QUALIFICATION OF LEAD–ACID BATTERIES FOR TRACTION APPLICATIONS

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Introduction

Simulated load cycles, applied in the laboratory, will play a substantial role in the future testing of batteries for electric vehicle propulsion. An assessment of the various parameters, such as energy capacity, power, thermal characteristics, charge times and life time, must be included in this type of testing. Such tests can be applied consistently under laboratory controlled conditions to provide data for accurate comparison and assessment of batteries in realistic working conditions. Furthermore, power levels can be conveniently scaled to suit single cells, multi-cell modules or any arbitrary fraction of a full sized electric vehicle battery. The performance behaviour of batteries when used in electric vehicles differs from those observed during constant current testing [1 - 3]. The reason for this is the intermittent discharge and charge during regenerative braking, with very high peak currents and a considerable degree of discharge depth. It is therefore necessary to employ current test profiles which take account of the special demands of electric vehicles. As a result it is proposed to adopt:

(i) A simulated power–current profile based on the SAE J227A velocity profile (driving cycle)

(ii) A normalization method which establishes a uniform procedure for testing and comparison of cells and batteries of different physical size and capacity.

Theory

The energy consumption of electric vehicles is mainly due to four forces:

F_R: Energy loss due to rolling resistance
F_D: Energy loss due to aerodynamic drag
F_P: Increase/decrease in potential energy
F_K: Increase/decrease in kinetic energy

Furthermore, there will be an energy loss due to frictional forces in the transmission and electric losses in the drive train.

The power consumption, P, from the battery can thus, in a simple way, be expressed:

$$P = (F_R + F_D + F_P + F_K)v/\eta \quad (1)$$

where v is the vehicle speed and η is the combined efficiency of electronic controls, motor and transmission.

Assuming that the rolling resistance is constant in the electric vehicle speed range and an approximation of the aerodynamic drag, eqn. (1) can be written:

$$P = (fMg + \tfrac{1}{2}\rho v^2 A c_w + Mg \sin\alpha + M'a)v/\eta \quad (2)$$

where f = the rolling resistance coefficient
M = the vehicle mass
g = the gravity
ρ = the specific gravity of air
A = the frontal area of the car
c_w = the air resistance coefficient
α = the angle to the horizontal
a = the vehicle acceleration
M' = the total mass of the vehicle (all rotating masses transformed into translational masses)

In the case of regenerative braking the acceleration and thus the power becomes negative.

Test procedure

The purpose of SAE J227A is to determine the maximum range travelled and energy consumed by a test vehicle when operated on a level surface in a defined and repeatable driving cycle. It thus provides a standard procedure for testing electric road vehicles so that their performances can be compared.

The electric vehicle test procedure — SAE J227A — defines a test cycle as shown in Fig. 1. This has several schedules, but we have found that the most common vehicle type in production today falls within category C [4], and this is therefore used as the basis for the proposed battery test cycles.

Using schedule C and eqn. (2) with defined efficiency, a theoretical power–time profile can be calculated for a given vehicle. In Fig. 1 such an idealised power profile is compared with a power profile measured in a real test programme. The efficiency factor for the theoretical power profile was calculated from the measured power profile during the constant speed period. Comparison between the experimental result and the idealised theory highlights the problem faced — that the efficiency, neither in the motor nor in the controls, is not constant, but is dependent on the acceleration and the velocity.

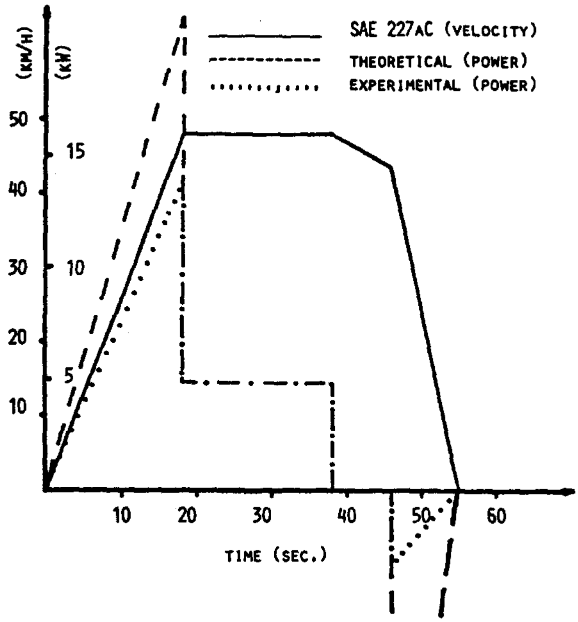

Fig. 1. SAE 227 A-C electric vehicle test cycle with theoretical and experimental power profiles.

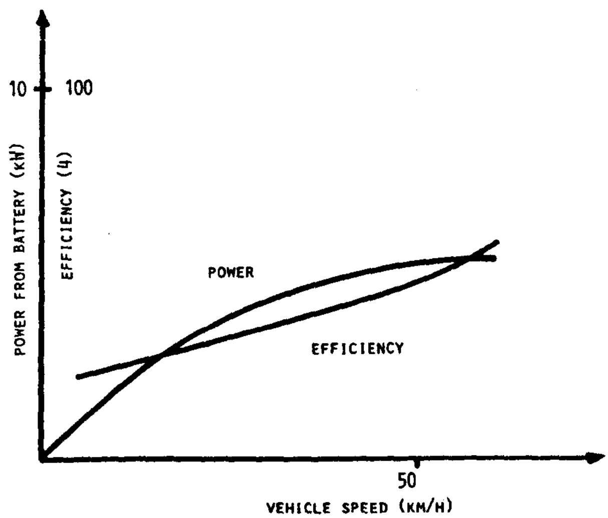

Fig. 2. Power drawn from battery and drive train efficiency *vs.* vehicle speed.

This dependency on velocity is shown in Fig. 2 for a test vehicle and shows that the efficiency of the electromechanical drive train is very dependent on the velocity and is greatest at top speed. The efficiency dependency on acceleration is more complex because it is dependent on both acceleration and velocity.

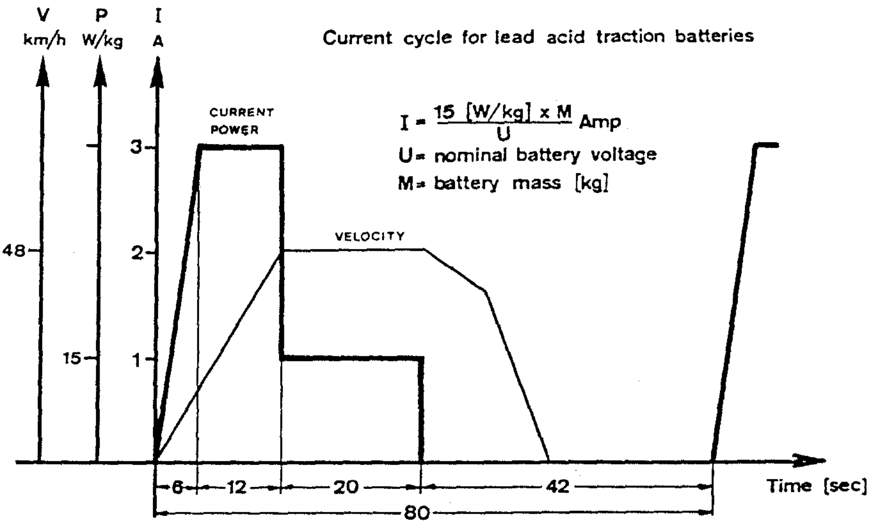

Fig. 3. Power and current test cycle for electric vehicle batteries.

The above considerations are even more distinct during regenerative braking and we have therefore made comparative measurements on different cars cycled on a roller bench.

Based on these experiments we have proposed the power cycle shown in Fig. 3, which seems very representative for today's electric vehicle technology.

To normalise a standard power cycle to different batteries the problem arises: will the manufacturer construct his vehicles to carry the optimal energy related to range, cost/km ton^{-1}, cost/km or does he only want to carry enough capacity for a predetermined range? Another possibility is to optimize the car to a given battery to obtain maximum energy capacity utilization. After a survey of the electric vehicle market [4] we found:

Fractional weight of battery 33%

Vehicle power demand at constant operational speed 5 kW ton^{-1}.

Thus operational power becomes 15 W h/kg of battery and the suggested cycle is as shown in Fig. 3.

Conclusion

The proposed load profiles provide a method for comparison and assessment of electric batteries under realistic working conditions. Furthermore, power levels can be scaled to suit convenient fractions of full-sized electric vehicle batteries. The profiles are based on SAE 227A-C, and we consider that so far they are the most suitable for today's electric vehicles and batteries. However, the profiles can easily be scaled to follow future developments.

References

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