REQUIREMENTS FOR EV-BATTERIES AND CONSEQUENCES FOR TEST PROCEDURES

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Safe driving requires sufficient battery power

In a conventional car with an ICE only the engine limits the maximum power which is necessary for acceleration and for driving at high velocity. One could say: the power of the petrol tank is significantly greater than the rated power of the ICE

$$P_{tank} \gg P_{mot}$$

so that the performance of the car does not depend on the content of the petrol tank.

For reasons of safety on the road an EV should behave similarly, but behaviour is limited because driving performance is sufficient only as long as the battery can provide the motor power requirements. Experience shows that this is a basic requirement, because the achievable battery power depends very much on the state of charge, temperature, age, etc.

In urban traffic, which is the most important application for EVs, driving- and standstill-periods alternate quite frequently. This stop-and-go results in typical velocity profiles as defined in SAE J227a, A - D (Fig. 1(a)). According to our experience with lead–acid batteries, after a certain driving

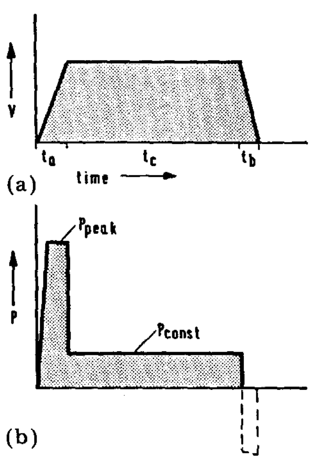

Fig. 1. (a) Velocity profile (similar to SAE J227a); (b) power profile.

distance, and depending on the condition of the battery, the required peak power for acceleration is no longer fully achievable. Peak power then decreases rapidly. From this fact, the range of an EV is limited, although there is still sufficient power to drive at constant velocity.

The design of traction batteries for fork-lift trucks and similar battery-powered electric vehicles is determined by the mean value of the load. In modern electric road vehicles the peak value is significantly greater than the mean value, so there are considerable differences between the calculated range and the range which is achievable in practice. Batteries for electric road vehicles must be governed by the number of micro cycles (for example, as shown in Fig. 1(b)) which can be driven without reducing acceleration [1].

The EV-design must consider the battery power performance

Safety requirements and the demand for high driving performance compel the designer of an EV to provide sufficient power over the entire driving range. The sizes of motor and controller depend on the maximum current I(max). During discharge a decreasing battery voltage must be compensated by an increasing current in order to ensure constant power (Fig. 2). Consequently the sizes of motor and controller are greater than are demanded by the maximum driving power.

$$P_{\text{drive max}} < P_{\text{mot}} = P_{\text{contr}} = U_r I_{\text{max}}$$

Below a certain depth of discharge (DOD) the voltage of a lead–acid cell, in order to avoid deep discharge, should not continue to decrease. This can

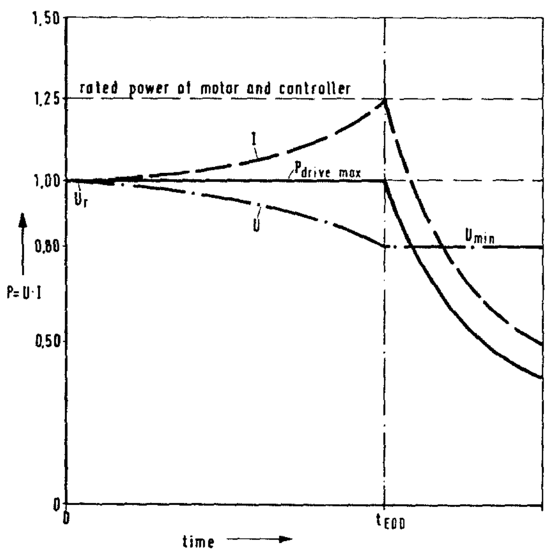

Fig. 2. Design of motor and controller depends on decrease of cell voltages.

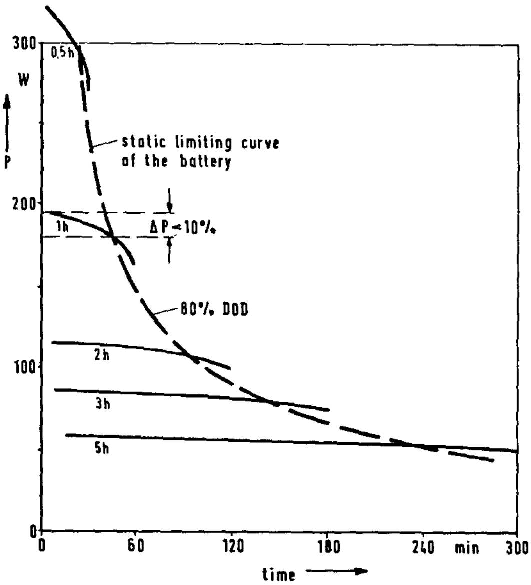

Fig. 3. Static power characteristic of a 140 A h lead–acid cell.

be ensured by a voltage-dependent current reduction. As a result the power required is no longer available, and the discharge comes to a very rapid end (EOD).

In general, battery manufacturers publish the time of discharge for constant current loads. The corresponding power characteristics of a 140 A h lead–acid cell are shown in Fig. 3.

Up to 80% DOD the power reduction is less than ΔP = 10%. The resulting limiting curve (dashed) allows the EV designer to assess the available range for constant velocities and equivalent constant power demand. For correct calculation, only the power obtainable from an aged battery at EOD should be taken into consideration.

Factors governing the dynamic load

As already mentioned, normally in urban traffic the battery load changes frequently. Up to now there have not been many investigations of the impact of this mode of operation on battery life. Experience shows that traction batteries fail much earlier on the road than during constant current bench-tests. On-the-road tests cover a number of parameters which differ from bench test conditions — but this is not the subject of this paper.

The intention of the authors is to stimulate the battery manufacturers to provide useful information for EV designers. For the design of the propulsion system it is necessary to know more about the dynamic characteristics of the battery.

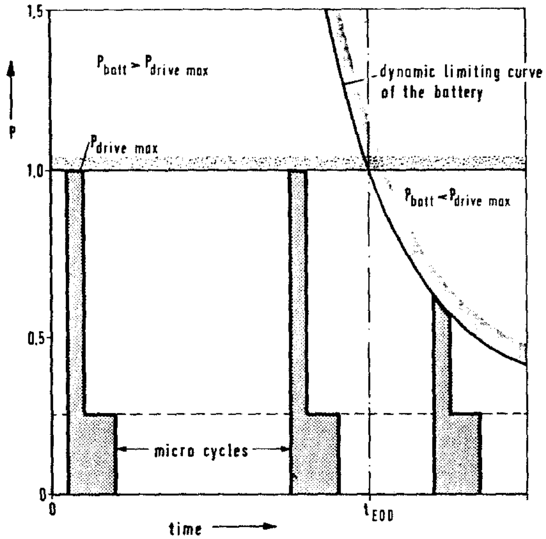

Fig. 4. The dynamic characteristic of the battery limits the range of an EV.

It is essential to know at what state of discharge the available acceleration is no longer sufficient (Fig. 4). Below this point, only driving at a significantly reduced power level is possible. This, of course, conflicts with safe driving and consequently limits vehicle range because battery power is less than the required driving power.

$$P_{\text{batt}} \leqslant P_{\text{drive max}} \mid t \geqslant t_{\text{EOD}}$$

It is unquestionable that actual driving conditions differ somewhat from a synthetic profile consisting of micro cycles.

Dynamic characteristics as an aid for the designer

Several proposals have been made for defining micro cycles or other dynamic discharge profiles (for example, SAE, A.V.E.R.E.). The proposed profile (Fig. 5) does not contain periods of rest and regenerative braking. Since both modes of operation relieve the battery and represent a non-calculable bonus in practical operation, the proposed profile represents an extreme requirement, which is typical for type tests of new batteries.

When using the power profile from Fig. 5 for different mean values P(mean) (for example, multiples of 100 W) and for various ratios $p = P(\text{peak})/P(\text{const}) = 1, 2, 3 \ldots$, characteristics as shown in Fig. 6 can be obtained. The static characteristic ($p = 1$) corresponds approximately to the customary data given by the battery manufacturers (Fig. 3). The dynamic characteristics ($p \geqslant 2$) help the designer to determine the number and type of cells when driving power and desired EV range are given.

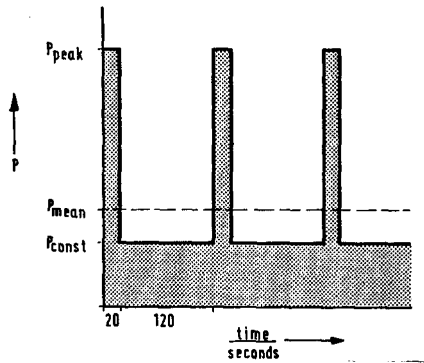

Fig. 5. Power profile for type tests.

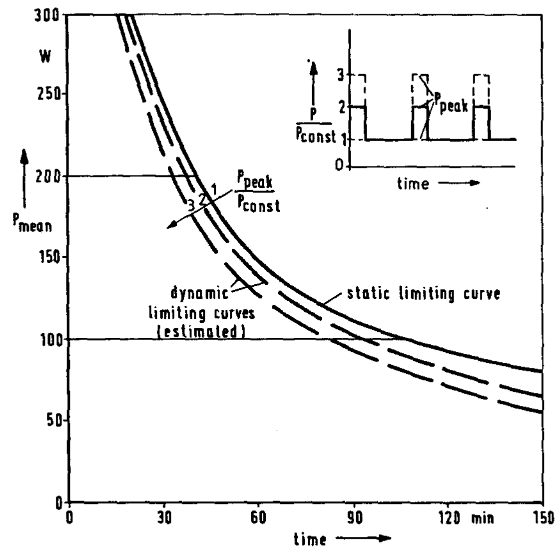

Fig. 6. Dynamic power characteristics of a lead–acid cell (estimated).

Conclusion

Safety on the road and driving comfort require the equivalent ICE power for EVs. Depending on the battery condition the power of an EV is limited by the motor as well as by the battery.

Battery manufacturers are asked to provide information concerning the dynamic behaviour of the batteries and to prove this by type tests.

The authors are aware that it is impossible to fulfill the requirements laid down in this paper in one step. For further standardization, it might be acceptable to allow a power drop of 10% between the beginning and the end of the range. It would also be acceptable to apply current profiles instead of power profiles in order to simplify the discharge equipment when equivalent results can be ensured.

In any case, the customary data do not provide sufficient valid information for EV application.

References

1 F. Hornstra and N. P. Yao, *Standard Test Procedures for Electric-Vehicle Batteries at the National Battery Test Laboratory*, SAE-Paper 820401.