POWER SOURCES 6

RESEARCH AND DEVELOPMENT IN NON-MECHANICAL ELECTRICAL POWER SOURCES

Proceedings of the 10th International Symposium
held at Brighton, September 1976

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ELECTRICAL POWER SOURCES COMMITTEE

Edited by
D. H. COLLINS

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Also edited by D. H. Collins:

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POWER SOURCES, 3. Research and Development in Non-Mechanical Electrical Power Sources. 1971

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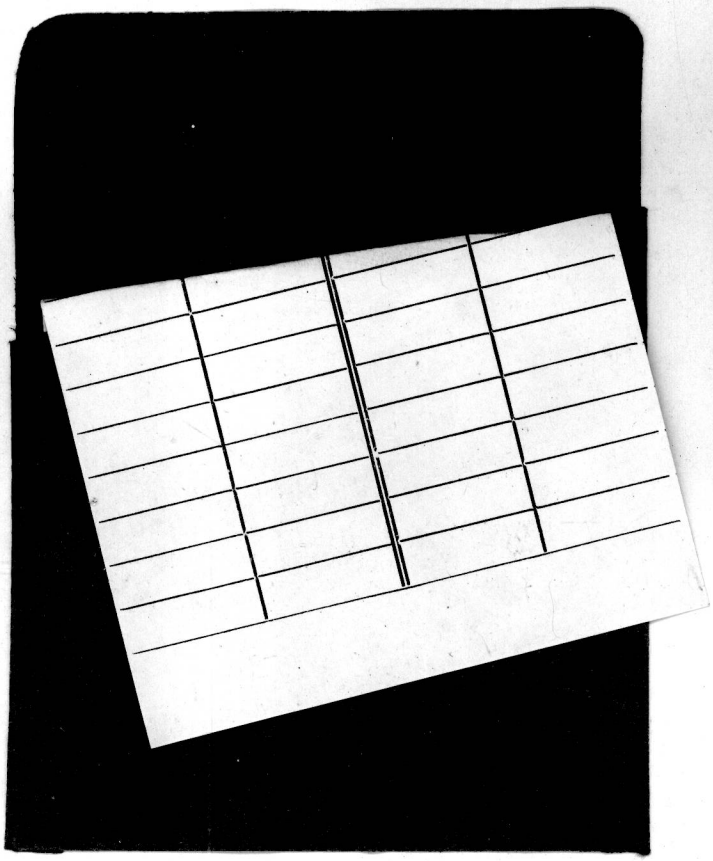


FOREWORD

In 1958 a Battery Symposium, organized by the late F. M. Booth with the support of a working group from the Inter-departmental Committee on Batteries, was held at the Signals Research and Development Establishment, now the Royal Signals and Radar Establishment (Christchurch). This three-day meeting was attended by about 200 people and aroused so much interest that a second symposium was held at the Bournemouth Pavilion two years later. The support for the second meeting was such that the Inter-departmental Committee on Batteries decided to continue the meetings at regular two-yearly intervals, and a working committee on which British commercial and government organizations were equally represented was set up to put this decision into effect.

From this modest beginning the symposia have continued with the basic organization unchanged and meetings are held regularly every two years at Brighton in September. Originally entitled "Battery Symposia" the scope has been widened to include recent developments in electrical power sources of all types other than rotating machinery and the title changed accordingly to "International Power Sources Symposia."

The basic purpose of the meetings is to provide an opportunity for people working in the power sources field and for users to discuss their work and problems. To promote this objective, pre-prints of papers are issued in advance of each Symposium and attendance is limited to 400.

There is no other restriction on attendance and more than half the delegates and papers come from overseas countries. The majority of papers come from industry, universities and government or other establishments where work on power sources is in progress, but papers from users are also encouraged as these draw attention to the practical problems and difficulties of selecting power sources for particular applications as well as giving an indication of the requirements to be met by manufacturers.

This book contains the papers presented at the 10th, 1976, Symposium together with an edited record of the discussions on them and also includes an index to the authors and titles of papers presented at all ten Symposia.

THE FRANK M. BOOTH AWARD

In 1970, the Frank M. Booth award was established. Named after the founder of the Symposia, the award has the form of a silver medallion engraved on one side with the name of the recipient and the year in which it was awarded, and on the other with the symbolic representation of non-mechanical electrical power, international interest and persons in conference.

The award is made to persons who have made outstanding contributions to the advancement of Power Sources either technically or by increasing the effectiveness of the Symposia.

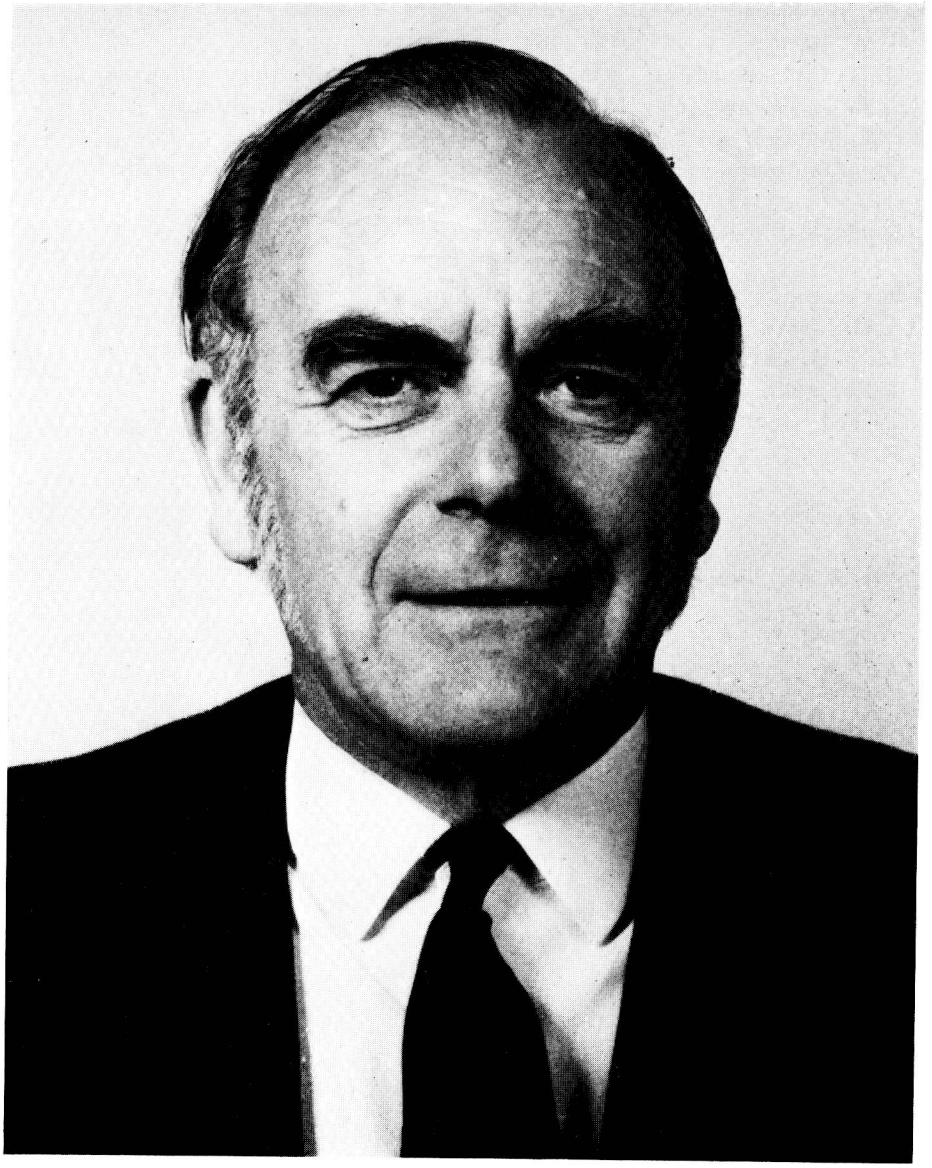
Previous recipients of the award have been:

Dr M. Barak Dr P. Reasbeck Mr A. L. Taylor	1960/1970
Mrs Jeanne Burbank	1970
Dr J. F. Laurent	1972
Dr M. I. Gillibrand	1974

The 1976 Frank Booth award was made to D. H. Collins at the express wish of the ordinary members of the Symposium Committee.

Derek Collins joined the Admiralty Engineering Laboratory in 1938 and on his retirement was head of the battery division. He was one of the members of the then I.D.C.B. which organized the first Battery Symposium at Christchurch in 1958. On the death of Frank Booth in 1961 he took over as Chairman of the Symposium Committee and during the period to 1976 his percipient and skilful leadership has brought the Symposium from humble beginnings to its present pre-eminent standing as a major International discussion conference on power sources.

The award marks his retirement from the Committee of which he was Chairman for 15 years, covering the 3rd to 10th Symposia, and from the Editorship of the proceedings over this period.



1976 Frank M. Booth Medallist
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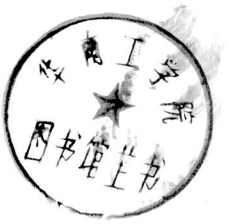

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THE EFFECT OF GRID CONDUCTIVITY ON THE PERFORMANCE OF TALL LEAD–ACID CELLS

Norman E. Bagshaw, Keith P. Bromelow and Jack Eaton
Chloride Industrial Batteries Limited, Clifton Junction, Manchester, England

ABSTRACT

Tests on 3-electrode cells showed that an additional conductor to the bottom of a tall flat pasted positive electrode increased the capacity by 8 and 12% at the 5 h and ½ h rates respectively. An extra conductor to the bottom of the negative electrode increased the capacity by 12% at the high rate. Tall multi-electrode cells containing high-conductivity grids gave 18% more energy than standard cells at the ½ h discharge rate and 43% more energy when discharged at constant high power. Increased grid conductivity had a more marked effect in the case of the positive than in the negative electrode.

INTRODUCTION

One of the many factors which have to be taken into account in designing a lead–acid cell is the grid conductivity. This design feature becomes more important as the size of the cell increases and with very tall cells, grid conductivity becomes one of the factors which limit performance, particularly at high discharge rates.

If electrodes of varying height are considered and it is assumed that the current density on the electrodes and the cross sectional area of the grids are constant, the current increases linearly with electrode height but the voltage drop in the grid itself increases at a much higher rate (Ludwig, 1965; Euler and Horn, 1965). In tall cells there can be a substantial voltage drop in the grids, thus reducing the terminal voltage of the cell. It has even been suggested that there is no point in making electrodes greater than 1000 mm in height (Euler and Horn, 1965).

In practice, the current density on the electrode is not uniform and at the beginning of discharge, the current density in the upper section of the electrode is higher than that in the lower section (Crennell and Lea, 1928). During discharge, the current density distribution across the electrode will vary with time but some part of the electrode will always be operating at higher current densities than others. Since the capacity of an electrode

decreases with increase in current density, this effect causes a further decrease in performance.

The considerable voltage drop in the grids of tall cells, particularly at high discharge rates, causes electrical losses which can result in a rapid rise in temperature. This further increases the resistance of the grids, causing an even greater loss in performance. Since the current in the grid increases from the base of the electrode to the take-off lug at the top, the upper sections of the cell are likely to be heated to a higher temperature than the lower sections, an effect which cannot be corrected by natural circulation of the electrolyte.

The above effects become more important in large cells designed specifically for high energy density where often thin electrodes are employed. Grid conductivity is likely to be no problem in Plante cells where thick heavy electrodes are employed and relatively tall cells containing such electrodes are capable of operating at the same current density as much smaller Plante cells to the same end voltage.

The tallest motive-power cell in common use in the U.K. contains electrodes approximately 510 mm high. These give an equivalent 5 h rate performance to much shorter electrodes of the same design when operated at the same current density. However, even with this type of cell, equivalent ampere hour capacities at the 10 min rate can only be achieved from the taller electrodes by discharging to a lower end voltage. Since the mean discharge voltage at these high rates is lower for the taller cells, the actual watt hour capacity is lower, reflecting the effect of grid conductivity.

Much taller cells are in use for such applications as submarine propulsion where high capacities are required (Smith, 1964). In this case, grid conductivity is very important. This can be illustrated by cutting down electrodes of height 800 mm to 500 mm and testing at the same current density. At the $\frac{1}{2}$ h rate, cells containing the 500 mm electrodes give approximately 12% longer duration than cells containing the original electrodes. There are therefore advantages to be gained by improving the conductivity of the grids.

In the early days of battery development, many attempts were made to increase the conductivity of the grid. Gold, platinum foil and copper sheets or copper wire gauze coated with lead were all proposed (Wade, 1908). More recently, a lead-coated expanded copper grid (Ruben, 1969; Kiessling, 1974) and a more conventional lead grid with additional lead-coated copper members (Steig, 1975) have been proposed for negative electrodes in order to increase the utilization of the negative active material. Since copper has a lower density than lead, the specific energy density of the electrode is further increased although the energy per unit volume is not affected. In this connection, a plastic grid coated with a good conductor (tin, silver) followed by lead has also been proposed (Mandil, 1971) for motive-power cells. Anodic corrosion of the positive grid makes it difficult to use copper in positive electrodes because of the dangers of copper poisoning.

An alternative approach has been suggested in which the tall electrodes are replaced by separate vertically superimposed component electrodes which are mechanically and electrically interconnected in parallel by a conductor (Brinkmann *et al.*, 1972). If this conductor is copper, special precautions such as lead coating followed by plastic coating would have to be employed to prevent any possibility of copper poisoning. This proposal has the added advantage of giving more uniform temperatures within the cell during discharge. When tubular cells are being manufactured it is also an advantage that the electrodes are relatively small since the vibratory filling of the tubular electrodes with lead oxide is facilitated. It has less advantage in the manufacture of pasted electrodes.

The aim of the present work was to investigate the effect of conductivity in both positive and negative grids on the initial performance of tall flat pasted electrode cells at various discharge rates not considering, at this stage, the life of the cells. It was proposed to test single electrodes with an additional conductor connected to the bottom of the electrodes and multi-electrode cells containing high-conductivity grids.

EXPERIMENTAL PROCEDURE

Single Electrodes with Additional Conductor

Positive grids of height 864 mm, width 294 mm and thickness 3·9 mm were cast in Admiralty B alloy containing 3% antimony, 1·5% tin and 0·05% selenium (Waterhouse and Willows, 1949) and negative grids of dimensions 867 × 297 × 2·9 mm were cast in lead–12% antimony followed by lead plating. The grids were pasted with standard positive and negative pastes and formed in tanks against blanks in the normal way.

They were then assembled in 3-electrode cells (pos–neg–pos and neg–pos–neg) in order to test both positive and negative electrodes with excess of the active material of opposite polarity. Excess acid (approx 200% of a standard cell) was also used.

Increased conductivity of the electrodes was introduced by welding lead-coated copper strip to the bottom of the electrode. Calculations from the areas of the copper strip, and the vertical ribs and side frames of the grids showed that the ratios for grid/copper strip conductivity were approximately 1:1 and 1:1·5 for the positive and negative grids respectively.

The 3-electrode cells were discharged at the $\frac{1}{2}$ h, 3 h and 5 h rates with intermediate recharges.

Cells with High-conductivity Grids

Positive grids of height 800 mm, width 278 mm and thickness 3·9 mm were cast in Admiralty B alloy. The mean weight of the grids was 1875 g. Negative

grids of height 803 mm, width 281 mm and thickness 2·9 mm were cast in lead–12% antimony alloy with a mean weight of 1392 g.

The conductivity of the grids was then increased by dissolving a portion of the grid alloy, plating with copper and finally replating with lead. The weights of alloys and metals in the final grids are shown in Table I. The positive and negative grids contained approximately 27 and 16% by volume of copper respectively.

TABLE I DISTRIBUTION OF ALLOY AND METAL WEIGHTS IN HIGH-CONDUCTIVITY GRIDS

Constituent	Weight (g)	
	Positive	Negative
Lead alloy	880	824
Copper plating	398	198
Lead plating	512	512
Total	1790	1534

The conductivity of the experimental positive grid was approximately four times that of a standard grid, whereas there was an increase in conductivity of the experimental negative grid compared with a standard negative grid by a factor of about 3.

The grids were pasted with standard positive and negative pastes and formed in tanks against blanks in the normal way. They were then assembled into multi-electrode cells. Some cells contained both experimental positive and negative electrodes while some were assembled with standard positive and experimental negative electrodes and others with experimental positive and standard negative electrodes.

All the experimental cells were then discharged together with standard cells at a constant current of 1244 A (nominal $\frac{1}{2}$ h rate), controlling the current by means of a variable resistance. The discharge was taken to 1·4 and 1·31 V per cell. After recharging, constant power discharge tests at 2·117 kW were carried out by monitoring the voltage during discharge and adjusting the current to maintain constant power. The end of discharge in this case was 1·4 V per cell.

RESULTS

Single Electrodes with Additional Conductor

The effect of an additional conductor on the capacity of positive and negative electrodes is shown in Table II, where the capacities are compared with results from standard electrodes at various discharge rates. The results