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Improvement of bench life-tests for automotive batteries

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Abstract

A common method for rating the endurance of automotive batteries is the bench life-test according to DIN, IEC, SAE or JIS. With an increasing number of maintenance-free batteries on the market, the application of these tests becomes more problematic. This is due to a step-by-step capacity decline during cycling if the content of antimony in the grid-alloy is decreased. The degradation in performance is caused by the phenomenon of acid stratification. Because this debilitating effect occurs only rarely in service (vehicle movement) if charging and discharging is well balanced, there is a need for a new bench life-test with conditions that are more representative of practical conditions. Research has shown that the main changes should be: (i) an accelerated (moved) battery during cycling; (ii) slightly lower charging or discharging capacity amplitude, also with a lower mean value.

Bench tests

Four different methods for rating automotive batteries are possible: (i) the theoretical approach that is often too optimistic but requires a minimum of cost; (ii) the bench test that requires limited effort, but provides results that depend on the conditions; (iii) the practical operating test (in-field test) that more closely corresponds to actual conditions, but is time consuming and expensive; (iv) statistics about rejections during the warranty period that can sometimes be an extremely expensive method.

This means that bench tests exhibit a good cost/advantage ratio and are therefore important for battery research and development. The problem here is that bench tests must also be modified as battery technology improves. Examples of inadequate bench tests to rate certain battery characteristics are:

- charge acceptance with regard to the amount of active mass that is actually transformed
- water consumption under conditions of relatively new batteries
- deep discharging under conditions that can lead to the destruction of batteries
- endurance or life tests that are not operationally oriented

The example most often used is the endurance, or cycle test, according to DIN. This test procedure (Table 1, column 1) is so far from practical operation in service that there is only a very low probability of generating typical battery failures such as: corrosion at the positive grids; shedding of the positive mass; shrinkage of the negative mass; excessive loss of water; short circuits due to grid growth.

The main reason why the applicability of the DIN life test does not hold for all common alloys is the capacity decline exhibited by batteries using positive grids with low contents of antimony. This gradual capacity decline becomes apparent when the final discharge voltage versus the number of cycles is observed (Fig. 1).

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TABLE 1

Specifications of bench life-tests for automotive batteries

	DIN 43539/2	New life test (draft)	SAE J573 J240-June 1982	JIS[a]	IEC
Temperature (°C)	40	25	40	40	40
Cycles/test unit	10	50	430	200–375	32
Discharge conditions	2 h at 5 I_{20}	1/3 h at 6 I_{20}	4 min at 25 A ≈1.7 A h	1 h at 20 A ≈20 A h	1 h at 5 I_{20}
Charge conditions	5 h at 14.8 V maximum 5 I_{20}	40 min at 14.0 V maximum 6 I_{20}	10 min at 14.8 V maximum 25 A	5 h at 5 A	2 h at 14.8 V maximum 10 I_{20}
Upper capacity level (C_U) (%)	100	50	100	100	100
Lower capacity level (C_L) (%)	50	40	C_L[b]	C_L[c]	75
Average capacity level (%)	75	45	C_A[d]	C_A[d]	87.5
Failure mode	<50% C_5 U_{30s}<7.2 V	U_{10s}<6 V I_{CC} U_{30s}<7.2 V I_{KP}	U_{30s}<7.2 V I_{CC}	<50% K_5	U_{30s}<7.2 V I by manufacturer

[a] $C_{20} \approx \frac{C_5}{0.85}$.

[b] $C_L = 100\% \left(1 - \frac{1.7\text{ A h}}{C_{20}}\right)$.

[c] $C_L = 100\% \left(1 - \frac{20\text{ A h}}{C_{20}}\right)$.

[d] $C_A = 0.5 \times (C_L + C_U)$.

I_{CC} = cold-cranking current (SAE).
$I_{KP} = I_{CC} \times 0.6$ (DIN).

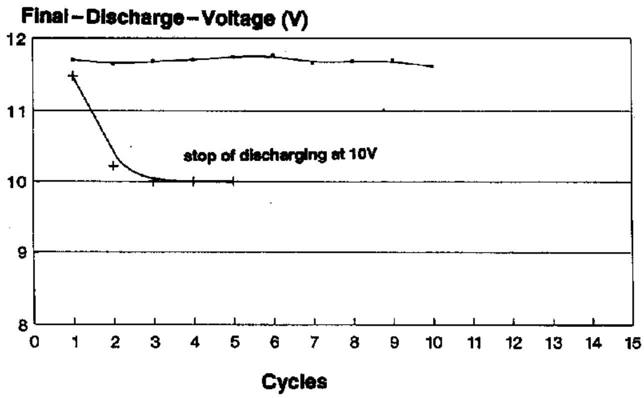

Fig. 1. Performance of automotive batteries under DIN 43539 TI.2 life test: (■) Pb–2.5wt.%Sb, and (+) Pb–Ca.

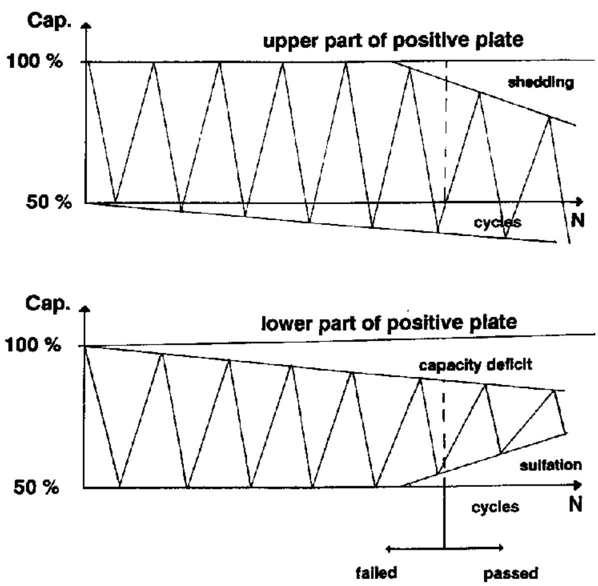

Fig. 2. Development of capacity amplitudes at acid stratification.

Acid stratification

Acid stratification occurs rapidly under the boundary conditions of amplitudes between 50% (discharging) and 100% nominal capacity (charging) and a non-stirred electrolyte (non-accelerated, stationary batteries). The consequence to charging and discharging if stratification is pronounced can be described as follows (Fig. 2):

- acid stratification decreases the charge acceptance of the lower part of the positive plate because the counter-electromotive force (given by the Nernst equation) is higher

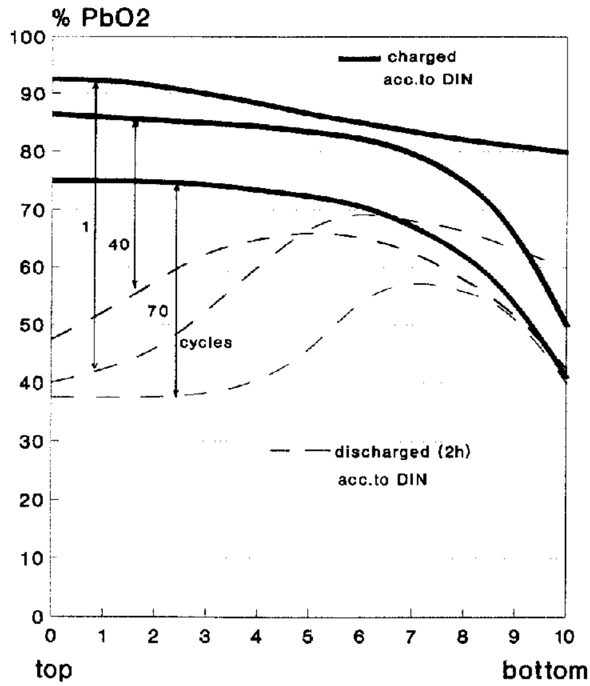

Fig. 3. Content of PbO_2 after 1, 40 and 70 DIN cycles.

immediately after discharging; additionally, the grid resistance is higher at the bottom of the plate

- the low density promotes charge acceptance of the upper part of the positive plate
- subsequent discharging under constant current overstresses the upper part of the positive plate because it has to deliver a level of capacity that cannot be provided by the lower part (which is not charged)

The effects of overstressing the upper part and inadequate charge acceptance of the lower part accumulate and eventually result in shedding of positive mass over the upper third of the plate and sulfation of the lower third. Confirmation of this model is provided by: (i) an analysis of the positive mass (PbO_2 and $PbSO_4$) after different numbers of cycles, and (ii) a study of the cases where acid stratification is negligible.

According to an analysis [1] of the positive mass of Pb–Ca plates after 1, 40 and 70 cycles (Fig. 3: PbO_2, Fig. 4: $PbSO_4$), the following results correlate with theoretical considerations:

(i) The content of PbO_2 in the lower third of the positive plate decreases with the number of cycles in accordance with DIN when the plate is in a charged state.

(ii) The content of PbO_2 in the upper third of the positive plate decreases with the number of cycles in accordance with DIN when the plate is in a discharged state.

(iii) The content of $PbSO_4$ in the lower third of the positive plate increases with the number of cycles in accordance with DIN when the plate is in a charged state.

(iv) The content of $PbSO_4$ in the entire plate is approximately zero, irrespective of the number of cycles charged with constant current, when the plate is in a charged state.

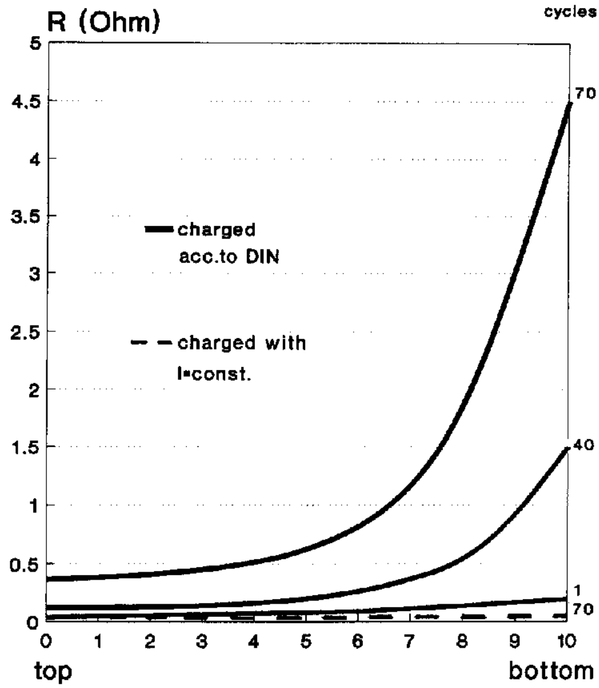

Fig. 4. Resistance (Ω) of positive active mass as a function of charging regime.

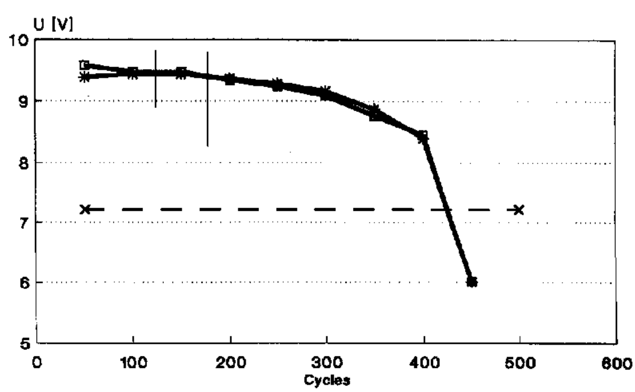

Fig. 5. 30-s voltage data from new life test (Table 1) on automotive batteries: (∗) BA5 Pb–Ca; (□) BA6 Pb–Ca; (×) failure.

A further confirmation is provided by experimental knowledge that there is no significant capacity decline for batteries with immobilized electrolyte, low plate design, or stirred (moved) electrolyte.

The fact, that there is also no essential capacity decline when the life-test conditions are modified to lower capacity amplitudes and lower average capacity levels, points towards a promising method for future use.

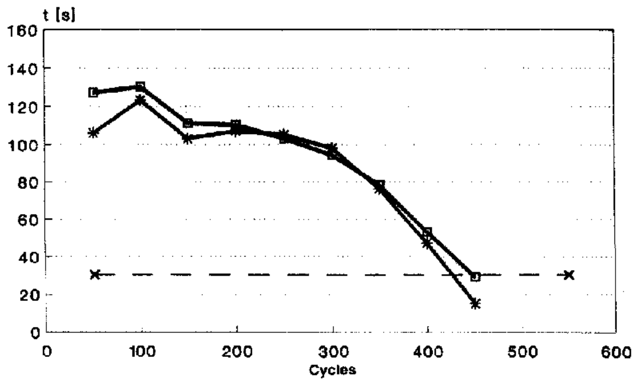

Fig. 6. Time to 7.2 V cutoff from new life test (Table 1) on automotive batteries: (∗) BA5 Pb–Ca; (□) BA6 Pb–Ca, and (×) failure.

New cycle test

The requirement made on a new bench life-test that is applicable to various grid alloys is: avoidance of acid stratification without the stirring effect of charging gas bubbles. Two solutions are possible: (i) low capacity amplitudes and a low mean capacity value (Table 1, col. 2), or (ii) electrolyte motion by acceleration of the battery as occurs under operating conditions (braking, starting, cornering).

The influence of the new bench life test parameters on the behaviour of maintenance-free automotive batteries is shown in Fig. 5 (30-s voltage) and Fig. 6 (time to 7.2 V). Both diagrams show excellent results that are better than those for Pb–Sb batteries. This demonstrates the preference for Pb–Ca batteries in the applied test conditions. Consequently, the solution for an improved bench test that can be applied to different grid alloys is found by acceleration of the battery during charging and discharging, while avoiding acid stratification. A slight modification to lower capacity amplitudes with a lower mean value than specified by DIN test conditions is also necessary.

Conclusions

The requirements of automotive batteries during operation are very diverse. These make it difficult to simulate service conditions. A first step towards achieving representative operating conditions should be the simulation of vehicle acceleration (starting, acceleration, cornering).

References

1 K. Wiesener, Technical University, Dresden, Germany, personal communication.