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**GULTON INDUSTRIES, INC.**

Metuchen, N. J.

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OF STORAGE BATTERIES FOR FUTURE

SATELLITES Quarterly ... Report No. 5, 4 Nov. ...

5

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# V. [illegible]

## 1. FABRICATION OF [illegible] CELLS

The function and appearance of the cell package has been much improved. Dies for deep drawn cases and covers are being fabricated so that the first cells in these cases may be expected within the next reporting period.

## 2. THERMAL [illegible]

A [illegible] thermal conductivity [illegible] the VC-5 MS cell has been experimentally determined and is noted in the tabulated results of section III-A of this report. The data obtained, combined with available data from the VC-20 HC cell, makes it possible to predict characteristics of other size cells as is done in section III-[illegible] of this report.

## 3. [illegible]

In order to maintain reasonable cell weights, a cell having a total thickness of 1.[illegible] inches is proposed. This is rather a thick cell and may require modification in order to provide a cell that is self supporting on its edges. Further analysis of thermal characteristics and weights will be necessary before this design is finalized.

## VI. [illegible]

With the program extended for another year, a continuation of our research efforts will result in the following program for the next period.

Item I. Continue to design and initiate the construction of 10 AH cells.

Item II. Perform studies on the thermal properties of battery packages where it is necessary to remove heat from the inside of the cells to the heat sink.

Item III. Initiate studies on techniques to reduce self discharge of cells.

Item IV. Consider methods whereby the pressure in sealed cell battery packages can be monitored.

The overall program for the coming year, in addition to the above four items, includes further studies on:

1. Thin film batteries
2. Charge, discharge and recharge data at minus 10°F up to 140°F.

# I. ABSTRACT

15187

One hundred and three additional VO-6 HS cells have been delivered to NASA in this reporting period. Now specifications have been published to improve the quality of the welded VO-6 HS case. Dies are being made to deep draw cases and covers for these cells.

Mean thermal conductivities have been determined for the VO-6 HS cell at various charge rates in an 80°F ambient. The method of determination is shown along with sample calculations.

Thermal data obtained is applied to predict the behavior of other size cells of similar construction.

A preliminary design for a 50 AH cell is presented along with comments on the concept of a composite terminal for large hermetically sealed cells.

Author

deep drawn VO-6 HS cases and covers are expected about the middle of March. If the cases obtained live up to our expectations, we should have very nearly attained the ultimate in closures for prismatic type hermetically sealed cells.

## II. FABRICATION OF VO-6 HS CELLS

Since the last report, a total of 103 type VO-6 HS cells have been delivered to NASA. Table I summarizes the serial numbers of these cells as well as the test data obtained in the cell check-out procedure prior to shipment.

The cells shipped to date have all been assembled with fabricated cases. Considerable effort has been expended to improve the quality of the fabricated case. The necessary technique for making satisfactory case welds was developed in the pilot plant while we were solving the problems involved in closing the cells. Engineering teams from Gulton have visited our suppliers of welded cases to discuss and demonstrate the techniques of fabrication. Gulton specification 5714 (Figure 1) has been prepared and circulated to interested parties to provide the criteria upon which cases will be accepted for use in hermetically sealed cells.

The welded cases, even those meeting the new specifications, have always presented problems in sealed cell applications. In a space environment, the problem of the removal of heat from the cell becomes significant in a battery configuration, so the major surfaces of the cell must maintain a good contact with whatever heat sinking means is used. This means that cell dimensions must be held closely, and the surface must be as flat as possible to give the desired contact.

The solution to the problems of the welded case appears to be the deep drawn case. The requirements for such a case were carefully considered, then a number of deep draw specialists were contacted to determine if a case could be made to the necessary standards. After much consideration, a vendor was selected to produce a pilot run of cases and matching covers. The first

TABLE I

TEST HISTORY OF VO-6 HS CELLS
DELIVERED TO NASA SINCE LAST REPORTING

| CELL SERIAL NO. | OVERCHARGE RATE | OVERCHARGE VOLTAGE | OVERCHARGE PRESS. | CAPACITY 3 AMP TO 1 VOLT | * CYCLES | SHORT TEST OCV AFTER 24 HRS. |
|---|---|---|---|---|---|---|
| 515 | .6 Amp. | 1.45 | 40 | 6.60 AH | 10 | 1.20 |
| 516 | | 1.45 | 45 | 6.40 | | ↑ |
| 519 | | 1.50 | 25 | 6.90 | | |
| 520 | | 1.50 | 20 | 6.80 | | |
| 523 | | 1.44 | 47 | 6.60 | | ↓ |
| 524 | | 1.44 | 48 | 6.15 | | 1.20 |
| 527 | | 1.48 | 50 | 6.30 | | 1.22 |
| 529 | | 1.42 | 50 | 6.05 | | 1.20 |
| 531 | | 1.44 | 45 | 6.00 | | 1.21 |
| 533 | | 1.48 | 36 | 6.20 | | 1.21 |
| 538 | | 1.50 | 45 | 6.20 | | 1.20 |
| 539 | | 1.48 | 25 | 6.15 | | 1.22 |
| 545 | | 1.44 | 20 | 6.70 | | 1.20 |
| 550 | | 1.44 | 31 | 6.20 | | 1.20 |
| 551 | | 1.46 | 21 | 6.20 | | 1.20 |
| 553 | | 1.42 | 26 | 6.00 | | 1.21 |
| 556 | | 1.42 | 21 | 6.40 | | 1.20 |
| 560 | | 1.46 | 34 | 6.05 | | 1.22 |
| 563 | | 1.44 | 26 | 6.05 | | 1.22 |
| 564 | | 1.44 | 32 | 6.05 | | 1.20 |
| 567 | | 1.42 | 31 | 6.80 | | 1.22 |
| 569 | | 1.40 | 25 | 6.25 | | 1.20 |
| 570 | | 1.40 | 30 | 7.25 | | 1.21 |
| 572 | | 1.42 | 31 | 6.45 | | 1.22 |
| 574 | | 1.40 | 48 | 6.30 | | 1.21 |
| 575 | | 1.40 | 25 | 6.30 | | 1.20 |
| 577 | | 1.40 | 12 | 7.60 | | 1.22 |
| 578 | | 1.42 | 24 | 6.70 | | 1.21 |
| 579 | | 1.42 | 19 | 7.20 | | 1.20 |
| 582 | | 1.42 | 20 | 6.76 | | 1.20 |
| 583 | | 1.40 | 11 | 6.80 | | 1.20 |
| 584 | | 1.40 | 7 | 7.60 | | 1.21 |
| 585 | | 1.40 | 43 | 6.40 | | 1.19 |
| 586 | | 1.40 | 20 | 7.35 | | 1.20 |
| 587 | | 1.40 | 30 | 6.35 | | 1.20 |
| 588 | | 1.42 | 12 | 7.55 | | 1.21 |
| 589 | | 1.40 | 26 | 6.50 | | 1.19 |
| 590 | | 1.40 | 20 | 6.25 | | 1.20 |
| 595 | | 1.40 | 16 | 6.15 | | 1.20 |
| 596 | | 1.40 | 26 | 6.55 | | 1.20 |
| 597 | | 1.40 | 17 | 7.05 | | 1.22 |
| 602 | | 1.42 | 20 | 6.45 | | ↑ |
| 604 | | 1.41 | 10 | 6.40 | | |
| 607 | | 1.42 | 12 | 7.10 | | |
| 610 | | 1.41 | 19 | 6.40 | | |
| 611 | | 1.43 | 22 | 6.90 | | |
| 615 | | 1.40 | 14 | 6.45 | | ↓ |
| 617 | | 1.41 | 12 | 6.80 | | 1.22 |
| 619 | | 1.43 | 16 | 7.45 | | 1.21 |

TABLE I - Cont'd.

TEST HISTORY OF VO-6 HS CELLS
DELIVERED TO NASA SINCE LAST REPORTING

| CELL SERIAL NO. | OVERCHARGE RATE | OVERCHARGE VOLTAGE | PRESS. | CAPACITY 3 AMP TO 1 VOLT | * CYCLES | SHORT TEST OCV AFTER 24 HRS. |
|---|---|---|---|---|---|---|
| 620 | | 1.42 | 13 | 7.00 | | 1.22 |
| 623 | | 1.42 | 9 | 6.50 | | 1.22 |
| 624 | | 1.40 | 32 | 6.15 | | 1.20 |
| 627 | | 1.41 | 14 | 6.50 | | 1.22 |
| 628 | .6 Amp | 1.40 | 11 | 8.30 | 10 | 1.22 |
| 631 | .6 Amp | 1.40 | 10 | 7.35 | 10 | 1.21 |
| 632 | | 1.40 | 16 | 6.70 | | 1.22 |
| 644 | | 1.42 | 18 | 7.00 | | |
| 645 | | 1.40 | 13 | 6.45 | | |
| 647 | | 1.40 | 18 | 6.75 | | |
| 648 | | 1.40 | 14 | 6.70 | | |
| 653 | | 1.41 | 15 | 6.70 | | |
| 654 | | 1.41 | 18 | 6.70 | | |
| 656 | | 1.42 | 22 | 6.65 | | |
| 657 | | 1.42 | 8 | 6.75 | | |
| 660 | | 1.42 | 8 | 7.05 | | |
| 661 | | 1.41 | 20 | 7.10 | | 1.22 |
| 662 | | 1.41 | 25 | 7.10 | | 1.21 |
| 719 | | 1.40 | 19 | 6.10 | | 1.20 |
| 765 | | 1.40 | 15 | 6.50 | | 1.22 |
| 770 | | 1.40 | 21 | 6.35 | | |
| 778 | | 1.40 | 10 | 6.40 | | |
| 779 | | 1.40 | 10 | 6.30 | | |
| 780 | | 1.40 | 10 | 6.35 | | |
| 783 | | 1.42 | 21 | 6.55 | | 1.22 |
| 798 | | 1.42 | 26 | 6.50 | | 1.20 |
| 801 | | 1.42 | 19 | 6.50 | | |
| 804 | | 1.42 | 51 | 6.50 | | |
| 810 | | 1.42 | 19 | 6.50 | | 1.20 |
| 812 | | 1.40 | 34 | 6.35 | | 1.21 |
| 813 | | 1.42 | 24 | 6.95 | | 1.21 |
| 814 | | 1.41 | 16 | 6.95 | | 1.21 |
| 815 | | 1.40 | 40 | 6.95 | | 1.22 |
| 816 | | 1.40 | 25 | 6.95 | | |
| 819 | | 1.40 | 31 | 6.45 | | |
| 820 | | 1.40 | 19 | 6.80 | | |
| 822 | | 1.40 | 29 | 6.50 | | |
| 825 | | 1.40 | 23 | 6.80 | | 1.22 |
| 826 | | 1.40 | 45 | 6.60 | | 1.21 |
| 827 | | 1.40 | 16 | 6.90 | | 1.22 |
| 829 | | 1.40 | 22 | 6.90 | | 1.22 |
| 830 | | 1.40 | 26 | 6.65 | | 1.22 |
| 884 | | 1.40 | 14 | 7.00 | | 1.24 |
| 885 | | 1.40 | 24 | 6.20 | | 1.24 |
| 886 | | 1.41 | 24 | 6.20 | | 1.26 |
| 887 | | 1.42 | 20 | 6.95 | | 1.26 |
| 888 | | 1.41 | 9 | 6.80 | | 1.24 |
| 889 | | 1.43 | 24 | 6.55 | | 1.25 |
| 890 | | 1.41 | 10 | 6.35 | | 1.24 |
| 891 | | 1.41 | 12 | 6.35 | | 1.25 |

TABLE I - Cont'd.

TEST HISTORY OF VO-6 HS CELLS
DELIVERED TO NASA SINCE LAST REPORTING

| CELL SERIAL NO. | RATE | OVERCHARGE VOLTAGE | PRESS. | CAPACITY 3 AMP TO 1 VOLT | * CYCLES | SHORT TEST OCV AFTER 24 HRS. |
|---|---|---|---|---|---|---|
| 892 | | 1.41 | 12 | 6.35 | | 1.26 |
| 893 | | 1.40 | 21 | 6.20 | | ↑ |
| 894 | | 1.42 | 10 | 6.80 | | ↓ |
| 895 | .6 Amp | 1.41 | 5 | 6.65 | 10 | 1.26 |

* Cycle consists of 90 minute charge @ 1.5 Amp.

30 minute discharge @ 3.0 Amp.

# III. THERMAL ANALYSIS

## A. VO-6 HS

### Test Objective

The primary objective of the test was to determine a mean thermal conductivity of a VO-6 HS cell as a function of charge, overcharge, and discharge current in an ambient environment of 80°F. For test setup (See Figure 2.)

### Test Procedure

Two cells were constructed with thermocouples placed internally in the cell, as well as welded to twenty-four points on the skin of the cell. (See Figure 3.) The cells were placed into an ambient environment of 80°F and charged at .25, .50, .75, 1.0, and 2.0 amperes until 115% of capacity was put into the cell. The cells were then overcharged at .25, .50, .75, 1.0, and 2.0 amperes until the internal temperature remained constant. Once constant temperature was reached, the cells were discharged at .25, .50, .75, 1.0, and 2.0 amperes until the internal cell temperature remained constant. During the charge, overcharge, and discharge at constant current, internal temperature, skin temperatures, and cell electrical characteristics were continuously monitored.

### Analysis of Data

It was noted from the data that as the overcharge rate increased from .25 amperes to 2.0 amperes, the internal temperature changed from 86°F to 89°F, while the mean skin temperature remained in the range of 82°F - 83°F. (See Table II.) The thermal conductivity of the cell increased as the overcharge current increased because the amount of heat generated by the cell increased at a greater

[illegible] No. V06HS

[illegible] 80°F

# TABLE II-1

Charge Rate [illegible]

4:00 AM 10-27-61 Went on Charge

10-28-61

| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11:45 | C | 90 | 83 | 83 | 83 | 84 | 84 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 86 | 87 | 87 | | .25 | 1.47 |
| 12:50 | | 86 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | | .25 | 1.47 |
| 1:20 | D | 86 | 80 | 81 | 80 | 80 | 80 | 80 | 81 | 81 | 81 | 81 | 81 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | | .25 | 1.5 |
| 2:00 | C | 86 | 82 | 82 | 82 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | | .25 | 1.5 |
| 2:30 | D | 86 | 82 | 82 | 82 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 82 | 82 | 82 | | .25 | 1.4 |
| 3:00 | | 86 | 83 | 83 | 83 | 83 | 82 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | | .25 | 1.33 |
| 4:00 | C | 86 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | | .25 | 1.30 |

| | | | 21 | 22 | 23 | 24 | | |
|---|---|---|---|---|---|---|---|---|
| 11:45 | C | 90 | 87 | 87 | 81 | 87 | .25 | 1.47 |
| 12:50 | | 86 | 80 | 80 | 80 | 80 | .25 | 1.47 |
| 1:20 | D | 86 | 82 | 82 | 82 | 82 | .25 | 1.5 |
| 2:00 | C | 86 | 83 | 83 | 83 | 83 | .25 | 1.5 |
| 2:30 | D | 86 | 82 | 82 | 82 | 82 | .25 | 1.4 |
| 3:00 | | 86 | 83 | 83 | 83 | 83 | .25 | 1.33 |
| 4:00 | C | 86 | 83 | 83 | 83 | 83 | .25 | 1.30 |

V26HS

80°F

# TABLE II-2

Charge Rate = .50 AHR

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9:00 PM 12-4-61 Went on Charge | | | | | | | | | | | | | | | | | | | | | | | |
| 12-5-61 | | | | | | | | | | | | | | | | | | | | | | | |
| 8:30 AM | | 83 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | .50 | 1.47 |
| 10:00 | D | 88 | 81 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | .50 | 1.5 |
| 10:30 | C | 88 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | .50 | 1.5 |
| 11:00 | D | 87 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | 83 | .50 | 1.52 |
| 11:30 | C | 86 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | .50 | 1.27 |
| 12:00 | | 86 | 81 | 81 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | .50 | 1.24 |

| | | 21 | 22 | 23 | 24 | | |
|---|---|---|---|---|---|---|---|
| 8:30 | C | 82 | 82 | 82 | 82 | 82 | .50 1.47 |
| 10:00 | D | 88 | 83 | 83 | 83 | 83 | .50 1.5 |
| 10:30 | C | 88 | 83 | 83 | 83 | 83 | .50 1.5 |
| 11:00 | D | 87 | 83 | 83 | 83 | 83 | .50 1.52 |
| 11:30 | C | 86 | 82 | 82 | 82 | 82 | .50 1.27 |
| 12:00 | | 86 | 82 | 82 | 82 | 82 | .50 1.24 |

TIME | CELL NO. V06HS | TEMPERATURES °F | BATTERY CYCLE

HMB TEMP 80°F

# TABLE II-3

CHARGE RATE = .75 AMPS

| Start Time | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | Time Min | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12:00 Midnight 12-12-61 Went on Charge | | | | | | | | | | | | | | | | | | | | | | | | | |
| 12-12-61 | | | | | | | | | | | | | | | | | | | | | | | | | |
| 9:30 | C | 87 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | | .75 | 1.5 |
| 10:30 | | 88 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | | .75 | 1.5 |
| 12:00 | C | 88 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | | .75 | 1.5 |
| 1:25 | | 88 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | | .75 | 1.5 |
| 2:28 | D | 85 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | | .75 | 1.27 |
| 3:23 | C | 82 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | | .75 | 1.24 |
| | | | 21 | 22 | 23 | 24 | | | | | | | | | | | | | | | | | | | |
| 9:30 | O | 87 | 82 | 82 | 82 | 82 | | | | | | | | | | | | | | | | | | .75 | 1.5 |
| 10:30 | | 88 | 82 | 82 | 82 | 82 | | | | | | | | | | | | | | | | | | .75 | 1.5 |
| 12:00 | C | 88 | 82 | 82 | 82 | 82 | | | | | | | | | | | | | | | | | | .75 | 1.5 |
| 1:25 | | 88 | 82 | 82 | 82 | 82 | | | | | | | | | | | | | | | | | | .75 | 1.5 |
| 2:28 | D | 85 | 82 | 82 | 82 | 82 | | | | | | | | | | | | | | | | | | .75 | 1.27 |
| 3:23 | C | 82 | 80 | 80 | 80 | 80 | | | | | | | | | | | | | | | | | | .75 | 1.24 |

VO6HS

80°F

# TABLE II-4

Charge Rate = 1.0 Amps

5:00 AM 12-19-61 Went on Charge

| 12-19-61 | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9:20 | C | 88 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 1.0 | 1.5 |
| 10:20 | | 88 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 1.0 | 1.51 |
| 11:10 | D | 88 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 1.0 | 1.52 |
| 11:45 | C | 88 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 1.0 | 1.52 |
| 1:15 | | 88 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 1.0 | 1.52 |
| 2:05 | D | 84 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 1.0 | 1.25 |
| 2:45 | | 84 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 1.0 | 1.22 |
| 3:15 | C | 84 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 80 | 1.0 | 1.18 |

| | | 21 | 22 | 23 | 24 | | |
|---|---|---|---|---|---|---|---|
| 9:20 | C | 88 | 82 | 82 | 82 | 1.0 | 1.5 |
| 10:20 | | 88 | 82 | 82 | 82 | 1.0 | 1.51 |
| 11:10 | D | 88 | 82 | 82 | 82 | 1.0 | 1.52 |
| 11:45 | C | 88 | 82 | 82 | 82 | 1.0 | 1.52 |
| 1:15 | | 88 | 82 | 82 | 82 | 1.0 | 1.52 |
| 2:05 | D | 84 | 80 | 80 | 80 | 1.0 | 1.25 |
| 2:45 | | 84 | 80 | 80 | 80 | 1.0 | 1.22 |
| 3:15 | C | 84 | 80 | 80 | 80 | 1.0 | 1.18 |

CELL NO. V06HS

AMB TEMP 80°F

# TEMPERATURES °F

## TABLE II-5

CHARGE RATE = 2.0 AMPS

| TIME MIN | | INTERNAL TEMP °F | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | BATTERY CYCLE TIME MIN | CURR AMP | POT VOLT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12-26-61 9:30AM | | | WENT ON CHARGE | | | | | | | | | | | | | | | | | | | | | | |
| 11:00 | | 89 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | | 2.0 | 1.5 |
| 11:30 | C | 89 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | | 2.0 | 1.54 |
| 1:00 | | 89 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | | 2.0 | 1.57 |
| 1:30 | D | 89 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | | 2.0 | 1.67 |
| 2:00 | C | 89 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | | 2.0 | 1.67 |
| 2:30 | D | 87 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | | 2.0 | 1.24 |
| 3:00 | C | 87 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | 82 | | 2.0 | 1.13 |
| | | | 21 | 22 | 23 | 24 | | | | | | | | | | | | | | | | | | | |
| 11:00 | | 89 | 82 | 82 | 82 | 82 | | | | | | | | | | | | | | | | | | 2.0 | 1.5 |
| 11:30 | C | 89 | 82 | 82 | 82 | 82 | | | | | | | | | | | | | | | | | | 2.0 | 1.54 |
| 1:00 | | 89 | 82 | 82 | 82 | 82 | | | | | | | | | | | | | | | | | | 2.0 | 1.57 |
| 1:30 | D | 89 | 82 | 82 | 82 | 82 | | | | | | | | | | | | | | | | | | 2.0 | 1.67 |
| 2:00 | C | 89 | 82 | 82 | 82 | 82 | | | | | | | | | | | | | | | | | | 2.0 | 1.67 |
| 2:30 | D | 87 | 82 | 82 | 82 | 82 | | | | | | | | | | | | | | | | | | 2.0 | 1.24 |
| 3:00 | C | 87 | 82 | 82 | 82 | 82 | | | | | | | | | | | | | | | | | | 2.0 | 1.13 |

rate than the thermal gradient. This is evident from the derived equation in Report #3 where

$$K = \frac{\dot{q}\ L^2}{2\ (T_{int} - T_{skin})}$$

in which

| | | | |
|---|---|---|---|
| $K$ | = | Thermal Conductivity | $\frac{BTU}{HR\ FT\ ^oF}$ |
| $\dot{q}$ | = | Internal Heat Generation | $\frac{BTU}{FT^3\ HR}$ |
| $(T_{int} - T_{skin})$ | = | Thermal Gradient | $^oF$ |
| $\frac{L^2}{2}$ | = | Constant | $FT^2$ |

It can be seen from this, that the thermal conductivity is not a constant, but it is a function of overcharge rate. From other studies carried on at Gulton, but not connected with this contract, it has been found that thermal conductivity is also a function of ambient temperature.

In (Figure 4) there is a plot of thermal conductivity versus overcharge current at an ambient temperature of 80°F. It is presumed that this curve will move downward as the ambient temperature is increased, and upward as the ambient temperature is decreased, resulting therefore, in a family of curves for thermal conductivity. This presumption will be further investigated.

The important significance of these curves is that once knowing the overcharge current and the ambient temperature, one will be able to determine the thermal conductivity and predict the thermal gradient in the cell.

<u>Sample Calculations</u>: Using the equations derived in Report #3.

1. $K = \frac{\dot{q}\ L^2}{2(T_{int} - T_{skin})}$

2. $$\dot{q}_x = \left[ \frac{\frac{1}{L_x^2}}{\frac{1}{L_x^2} + \frac{1}{L_y^2} + \frac{1}{L_z^2}} \right] \dot{q}$$

3. $$\dot{q}_y = \left[ \frac{\frac{1}{L_y^2}}{\frac{1}{L_x^2} + \frac{1}{L_y^2} + \frac{1}{L_z^2}} \right] \dot{q}$$

4. $$\dot{q}_z = \left[ \frac{\frac{1}{L_z^2}}{\frac{1}{L_x^2} + \frac{1}{L_y^2} + \frac{1}{L_z^2}} \right] \dot{q}$$

5. $$\dot{q} = \frac{(V)\ (I)\ (K)}{\text{Cell Volume}}$$

Analysis for .25 ampere overcharge rate

$$\dot{q} = \frac{V\ I\ K}{\text{Cell Vol.}} = \frac{(1.5)\ (.25)\ (5.69 \times 10^{-2})\ (60)}{(3.44)\ (2.09)\ (.812}$$

$$\dot{q} = .219 \quad \frac{\text{BTU}}{\text{HR in.}^3}$$

$L_x$ = .406 inches $\qquad 1/L_x^2$ = 6.06

$L_y$ = 1.05 inches $\qquad 1/L_y^2$ = .91

$L_z$ = 1.72 inches $\qquad 1/L_z^2$ = .338

$$\dot{q}_x = \left[ \frac{\frac{1}{L_x^2}}{\frac{1}{L_x^2} + \frac{1}{L_y^2} + \frac{1}{L_z^2}} \right] \dot{q} = \left[ \frac{6.06}{6.06 + .91 + .338} \right] .219$$

$$\dot{q}_x = .1815 \quad \text{BTU/HR in.}^3$$

By similar calculation

$$\dot{q}_y = .0272 \quad \text{BTU/HR in.}^3$$

$$\dot{q}_z = .0103 \quad \text{BTU/HR in.}^3$$

$$K = \frac{\dot{q}_x\ (L_x^2)}{2\ (T_{int} - T_{skin}} = \frac{(.1815)\ (.406)^2}{(2)\ (3)}$$

$$\therefore\ K = \left[ 4.98 \times 10^{-3} \right] \quad \text{BTU/HR in } ^{\circ}\text{F}$$

This procedure was followed for analyzing the .50, .75, 1.0, and 2.0 ampere overcharge rate. The results are tabulated below and plotted in Figure 4.

## TABULATED RESULTS

| OVERCHARGE RATE (AMPERES) | THERMAL CONDUCTIVITY (BTU/HR in°F) |
|---|---|
| .250 | $4.38 \times 10^{-3}$ |
| .500 | $5.99 \times 10^{-3}$ |
| .750 | $7.51 \times 10^{-3}$ |
| 1.00 | $10.0 \times 10^{-3}$ |
| 2.00 | $19.1 \times 10^{-3}$ |

**FUTURE ANALYSIS:**

In the preceeding analysis it was assumed that a mean thermal conductivity existed. Tests will be run to determine the variability of the thermal conductivity in the three mutually perpendicular directions of the cell.

Tests will be run to verify the presumption of the shifting of the curve of thermal conductivity versus overcharged rate for different ambient conditions.

B. LARGE CELLS VO-20 HS, VO-40 HS & VO-50 HS.

Objective

The primary objective of the analytical analysis was to predict the thermal gradient in a VO-40 HS, and VO-50 HS cell.

Procedure

Using thermal data accumulated for the VO-6 HS and VO-20 HS cells, as well as employing the assumptions that the thermal conductivity of the cells are all the same and the terminal voltages will be equal for

all the cells at the same $\frac{\text{Overcharge Rate}}{\text{Capacity}}$, one will be able to use the equations derived in Report #3 to predict the thermal gradient.

## Analysis of Data

Looking at the tabulation of results (Table III) and the curve of thermal gradient versus $\frac{\text{Overcharge Rate}}{\text{Capacity}}$ (Figure 5) one can see that the rate of increase of the thermal gradient for a VO-50 HS is much greater than that of a VO-40 HS and a VO-20 HS. This can be attributed to the fact that at the same $\frac{\text{Overcharge Rate}}{\text{Capacity}}$ for all the cells, the larger capacity cells will be producing more heat. Since the heat produced by the larger cells must traverse a greater path, the geometry of the larger capacity cells being larger than the smaller capacity cells, it also produces an increase in the thermal gradient.

## Future Analysis

An investigation will be made on the VO-50 HS cells to see how the thermal gradient may possibly be reduced.

## TABULATED RESULTS FOR VO-40 HS

### TABLE III-2

| OVERCHARGE CURRENT (AMPS) | ESTIMATED TERMINAL VOLTAGE | TOTAL HEAT GENERATED (q) BTU/HR | TOTAL HEAT GENERATED PER UNIT VOL. BTU/HR in$^3$ | HEAT TRANS. in x Dir. $\dot{q}_x$ BTU/HR in$^3$ | HEAT TRANS in y DIR. $\dot{q}_y$ BTU/HR in$^3$ | HEAT TRANS in z DIR. $\dot{q}_z$ BTU/HR in$^3$ | $\Delta T$(T int. -T$_{mean\ ski}$ °F |
|---|---|---|---|---|---|---|---|
| 2 | 1.350 | 9.26 | .324 | .250 | .0613 | .0127 | 14.38 |
| 3 | 1.420 | 14.61 | .512 | .391 | .0969 | .0241 | 21.25 |
| 4 | 1.450 | 19.91 | .698 | .539 | .132 | .027 | 31.00 |
| 5 | 1.463 | 25.15 | .881 | .680 | .1665 | .0345 | 39.11 |
| 6 | 1.465 | 30.15 | 1.055 | .814 | .1995 | .0415 | 46.82 |
| 7 | 1.470 | 35.32 | 1.237 | .955 | .234 | .048 | 54.45 |

## TABULATED RESULTS FOR VO-50 HS

TABLE III.

| OVERCHARGE CURRENT (AMPS) | ESTIMATED TERMINAL VOLTAGE | TOTAL HEAT GENERATED (q) BTU/HR | TOTAL HEAT GENERATED PER UNIT VOL. ($\dot{q}$) BTU/HR in$^3$ | HEAT TRANS. in x DIR. $\dot{q}_x$ BTU/HR in$^3$ | HEAT TRANS. in y DIR $\dot{q}_y$ BTU/HR in$^3$ | HEAT TRANS in z DIR $\dot{q}_z$ BTU/HR in$^3$ | $\Delta T$(T internal - T skin mean) $^oF$ |
|---|---|---|---|---|---|---|---|
| 2.0 | 1.310 | 8.96 | .245 | .1785 | .0571 | .0094 | 13.52 |
| 3.0 | 1.385 | 14.19 | .388 | .283 | .0904 | .0146 | 21.40 |
| 4.0 | 1.428 | 19.51 | .533 | .389 | .1241 | .0199 | 29.00 |
| 5.0 | 1.450 | 24.75 | .676 | .493 | .1575 | .0255 | 37.35 |
| 6.0 | 1.458 | 29.90 | .817 | .596 | .1904 | .0306 | 45.15 |
| 7.0 | 1.460 | 34.91 | .954 | .695 | .222 | .037 | 52.60 |
| 8.0 | 1.465 | 40.00 | 1.093 | .797 | .254 | .042 | 60.40 |

## TABULATED RESULTS FOR A VO-20 HS

### TABLE III-3

| OVERCHARGE CURRENT (AMPS) | ESTIMATED TERMINAL VOLTAGE | TOTAL HEAT GENERATED (q) BTU/HR | TOTAL HEAT GENERATED PER UNIT VOL. ($\dot{q}$) BTU/HR in$^3$ | HEAT TRANS in x DIR ($\dot{q}_x$) BTU/HR in$^3$ | HEAT TRANS in y DIRECT ($\dot{q}_y$) BTU/HR in$^3$ | HEAT TRANS in z DIR ($\dot{q}_z$) BTU/HR in$^3$ | $\Delta T$ (T int. -T mean skin) °F |
|---|---|---|---|---|---|---|---|
| 1 | 1.35 | 4.63 | .238 | .209 | .0233 | .006 | 5.62 |
| 2 | 1.45 | 9.94 | .510 | .449 | .050 | .011 | 12.1 |
| 3 | 1.465 | 15.1 | .774 | .681 | .0759 | .0171 | 18.35 |
| 4 | 1.47 | 20.2 | 1.035 | .912 | .1015 | .0165 | 24.6 |

## IV. DESIGN OF A 50 AH HERMETICALLY SEALED NICKEL-CADMIUM CELL

### A. DETERMINING FACTORS IN CELL DESIGN

As noted in the section on thermal analysis, there are certain restrictions on the configuration to obtain good transfer of heat from within the cell. Ideally, a cell would consist of three plates so that heat might be rejected through a minimum thickness of cell to the largest possible rejecting area. Obviously, this is not practical, as it would impose an extreme weight penalty due to the larger case area involved, and the structure required to retain the larger face against internal pressures. A compromise is then proposed which will give a reasonable weight and ratio of positive to negative active material which will provide reasonable internal pressures.

Other areas of particular interest are the head space required for terminals and plate connection to the terminals, and the terminal configuration itself. These will effect the weight the resistance of the cell, and the reliability of the seal.

### B. CELL DESIGN FOR 50 AH CAPACITY

The plates we have presently selected for this design have an active area of 105 cm.$^2$. An electrode stack using 39 of these plates would have a calculated capacity of 55.4 Ampere hours. This calculated capacity will provide for the necessary tolerance to obtain 50 AH in a practical cell.

The proposed design would have the negative element of the electrode grounded to the cell case. This is done for two reasons; first, the grounded negative may be in intimate contact with the case so that heat may be better removed through the case and the negative terminal; and second, placing the case at the same potential as the negative element will cathodically protect the case from corrosive elements within, and will thus in-

hibit stress corrosion of the case.

Using a 22 gauge (.0312") stainless steel case, the estimated dimensions of the 50 AH cell would be 1.7" thick, 3.0 wide, and at this time 7.4 high over the case. The height of the cell is being studied with respect to reducing the head-space within the cell required for the terminals and the plate tabs.

Since the cover of this cell is quite wide, and since the terminals would be required to carry larger currents, a method of inserting a sealed, composit, terminal by means of a welded joint is being studied. This will permit the use of existing equipment for generating the ceramic-to-metal seal by keeping the sizes of the parts placed in the furnace within reason.

It is expected that the use of terminals designed for solder connection of intercell connectors will be continued. The design will be altered to provide for a more positive assembly of the intercell connector with the terminal. The use of these terminals requires skill and care in making the solder joints, but it is a better electrical joint than a threaded terminal could provide. It is also probably less subject to damage since the type of joint would tend to discourage the unskilled technician who might be tempted to tamper with a threaded fitting. The value of a cell of this nature, and the reliability requirements of its application is such that only qualified personnel should be permitted to install and operate it.

In the next reporting period we expect to resolve all the terminal problems so that the cell may be completely specified and the fabrication of prototypes begun. The first prototypes of this cell will be made in cases fabricated by welding members together. They will incorporate all the developments attained on this type of case to date.

The concept of the composite terminal will be introduced on this cell to reduce the size of the terminal stud and consequently the size of

the ceramic insulator. Since larger ceramic diameters require greater lengths of ceramic-to-metal seal which must be made under adverse geometric conditions, the use of additional welded joints is justified in obtaining a reduction of diameter.

The composit terminal is basically a terminal having a material which is resistant to potassium hydroxide exposed to the inside of the cell while the fully covered current carrying internal stud could be a good conductor of electrical currents and need not be resistant to the electrolyte.

# V. CONCLUSIONS

## 1. FABRICATION OF VO-6HS CELLS

The production and appearance of the cell package has been much improved. Dies for deep drawn cases and covers are being fabricated so that the first cells in these cases may be expected within the next reporting period.

## 2. THERMAL ANALYSIS

A new thermal conductivity for the VO-6 HS cell has been experimentally determined and is noted in the tabulated results of section III-A of this report. The data obtained, combined with available data from the VO-20 HS cell, makes it possible to predict characteristics of other size cells as is done in section III-B of this report.

## 3. DESIGN OF A 50 AMPERE-HOUR HERMETICALLY SEALED NICKEL-CADMIUM CELL

In order to maintain reasonable cell weights, a cell having a total thickness of 1.158 inches is proposed. This is rather a thick cell and may require modification in order to provide a cell that is self supporting on its edges. Further analysis of thermal characteristics and weights will be necessary before this design is finalized.

## VI. PROGRAM FOR NEXT PERIOD

With the program extended for another year, a continuation of our research efforts will result in the following program for the next period.

Item I. Continue to design and initiate the construction of 10 AH cells.

Item II. Perform studies on the thermal properties of battery packages where it is necessary to remove heat from the outside of the cells to the heat sink.

Item III. Initiate studies on techniques to reduce self discharge of cells.

Item IV. Consider methods whereby the pressure in multi cell battery package can be monitored.

The overall program for the coming year, in addition to the above four items, includes further studies on:

1. Thin plate batteries
2. Charge, discharge and overcharge data at minus 10°F up to 160°F.

# SPECIFICATION

FOR THE WELDING AND FABRICATION OF CELL CASES
FOR HERMETICALLY SEALED CELLS.

A. GENERAL

The nature of this product is such that the quality of the case must be the absolute best obtainable. Cells fabricated from these cases may be expected to play an important part in the space and defense programs of our country.

B. DIMENSIONS

The dimensions and tolerances of the drawing shall take precedence over any other specification. The mission of cells fabricated with these cases requires close adherance to the drawing. Tolerances shown are not being made tight without good ahd sufficient reason for being tight.

All sides shall be parallel to opposite sides and perpendicular to adjacent sides within .010 T.I.R. All sides shall be smooth, free of dents, nicks and scratches.

There is a tendency in a structure of this nature to obtain a deflection of the sides often referred to as "oil canning" or "diaphragming". This condition must be eliminated to maintain a structure within the limits of the drawing. By using proper forms and chills when welding, this condition can and must be eliminated.

C. WELDING

a. All welds must constitute a hermetic joint capable of passing a leak detection test on a mass spectrometer helium leak detector of less than $10^{-9}$cc/sec. helium leakage under an absolute pressure of 5 psi. across the joint.

b. Welds must be made in one pass of the torch per side; being free of folds, surface cracks, porosity, and oxidized metal. Any of the above reasons shall be sufficient to reject a part regardless of the tightness of the joint.

c. The maximum variation in the welded surface may not exceed .015 inch. This means that from the highest peak to the deepest crater, the vertical distance may not exceed .015 TIR. See Figure 1.

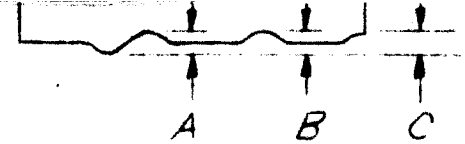
FIGURE 1

| APPLICATION | QTY. REQD. | NEXT ASSY. | USED ON | Next Assy. | Final Assy. |
|---|---|---|---|---|---|
| | | | | | |

FINISH

MATERIAL

UNLESS OTHERWISE SPECIFIED
Dimensions are in Inches.
Tolerances on:
Fractions ±1/64" Decimals .xx ±.010 .xxx ±.005 Angles ±0° 30'



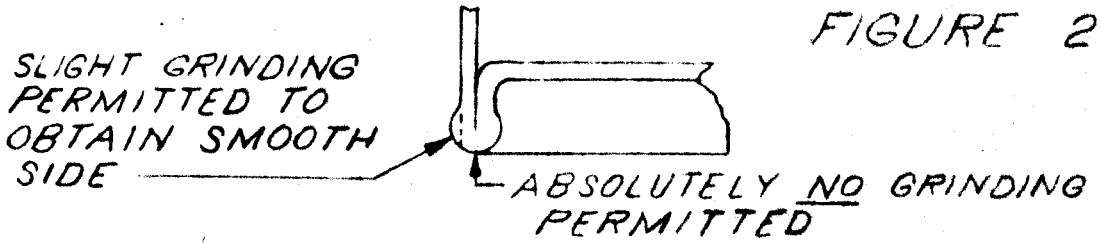

A, B AND C ≦ .015

d. All welds must be capable of withstanding an internal can pressure of 300 psig.

e. The can must present a smooth rectangular appearance. Any excessive flow of material at the sides of a weld must be ground off but the joint itself may not be ground. Figure 2 shows the cross section of a weld between a case bottom and the case sides. This figure indicates where grinding is permitted and where it is forbidden.

5714

FIGURE 2




f. No filler rod is to be permitted in the welds on these cases.

g. All welds must be certified as having been performed by a welder who has been certified under MIL-T-5021A.

h. All welding discoloration shall be removed from outside of case. Outside shall be polished with a felt wheel to produce a satin finish (Sanitary Grade).

REVISIONS

| CHG. No. | SYM. | DESCRIPTION | DATE | APPROVED |
|---|---|---|---|---|

FIGURE 1

| SIGNATURES | | DATE |
|---|---|---|
| DR. | J.P.B. | 11/1/62 |
| DSGN | | |
| CHKD. | | |
| PROJECT ENGINEER | K.J.D. | 11/1/62 |
| APPD. | | |

| ITEM | REQ'D | PART NO | DESCRIPTION | MATERIAL | MATERIAL SPECIAL |
|---|---|---|---|---|---|

LIST OF MATERIAL

SPECIFICATION
WELDED CELL CASE
QUALITY AND FINISH

GULTON INDUSTRIES, Inc.
METUCHEN
NEW JERSEY

SCALE [redacted] DWG SIZE E

DRAWING NO. 5714

AB 3000-5

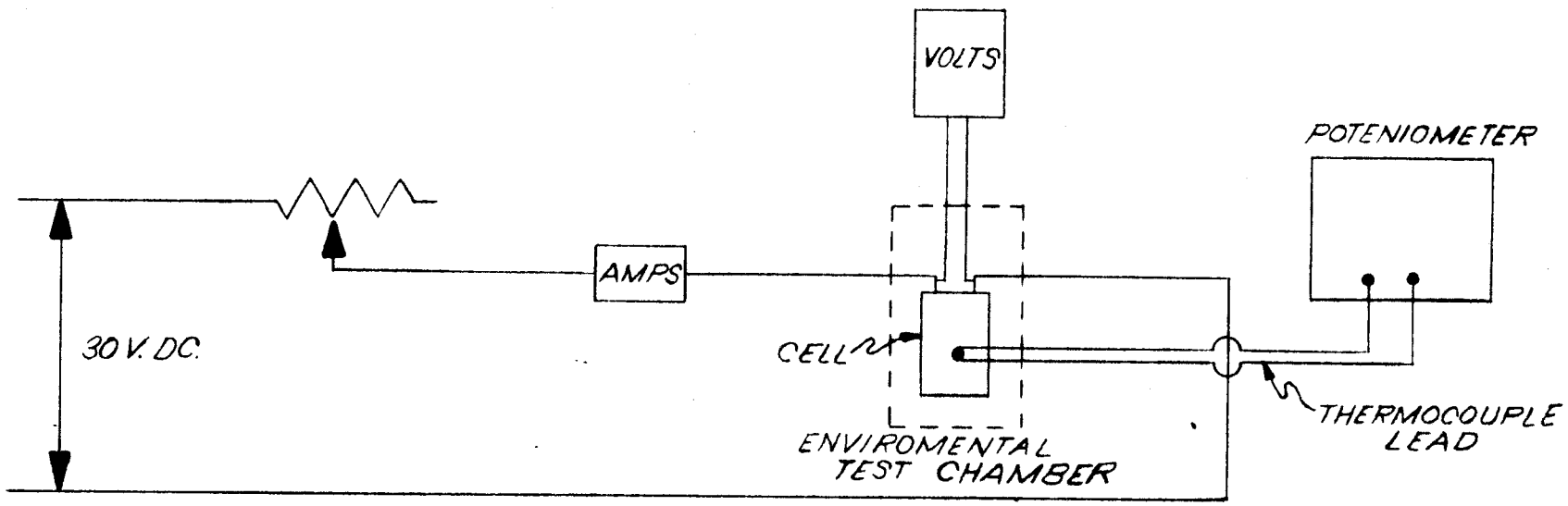
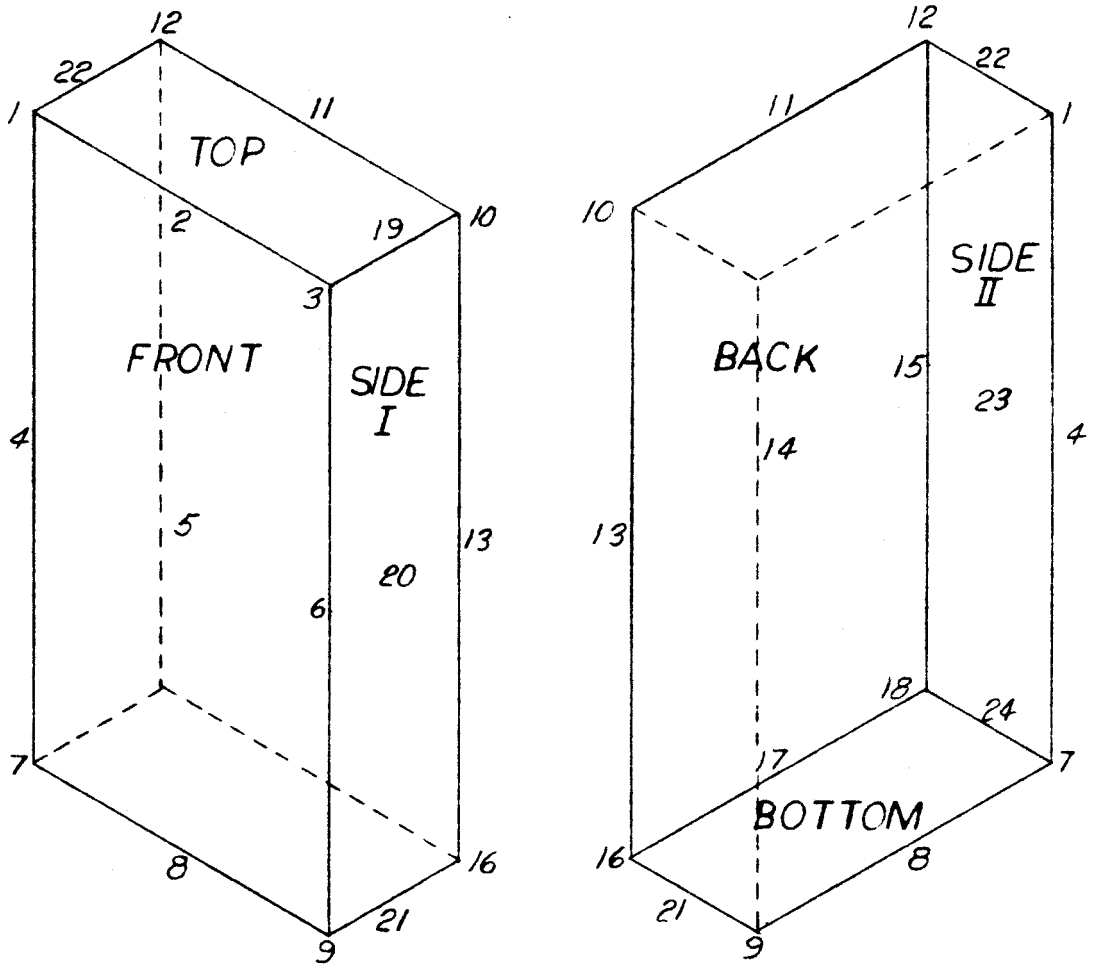



FIGURE 2
TEMPERATURE SURVEY
APPARATUS

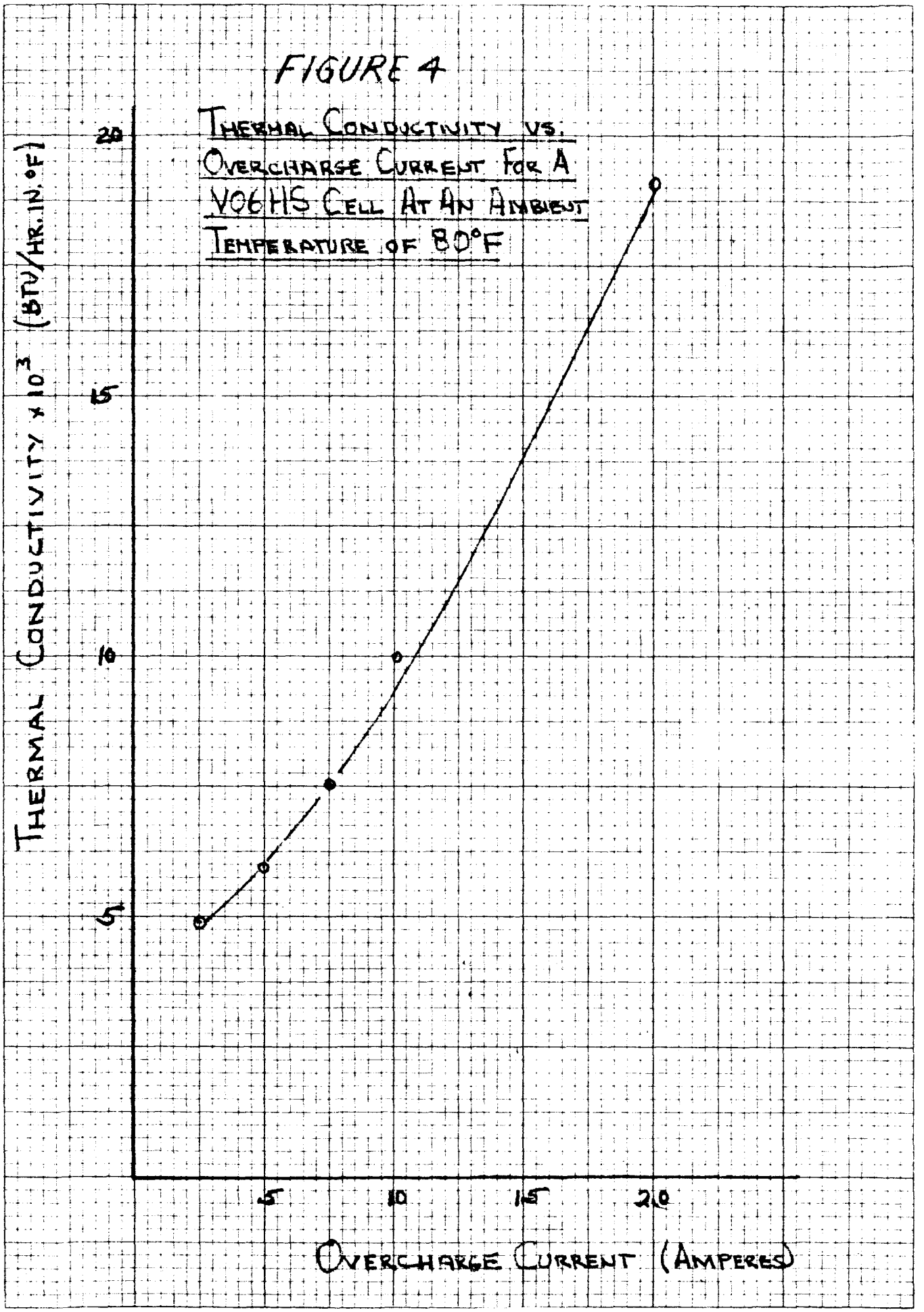
M0686
AB 3000-5

# FIGURE 3
## VO-6HS CELL




TEMPERATURE MEASUREMENT POINTS

M0685

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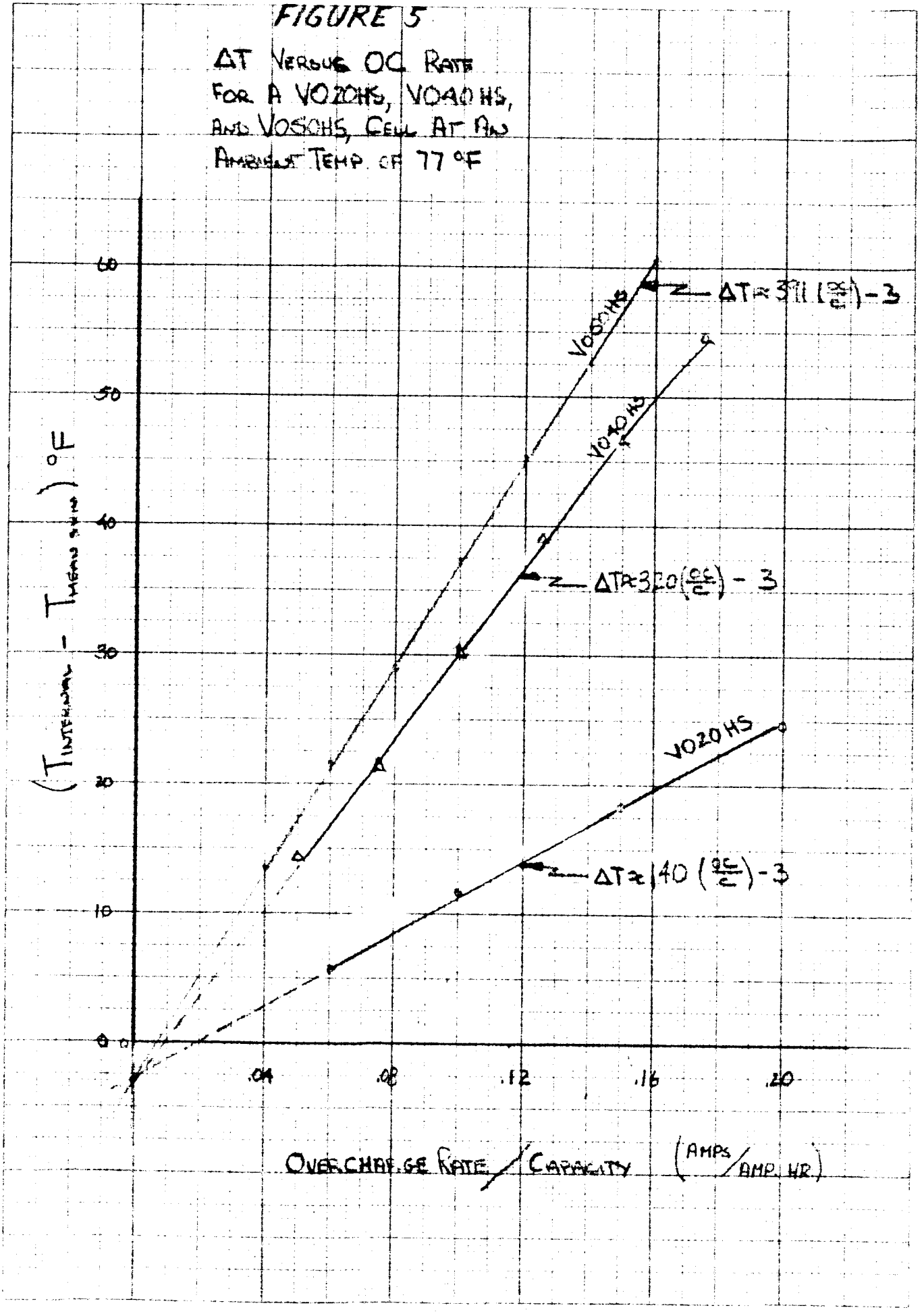
MADE IN U. S. A.
NO. 340-10 DIETZGEN GRAPH PAPER
10 x 10 PER INCH

M0742
AB 3000-5




M0694
AB 3000-5