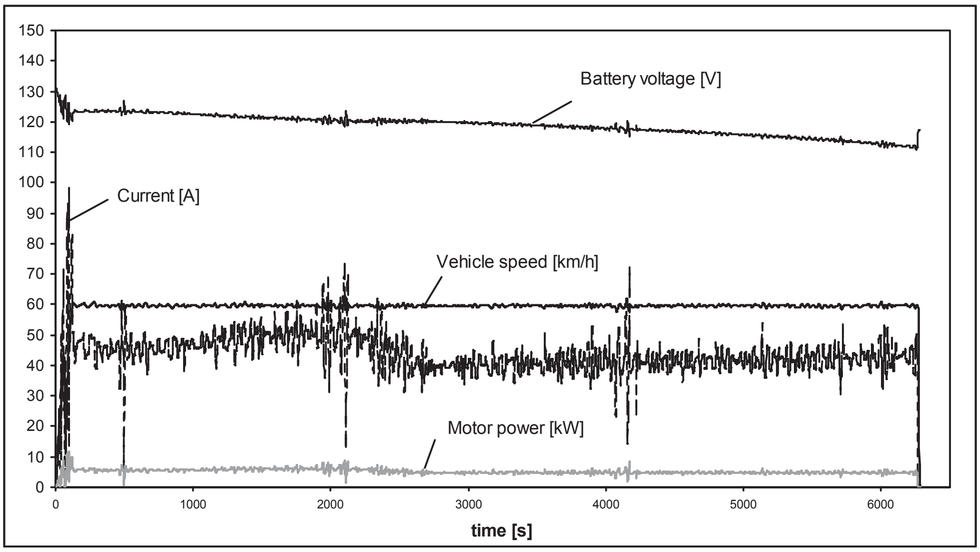


Fig. 12. The parameters of the selected test at 60 km/h, in accordance with the record AR205_0_2011-01-26_14-07-22

Tab. 16. Measurements of the energy consumption by the electric vehicle-driving test at 60 km/h, in accordance with the record AR205_0_2011-01-26_14-07-22

Work	[kWh]	9.05
Charge	[Ah]	76.1
Average current	[A]	43.6
Driving time	[min]	105
Average speed	[km/h]	58.9
Route	[m]	102813
Energy consumption	[kWh/100km]	8.80

During the test, the vehicle was driving at a speed of 60 km/h, and the transmission system was drawing on average the current of 43.6 A. The batteries voltage was falling along with their degree of charge, falling during the test.

As it can be seen (Fig. 12) during the course of the batteries discharge there was a change in the current power drawn from the batteries. The vehicle was driving at a constant average speed, and chassis dynamometer should provide a constant level of resistance to the motion, thus decrease of the power consumption from the batteries was not expected. This problem has not been clarified in this study.

After the discharge, the batteries were recharged, as in the records AR205_0_2011-01-26_16-00-41 (Fig. 13).

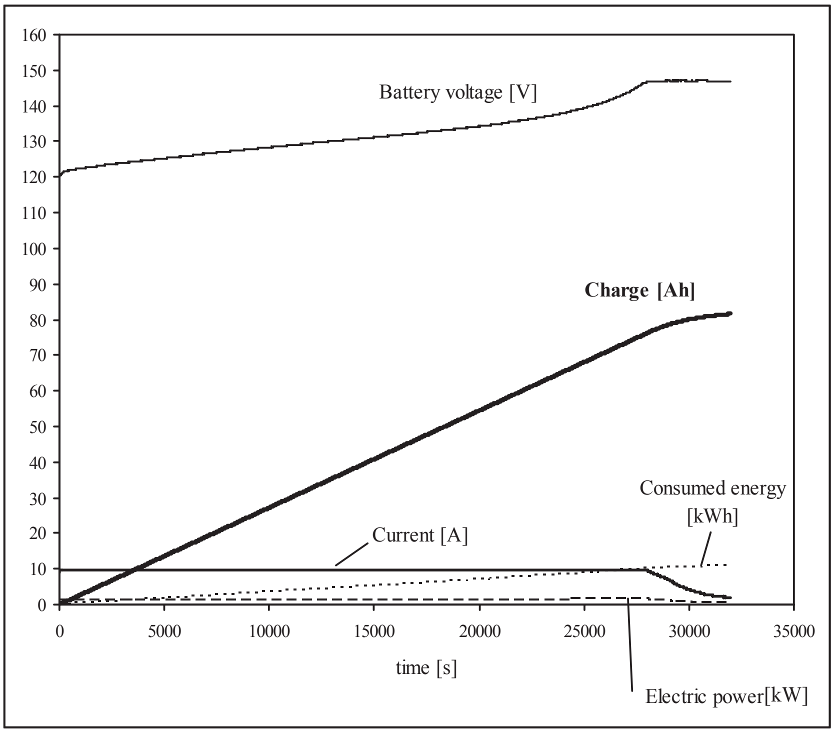


Fig. 13. Batteries charging measurements following the battery discharge, as in the records AR205_0_2011-01-26_16-00-41

Tab. 17. Batteries charging measurements following the battery discharge

File		AR205_0_2011-01-26_16-00-41
Energy	[kWh]	10.83
Charge	[Ah]	81.86
Average current	[A]	9.08
Cycle time	[min]	541

4.3.6. Tests in the real-time traction drives

The tests in the road conditions were carried out on public roads in Warsaw as part of the vehicle‘s normal use. Most vehicle mileage was conducted in the morning and then returning home hours. The roads travelled by the vehicle were in the lowland. The study was conducted during the summer months (July and August), so in the months in which there is a significant ease in the flow of traffic in Warsaw due to a decline in the number of road users in the holiday season.

Out of the additional devices in a vehicle, the low beam lights were used. Due to the time of the year, the heating of the interior was used nor were the windscreen wipers. So from the point of view of energy consumption the vehicle was operated at the optimum time during the year.

Records made by the user included driving time, mileage and energy consumption. Summary results are presented in the Tab. 18.

Tab. 18. The energy consumption measurements of the electric car 07-08.2011

Date	Mileage (km)	Travel time (hh:ss)	Energy / charge (kWh)
29.07.2011	59	02:00	13.78
30.07.2011	46	01:30	11.09
06.08.2011	81	02:10	16.96
07.08.2011	44	01:40	9.86
08.08.2011	72	02:10	14.10
09.08.2011	53	01:45	11.86
10.08.2011	70	01:40	13.31
11.08.2011	72	01:20	11.59
12.08.2011	53	01:30	11.05
13.08.2011	51	01:20	11.98
16.08.2011	46	01:20	10.63
17.08.2011	54	01:30	11.49
18.08.2011	48	01:35	9.95
19.08.2011	37	01:05	9.03
22.08.2011	51	01:20	12.11
23.08.2011	52	01:20	12.14
24.08.2011	62	01:50	13.50
25.08.2011	58	01:20	13.34
26.08.2011	49	01:30	10.44
27.08.2011	58	01:30	8.13
29.08.2011	32	01:10	8.00
TOTAL	1148	32:35:00	244.34

The data presented in the table shows that the average energy consumption of the electric test vehicle, in the given traffic conditions, with an average speed of VSR. = 35.24 km/h was 21.28 kWh/100 km.

5. The summary and conclusions

Seeing the difficulties with the road tests of the vehicle and ensuring repeatability of the results, in order to quickly obtain the energy consumption of the test vehicle it was decided to first perform the tests on a chassis dynamometer, where it was possible to very efficiently determine the energy consumption of the vehicle as a function of it's constant velocity. Because the chassis dynamometer was replicating driving resistance measured in real traffic conditions, the results of measurements of energy consumption by the vehicle can be considered reliable and certainly more accurate than methods based on statistical account.

In order to broaden the spectrum of knowledge about the energy consumption of electric vehicle in the transient conditions, the standard dynamic tests were carried out: FTP 75, NEDC, and Stop & Go. It turned out to be impossible to conduct the test motorway, because the vehicle did not have the power to achieve the maximum speed envisaged for this test.

Conclusions:

- in the case of an electric test vehicle, the optimal from the point of view of energy consumption is to obtain the minimum achievable speed. For this test object such speed was about 40 km/h,
- the driving technique has a strong influence on the characteristics of energy consumption by the electric vehicle, its range and performance characteristics of the batteries used,
- the methods of measuring the energy consumption by the vehicle tested on a chassis dynamometer can effectively replace the tests in real conditions,

– the energy measurement system used requires to be modified, because the sampling frequency ratio of 1 Hz is too small to record the course of current when driving the vehicle and it also lacks the possibility of measuring the power drawn from the grid, making it impossible to determine the efficiency of the battery.

References

[1] Regulation No 101 of the United Nations Economic Commission for Europe (UN-ECE) - *Uniform provisions concerning the type approval of passenger cars powered by internal combustion engine or a hybrid electric drive system for the measurement of carbon dioxide emissions and fuel consumption and / or the measurement of electricity consumption and range while using electrical energy and the M1 and N1 category vehicles equipped with an electric drive system, for the measurement of electrical energy consumption and the range while running on the electric energy.*