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ANALYZING CELL DESIGNS BY COMPUTER FOR OPTIMUM PERFORMANCE. A TECHNICAL NOTE*

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Summary

A practical approach is used to demonstrate that the electrical resistance of the component parts of a lead–acid cell can be correlated to the total cell resistance and the electrical performance of the cell. A computer program is used to analyze the cell design for the optimum use of materials.

Introduction

For many years the lead–acid battery industry has recognized the need to develop the tools that would enable the designer to optimize battery designs to obtain the maximum usage contributed by all of the component materials.

There have been many basic theoretical reviews presented that have been in-depth studies of the reactions of an individual part within the cell. The novelty of the approach used for this presentation is that it is based on many years of commercial type laboratory test work and the experience of correlating component testing to results of full sized cells. It is a practical approach.

Electrical performance, service life and costs are all involved, but for this presentation we will concentrate on the electrical performance.

Analysis of performance

The industry, in its analysis of performance, has used a basic formula as shown in eqn. (1):

$$E = K - I \times R \qquad (1)$$

where E = cell volts on discharge, K = cell volts on open circuit adjusted for specific gravity of the electrolyte, I = discharge current, R = apparent internal resistance of cell.

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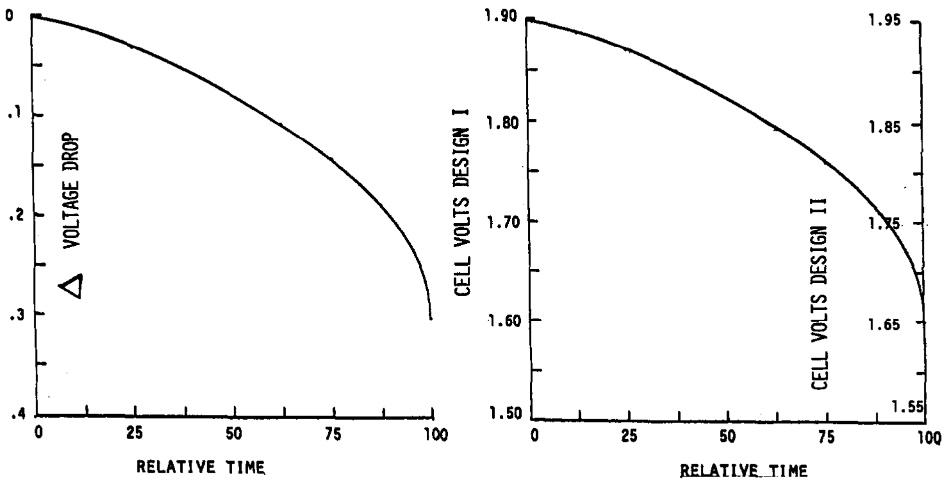

Fig. 1. Typical discharge curves.

This formula is elementary but it does represent the discharge characteristics of cells used within the range of most industrial applications. The formula, also, is useable to forecast the normal slope of the discharge voltage curve with time on discharge, with which we are familiar, when the values of "K" and "R" are understood and delineated.

The "R" or resistance value is the major influencing factor. As the cell "R" is made up of the "R" value of each component part, it is of particular importance to measure the resistance of each part and the contribution to the cell voltage on discharge. We should consider that during any discharge the values of "K" and "R" are constantly changing because of the normal products of reaction. The specific gravity of the electrolyte is falling as the active materials of the positive and negative plates are being sulfated. As the sulfate increases resistance, the "R" become higher as the discharge progresses. Therefore, the value of "K" is constantly being lowered and the value of "R" is constantly being increased.

If we can calculate the values of the "K" and "R" of the formula we have a means of comparing designs and measuring the effectiveness on discharge.

The electrical performance of a cell can be better understood if we analyze it in two parts. The first is the initial cell voltage at the start of discharge. The second is the hours or time of discharge as the voltage changes during the discharge and until it reaches a prescribed end voltage. Let us first consider the initial voltage and its importance in contributing to the final capacity.

Figure 1 portrays a typical discharge curve in two forms. Figure 1(a) shows a normal discharge of a design expressed as the voltage drop or voltage change plotted against time of discharge. In Fig. 1(b) we have applied the actual voltage of two different cell designs to the same voltage plot. The

TABLE 1

Major component parts contributing to cell resistance

Positive and negative group	Separation
Posts	Separator
Strap or burn	Retainer — glass mat
Plate lug	Retainer — perforated sheet
Plate top bar	Distance between plates
Plate body (grid & active material)	

designs of plates, separators, and electrolyte are exactly the same in both cells. The only difference in the cell construction is a change in posts and connectors which gives 50 mV less drop for Design 2 than for Design 1.

The plot on the right hand side can be analyzed to show the improvement when the resistance of the top construction of a cell is lower. A typical end voltage is 1.80 V per cell. Figure 1 can be analyzed and it shows that Design 2 will give 28% more time at the same current to the same end voltage.

The higher initial voltage shifted the whole voltage–time curve upward, resulting in the sizeable increase in capacity. This demonstrates that we should address ourselves to improving our understanding of all the cell components which contribute to resistance. We can then calculate the initial voltage (E_0) in our original formula as this serves as a base for all capacity measurements.

To achieve this better understanding we can divide the cell into many component parts and study the resistance of each and every component, both on an individual basis and on its contribution to the total cell resistance. As a practical approach we divided the cell into design areas as shown in Table 1.

For each of the components, a sufficient number of tests was completed to establish an initial or basic resistivity, and the effect of volume and length of path, type of material, and the influence of the specific gravity of the electrolyte. Formulae were also developed to relate the change to the cell resistance when more than one variable is adjusted.

A computer program was designed to use the data input of the design features of all the parts to determine the cell resistance. The computer prints out the resistance data which serves as a study sheet. A sample is shown as Table 2.

It will be noted that all the component assemblies as displayed in Table 1 are listed in Table 2 along with the calculated resistance of each of the parts as well as the final cell resistance. One can then analyze the component that contributes the most resistance toward limiting performance. On the other hand, one can also analyze the component with the least contribution to the cell "R" to determine the over-design possibilities.

TABLE 2

Computed resistance data

Total resistance						
	Positive		Negative		Separation	
Lug	4.036300E-05	Lug	6.268434E-05	Glass	1.676646E-05	
Top bar	3.739728E-05	Top bar	4.524822E-05	Perf.	0.000000E-01	
Plate	4.116027E-04	Plate	4.116221E-04	Free	1.097964E-04	
Tubing	0.000000E-01			Sepr.	1.485030E-04	
Group Sub-total	4.893629E-04		5.195546E-04		2.750658E-04	
Post	5.144338E-06	Post	5.110453E-06			
Strap	2.115188E-06	Strap	2.115188E-06			
Separation resistance (adjusted)					7.859021E-05	
Total cell resistance = 3.924305E-04						

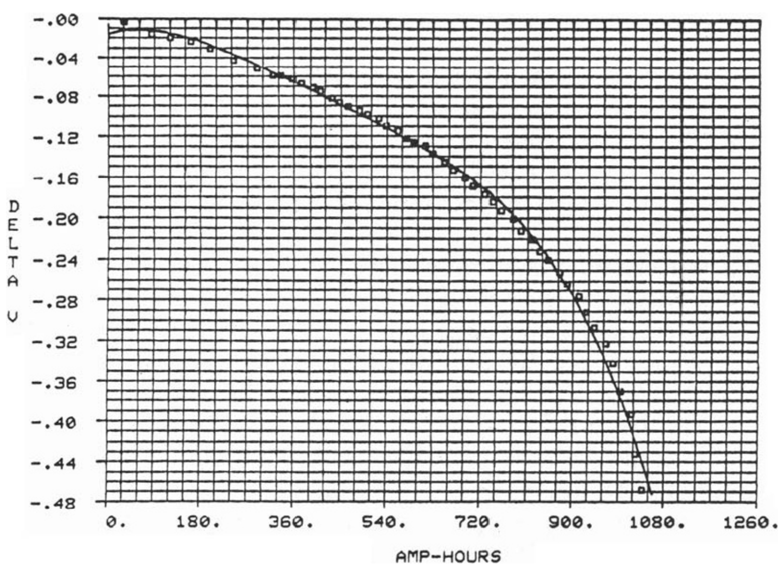

Fig. 2. Computer discharge curve.

The sensitivity of each component can be analyzed on the computer to arrive at the minimum cell resistance with the optimum use of materials. It is the total cell resistance that is related to the initial voltage (E_0) of a discharge to serve as a base for capacity performance.

In a similar manner the computer can also analyze the input to produce a delta voltage plotted against ampere hours of discharge at any number of discharge currents. A typical print-out is given in Fig. 2. Also, in a similar

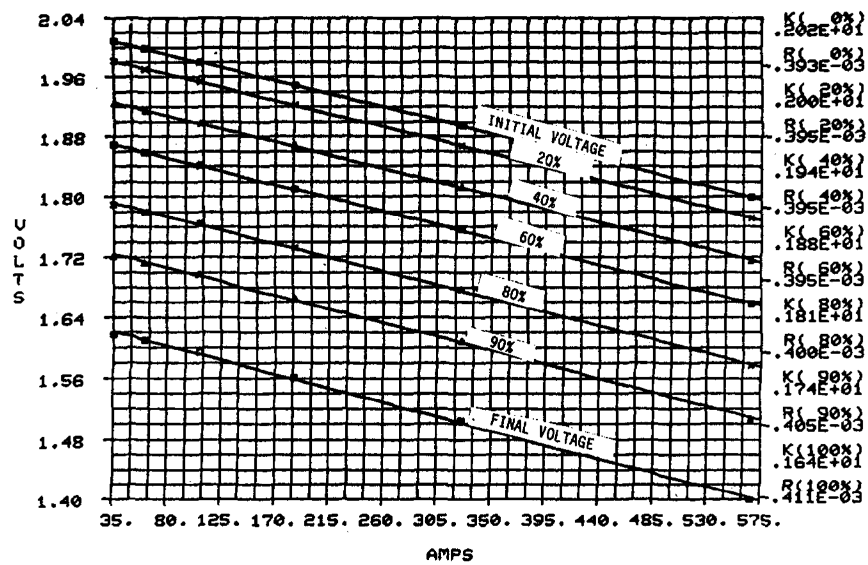

Fig. 3. Percent of time to final voltage.

manner, the designer modifies the inputs to determine the best performance and use of materials.

The computer then analyzes the series of delta voltage–discharge ampere hours, as well as the initial cell voltage response and produces a discharge cell voltage as affected by ampere rate and the depth of discharge. A sample of the computer print-out is shown in Fig. 3.

As will be noted, the computer has used a "K" and "R" value for each stage of discharge and this is used to effect improvements.

Conclusions

We believe the use of the old basic formula, eqn. (1), in conjunction with a computer will prove increasingly useful to analyze designs for optimum electrical performance, both for the benefit of the battery industry and those we supply.