COMPARISON OF LABORATORY, DYNAMOMETER, AND ROAD TESTS OF AN EV

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Summary

Two prototype EVs have been constructed as the product of the Finnish EV project. The vehicles have transistorized, microprocessor-controlled a.c. motors, on-board high frequency chargers, and pasted plate lead–acid batteries located in thermally controlled containers. The performance of the vehicles has been measured using a dynamometer. The results agree with the laboratory measurements on the batteries. The on-road performance will be monitored with an on-board data logger. The main result of the tests performed so far is that the driving range in SAE J227aC cycle is almost equal to the range obtained at a 50 km h^{-1} constant speed. This good performance in city driving is mainly due to the choice of the a.c. motor, exhibiting a high efficiency even at relatively low frequencies.

Introduction

Two prototype EVs have been constructed by a group of Finnish companies: Neste Battery Ltd., Imatran Voima Oy, Kymmene-Strömberg Corporation and Oy Saab-Valmet Ab. The vehicles were built on the chassis of two Talbot Horizons, ordinarily assembled by Saab-Valmet in Finland. The a.c. motor and the microprocessor-controlled, transistorized inverter were constructed by Strömberg. Imatran Voima was responsible for supplying the chargers and data loggers for the vehicles. Neste Battery Ltd. designed and built the batteries. The conversion of the vehicles was done at Neste Research Centre, which also coordinated the project.

Since the vehicles are primarily experimental prototypes, it is of importance to gather as much data as possible on their performance. The test program includes the following studies:

Laboratory tests on the batteries. Both the capacity and the cycle life of the batteries have been measured.

Bench tests on the motor and the inverter.

Dynamometer tests on the vehicles. These can be extended down to −40 °C.

On-road tests of the vehicles. The performance in winter conditions will be of special interest.

In addition to the bench testing of the motor during construction, tests on the batteries, and dynamometer tests on the vehicles at normal temperatures, have now been completed. The results of on-road testing are only preliminary at this stage.

Construction of the vehicles

The original IC motors of the vehicles were replaced by electric a.c. motors. The gearboxes were retained, although normal driving seldom requires other than the third gear. The battery containers were located both in the front and in the rear of the vehicle to ensure an even distribution of weight. The remaining space was occupied by the inverter, the charger, the 14 V a.c./d.c. converter, and auxiliary equipment.

The a.c. motor is of a modified 50 Hz type. Its rated power is 18.5 kW, and a power of 27 kW can be maintained for 15 min. The controller was also designed for heavy industrial applications, but its programming was adjusted for EV use, which proved to be an extremely demanding application for the inverter.

The charger is a lightweight, high frequency a.c./d.c. converter. It is therefore possible to mount it on the vehicle. The 14 V voltage required by the auxiliaries is also supplied by a converter backed up by a small battery.

The pasted-plate lead–acid battereis were manufactured by Pakkasakku Oy, which is a subsidiary of Neste Battery. They have a nominal voltage of 12 V. The grid material is a low antimony alloy to minimize maintainence and internal resistance. To ensure a sufficiently high operating temperature, even in winter conditions, the glass fiber reinforced battery containers have been thermally isolated with polyurethane foam and equipped with electric heaters, made from Chemelex cable [1]. It was necessary to synchronize the operation of the heater and the charger to ensure that the a.c. current from the mains remained below 10 A, or 16 A whenever possible.

The number of 12 V battery modules in a vehicle is 19. Thus the total voltage level is 228 V. This relatively high value was selected to ensure as high a controller efficiency as possible.

The weight of the cars and some of the components are given below.

Curb weight	1450 kg
Batteries	400 kg
a.c. motor	125 kg
Controller	42 kg
Charger	10 kg

Test results

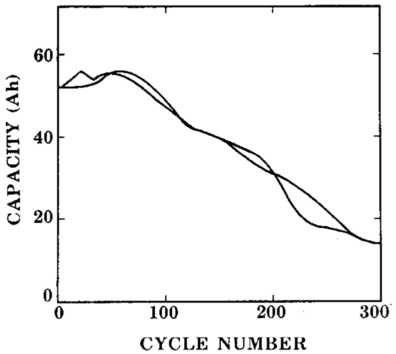
The batteries were studied for their capacity and cycle life. The capacity of the entire battery pack was measured as 60 A h in a 2 h discharge.

This value is actually 10% higher than the capacity of the individual batteries used for the life tests. The life test was carried out using the method proposed by the Energy Research Laboratory in Odense, Denmark [2].

The life test consisted of 100% D.O.D. pulsed discharges simulating the SAE J227aC driving cycle. At the beginning of a discharge pulse, the current is linearly increased over 6 s to 45 (M kg^{-1})/(U V^{-1}) amperes, where M is the mass and U is the nominal voltage of the battery, respectively. The discharge current is then kept constant for 12 s, thereafter it is reduced to one third for 20 s and finally to zero for 42 s. The pulses are repeated until the battery voltage, normal during the maximum current discharge, decreases below 8 V. The discharges are immediately followed by charging according to the W-pattern. Charging is terminated 2 h after the batteries have reached 15 V.

The life of the batteries was found to be 115 cycles (100% D.O.D.) to 80% of the capacity and 210 cycles to 50% of the capacity. The energy density at the beginning of the test was 30 W h kg^{-1}, measured in a 2.5 h pulsed discharge. The measured pulsed capacity *versus* cycle number results on two batteries are shown in Fig. 1.

The dynamometer tests were performed at the Motor Laboratory of Neste Research Centre. In these tests the vehicle was driven at constant speeds of 40 and 60 km h^{-1} and according to the SAE J227aC norm. Acceleration tests were also carried out. The test results are given in Table 1 and Fig. 2.



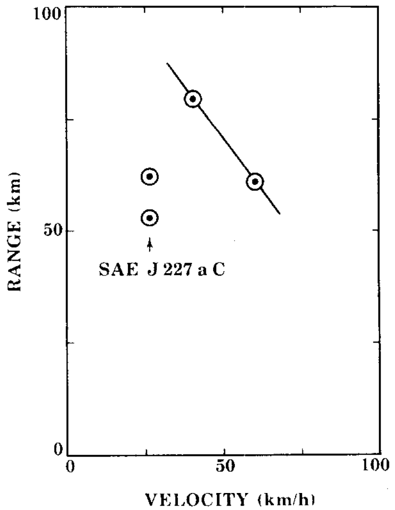


Fig. 1. The pulsed capacity *vs.* cycle number data of two EV batteries produced by Neste Battery Ltd. The data were measured with 100% D.O.D. pulsed discharges simulating the SAE J227aC cycle.

Fig. 2. The driving range *vs.* average velocity data measured on the Finnish EV. The connected points indicate the constant velocity results, and the separate points were measured with the SAE J227aC cycle. The upper and lower points were measured with, and without, regenerative braking, respectively.

TABLE 1

Test	Range
60 km h^{-1}	62 km
40 km h^{-1}	80 km
SAE J227aC cycle	
— with regenerative braking	62 km
— without regenerative braking	57 km
Acceleration 0 - 50 km h^{-1}	11.8 s

From the measurements performed at 60 km h^{-1} the following data on the power consumption of the vehicle were obtained.

Controller and a.c. motor	3.6 kW (25%)
Power train	2 kW (16%)
Road and wind resistances	7.1 kW (59%)
Total power consumption at 60 km h^{-1}	12.7 kW (201 W h km^{-1}).

The energy density of the batteries was also determined. In the 60 km h^{-1} measurement it was again found to be 30 W h kg^{-1}, now in a constant power 1 h discharge. Thus, the batteries were fully charged in these measurements.

Discussion

The life test results are typical for a pasted-plate lead–acid battery. One must compromise between cycle life and energy density. One testing problem is whether the 100% depth of discharge is appropriate in the determination of cycle life. It evidently increases the deterioration rate of the cell with the lowest capacity, and thus the results are sensitive to variations in the quality of individual cells. The results obtained on two batteries tested by us are, at least, similar, as shown in Fig. 1.

The driving range results show that the constructed electric vehicles are well suited for city driving. The range at the SAE J227aC cycle with regenerative braking, 62 km, is actually more than 80% of the range at constant 50 km h^{-1}. It has been proposed that a typical result is only about 50% [3]. Thus our vehicles show an improvement in city driving of a factor of about 1.7 compared with some earlier models. This is a considerable advantage. In terms of the weight of the batteries this would correspond to approximately 300 kg.

The high efficiency of these electric vehicles in city driving is mainly due to the chosen a.c. motors. They are of a modified 50 Hz type, whereby at 60 km h^{-1} the frequency of the motor corresponds to approximately 100 Hz. Thus the frequency range for high efficiency is located optimally for city driving. In addition, the efficiency of the controller and the low internal resistance of the batteries are significant factors.

Future tests

The road performance of the vehicles will be monitored with the onboard data logger. The data will be stored according to need, either once per second or at lower rates, and the driving profiles can be analyzed later. This provides the possibility of comparing the standard test data with the everyday driving patterns of various drivers. Another parameter of interest will be the ambient temperature. It will be possible to obtain first hand information about the performance of a modern EV in severe winter conditions. These results will be published later.

The dynamometer tests will also be continued. The performance at various temperatures will be monitored especially. The dynamometer used for these studies can simulate road conditions down to −40 °C. These measurements will be compared with on-road data and also with laboratory data concerning the properties of the batteries as a function of temperature.

The power consumption and efficiency of the vehicles will also be measured at several velocities in order to study more closely the ratio of the ranges in city and constant velocity driving.

Conclusion

The test results of the Finnish EV project indicate that an unusually good EV city driving performance can be obtained with a properly chosen motor system. This observation emphasizes the need to test the EV motor system in order to establish a reliable data basis for future developments. As far as the electric vehicles are concerned, one may question whether the weight of the electric motor should be minimized if the penalty in the battery weight greatly exceeded the possible savings in the motor weight.

Acknowledgements

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References

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