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NICKEL/CADMIUM AIRCRAFT BATTERIES:
FLOAT CHARGE TEST

by

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ABSTRACT

Manufacturers have been unable to supply nickel/cadmium aircraft batteries which could pass the float charge test specified in the Canadian Forces Specification CF-B-70. Battery behaviour under the conditions of the test has therefore been investigated.

The batteries tested started into thermal runaway because oxygen generated at the nickel plate reached the cadmium plate and reacted exothermally with it.

Recommendations are made for battery improvement, with respect to type of separator material and how it should be wrapped around the plates. Suggestions for modification of the float charge test are also made, so that it can be more useful in identifying those batteries which are best able to withstand floating at high temperatures. Suggestions for improved screening of defective cells and for limiting the overcharge on board the aircraft are made.

RÉSUMÉ

Jusqu'à maintenant, aucun fabricant n'a pu fournir de batteries au nickel/cadmium qui puissent répondre aux exigences du test de charge de batteries en floating, tel que précisé dans la spécification CF-B-70 des Forces armées canadiennes. Afin de bien situer la cause du problème, nous avons étudié au laboratoire, en milieu contrôlé, le comportement de batteries que l'on utilise dans les avions à réaction.

Durant le test de charge de batteries en floating, la température s'élève, surtout quand l'oxygène dégagé par la plaque positive (de nickel) traverse le séparateur et atteint la plaque négative. Il se produit alors une réaction exothermique avec le cadmium, résultant en un danger d'emballement thermique.

Nous proposons dans notre rapport: (a) des changements pratiques que les Forces canadiennes pourraient mettre en vigueur lorsqu'ils utilisent les batteries; (b) des modifications à l'intérieur de la batterie-même que le fabricant pourrait effectuer, surtout en ce qui concerne le matériel qu'il utilise pour le séparateur et les moyens de l'incorporer autour de la plaque; et (c) une façon de rendre plus efficace le test de charge de batteries en floating, en précisant la condition matérielle du séparateur.

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INTRODUCTION

Various aircraft in the Canadian Forces use nickel/cadmium batteries as a source of standby power. They supply electrical power for ground inspection, standby power in the event of generator failure, and to an increasing extent for turbine engine starting.

A specification, CF-B-70, was drafted by CAMESA for use in the procurement of such batteries for the Canadian Forces (1,2). One of the tests in the specification, the float charge test, is intended to ensure that the batteries will be able to safely withstand the prolonged constant potential overcharge at the high temperatures sometimes met in aircraft compartments (3).

The pertinent portion of CF-B-70 is as follows:

4.4.2.16 Float Charge Test - A fully charged battery, with cover secured in place, and the electrolyte at the correct level shall be placed in a temperature stabilized oven at $49^{\circ}\text{C} \pm 2^{\circ}\text{C}$. With the ambient maintained at $49^{\circ}\text{C} \pm 2^{\circ}\text{C}$ and with no air flow directed on or around the battery, the battery shall be placed on charge at 28.5 ± 0.5 volts for 50 hours. During this period no water shall be added to the battery. At the end of the 50 hour period the battery shall be discharged at 25°C 1-hour rate.

4.4.2.16.1 Requirement - The battery shall not spray or lose electrolyte. (A reduction in the electrolyte level may occur due to electrolysis and the evaporation of water). The battery intercell connector temperature shall not exceed 71°C , and the charging current after the first two hours shall not exceed 4 amps. The battery capacity shall not be less than 90% of the 1-hour 25°C capacity value specified on the applicable Detail Specification Sheet.

Batteries from several manufacturers were subjected to the CF-B-70 tests for CAMESA by Ogden Technology Laboratories Inc. (4) and generally failed to pass the float charge test. Failure was due to thermal runaway starting prior to elapse of the specified charge period. A study was therefore carried out at DREO to investigate battery behaviour under the conditions of the test with a view to evaluating the test and to gaining a better understanding of the battery performance under such conditions (5).

PROCEDURE

The procedure in this investigation, in general, was to perform float charge tests under conditions similar to those outlined in CF-B-70 and to monitor the behaviour of the batteries. Auxiliary experiments were performed as needed.

The batteries used were selected from those previously involved in the qualification tests at the Ogden Technology Laboratories. With one exception, the selected batteries had been subjected to tests other than the float charge test. The exception was the only battery which was reported to have passed the float charge test in the Ogden tests. (However there are unexplained variations in the associated data). This battery was retested in this study and failed.

EQUIPMENT

An oven was modified as required by CF-B-70 to prevent the forced air circulation from directly affecting the battery temperature. Two asbestos pads under the edges of the battery prevented direct contact of the latter with the metal parts of the oven. Leads for current, for temperature measurement (thermistors) and for individual cell voltages were brought out through a hole cut in the battery lid and through a port in the oven. Scanning equipment was designed and built to record monitored parameters on chart recorders. Limit switches automatically opened the charge circuit if either the battery temperature or the charge current exceeded preset limits.

After the first few tests it was recognized that more precise charging voltage regulation and measurement than specified in CF-B-70 were required and suitable improvements were made. Also the importance of making resistance measurements during the course of the test became evident. Provisions for doing so were therefore added.

A more detailed description of the above equipment was given in an earlier report (6).

BATTERY PREPARATION

Since the batteries had been in storage for a lengthy period they were reconditioned before initiating the float charge tests. Standard procedures (7) were followed using constant current charges and discharges at the five-hour rate. After each discharge one-ohm resistors were connected across each cell until the next charge period one or more days later. Cells that differed significantly from the rest in the battery were replaced with others from the same manufacturer.

Tests were carried out using electrolyte of normal concentration and purity (8) as well as with variations for special purposes. Samples were analysed before and after each test to determine what changes in KOH and K_2CO_3 concentration had taken place. Also battery capacity measurements were made at the one-hour rate at room temperature before and after each float charge.

TEST PROCEDURE

The battery, fully charged and at room temperature, was placed in the oven and all electrical connections were attached. Probes were positioned to monitor oven temperature and the temperature of a central intercell connector. The chamber was then closed and rapidly (about 5 minutes) heated to about 49°C. It was then left at that temperature under automatic control. The battery temperature limit switch was normally set to trip at about 72°C. Equipment limitations did not permit the immediate application of the full charging voltage. A lower value was therefore applied for the first few minutes and this was increased to 28.0 volts (the minimum specified) as the initial surge of current dropped. The current limit switch was then set to interrupt the charge if the current exceeded about 5 amperes. The test could then proceed automatically.

When the preset limit on either battery temperature or charge current was exceeded the charge circuit was opened but the oven continued to operate at 49°C and all monitored quantities continued to be recorded until manual

termination. During this period the battery cooled toward the oven temperature. After several hours the battery was removed from the chamber and cooled to room temperature. It was then discharged and the retained capacity was measured. Subsequently it was recharged so electrolyte samples could be taken for analysis.

TEST RESULTS

Float charge tests were carried out on a total of 9 batteries manufactured by four different manufacturers. Some of these were tested more than once. See Table I for details on test duration and electrolyte condition.

All of these tests resulted in early termination due to onset of thermal runaway conditions. In all cases both current and battery temperature, at termination, were rising very rapidly and both parameters would have exceeded the preset limits within a few minutes of each other (See Fig.1). Instead of the specified 50 hour test duration, these batteries endured the test for periods ranging only from 2.7 hours to 29.5 hours.

In general, all cells in each battery participated in the above failure mode. There was no evidence, for example, of a single cell heating up drastically and causing adjacent cells to heat up subsequently by thermal conduction. Had such a process taken place it would have become evident by an anomalous drop in voltage of the cell in question.

Except for the occasional cell (less than 3% of the cells involved) which developed faults leading to self discharge during the cooling off period, the batteries all passed the subsequent capacity check specified (i.e. 90% of nominal capacity). Also in subsequent cycling there were no indications, in general, of significant capacity changes resulting from the float charge test.

Electrolyte level fell during the test, the amount of course being largely dependent on the amount of gas generated. In some cells the final level was too low to permit samples for analysis to be readily obtained. Also it was frequently found that carbonate concentration in the electrolyte increased significantly during the test.

Measurements indicated that no significant changes in cell resistance take place during the course of float charge test. Details on battery resistance measurements are given in Appendix I.

The significant observations mentioned above are discussed in greater detail in the ensuing sections of this report.

TABLE IFloat Charge Test Results

Battery	Duration in hours			Initial Electrolyte Concentration	
	Test 1	Test 2	Test 3	KOH	K ₂ CO ₃
A-1	2.7			30%	4%
A-1		9.3		22	9
A-2	4.3			30	4
B-1	8.7			34	1
B-2	25.6			23	7
B-3	9.3			24	6
B-3		13.1		30	4
C-1	3.6			22	1
C-2	29.5			20	12
C-2		13.1		30	4
C-2			14.5	20	12
D-1	5.0			31	7
D-2	12.4			34	7

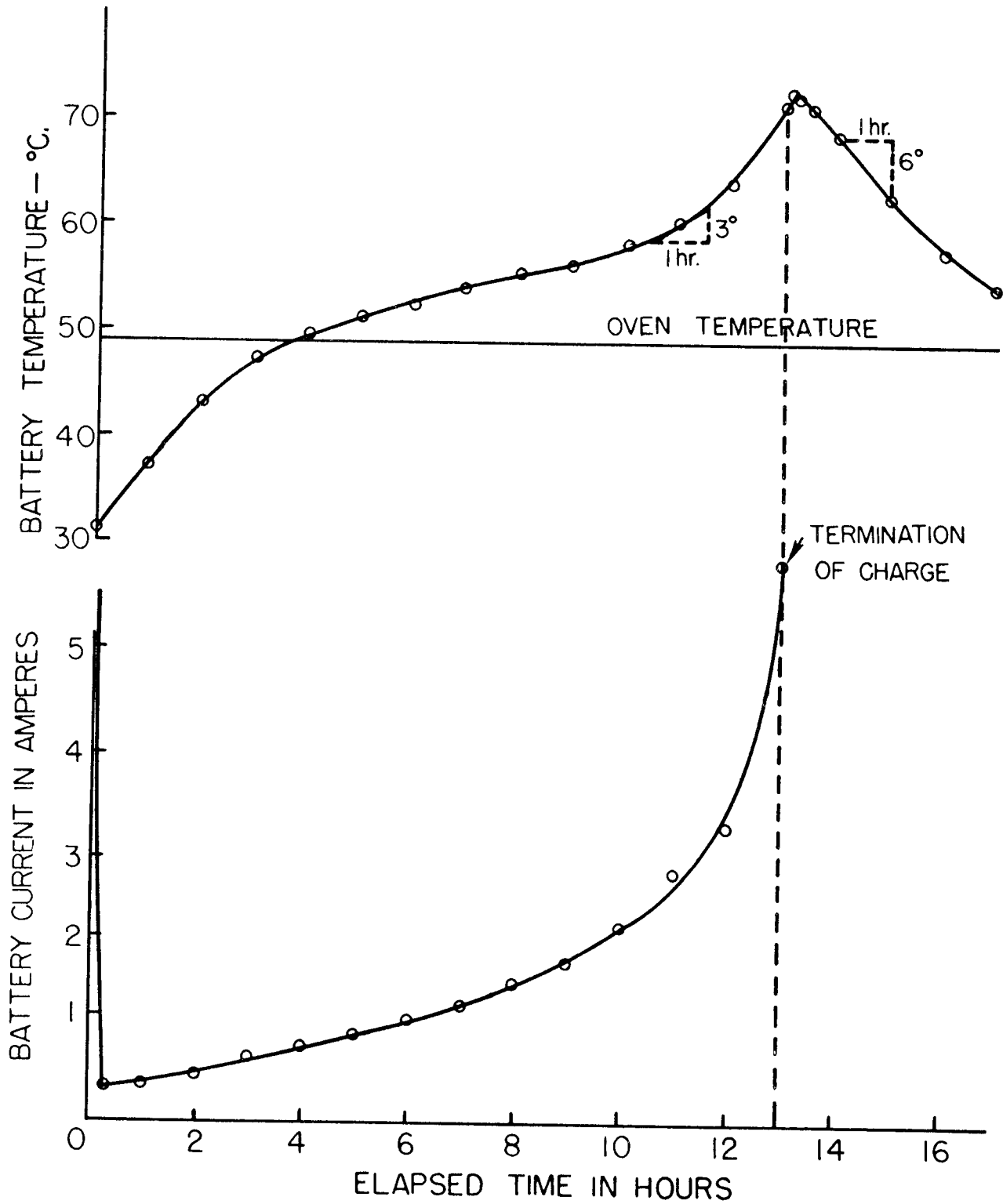


Fig. 1. Battery Current and Temperature behavior during a typical float charge test.

DISCUSSION

All the batteries in the above tests failed by overheating. Batteries in the field also, apparently, fail by overheating. In some cases this may be due to a short circuit in one cell. In other cases, however, it seems likely that the process is similar to that observed in the above tests. The importance of the problem therefore extends beyond the details of the test specification.

It is convenient to consider the observations in the present study under two headings: Thermal Aspects, and Electrical Aspects. (A preliminary reporting of these considerations was given in Ref. 9).

THERMAL ASPECTS

In each float charge test in this study, the battery was initially at room temperature. The chamber temperature after a few minutes reaches and remains at approximately 49°C. Auxiliary experiments showed that on open circuit the battery required about 7 hours to reach the oven temperature. On float charge this period was 5 hours or less. After reaching 49°C the battery temperature continues to rise above the oven temperature. Obviously significant heat is being generated within the battery.

Once the battery temperature exceeds the oven temperature, some of the heat generated is lost to the oven. The rest raises the battery temperature still further. For any given battery it is assumed that the rate of heat loss is proportional to the difference in temperature between the battery and the oven, and that this rate shortly before termination of charge is identical to that shortly after termination. The cooling rate after termination was observed and the rate over the temperature range of interest was plotted. (See Fig. 2) The observed rate of increase in battery

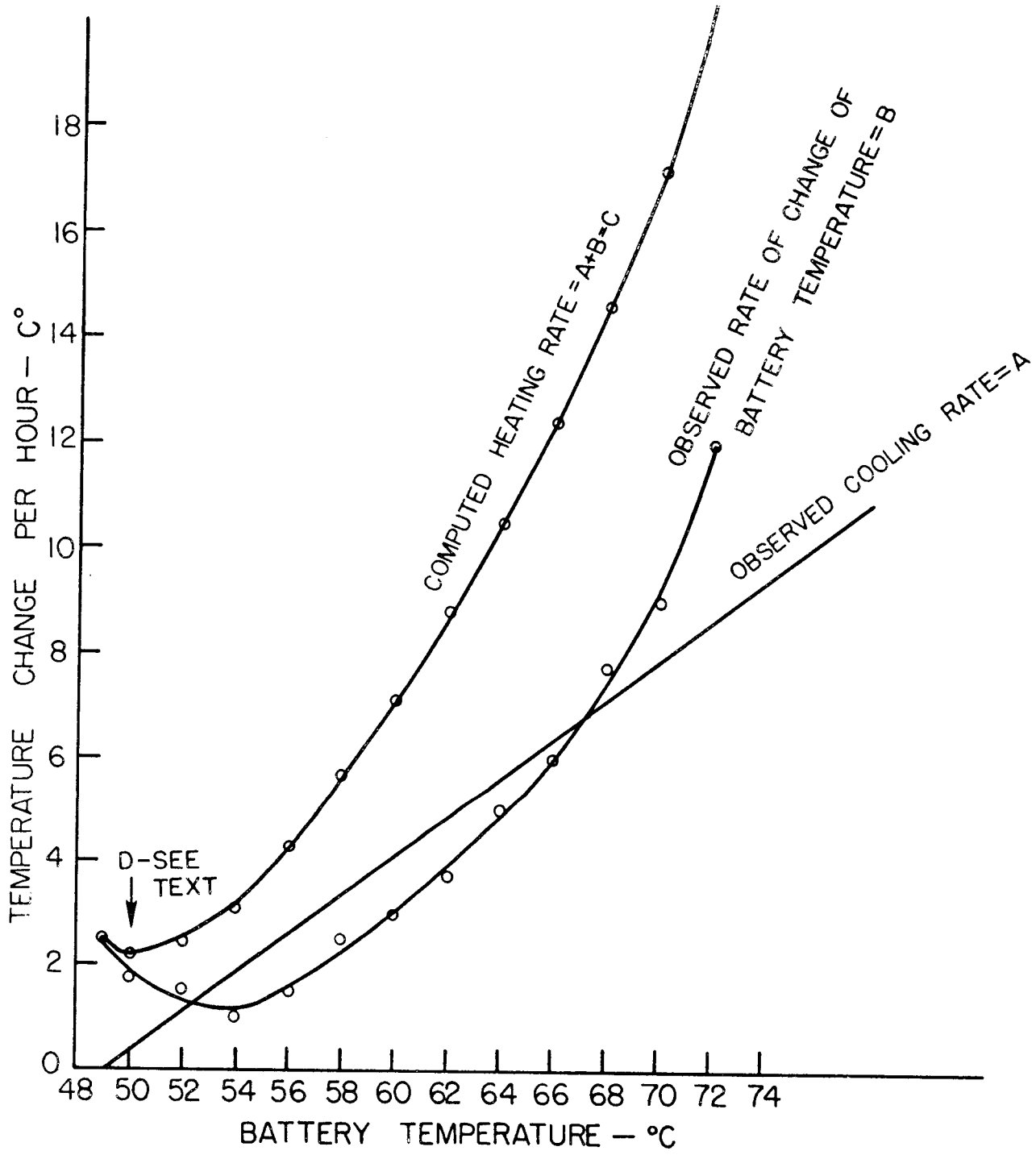


Fig. 2. Analysis of battery heating during a float charge test.

temperature was also plotted. The sum of these two curves indicates the total rate of heat generation. For convenience, these rates are plotted in terms of battery temperature change per hour.*

The plot of the computed rate of heating versus charging current during the test (See Fig. 3) indicates a linear relationship between these two parameters. This is not, of course, what would be expected if the heat generation was due entirely to direct electrical heating. For comparison, an I^2R plot is shown as the dashed curve in Fig. 3, arbitrarily matched at point M.

It may be noted that the heating rate due to the resistive portion of the battery is very small compared to the rates found. Measurements indicated the thermal capacity of a cell in the batteries to be approximately 600 joules per C° and the resistance approximately 0.002 ohms. Thus even at the worst point where current had reached 5 amperes it would take

$$\frac{600 \text{ j.}}{(5A) (5A) (0.002\Omega) (3600 \text{ sec.})} = 3.3 \text{ hours}$$

to raise the temperature by $1C^\circ$ (See Fig. 3). In actual fact the heating rate was some 50 times higher.

If the battery is fully charged, the passage of current through it requires the generation of oxygen at the nickel plate and hydrogen at the cadmium plate. This reaction, also, cannot produce the quantities of heat observed (10).

The above observations indicate that considerable heat is generated in the battery but that the main heat generating mechanism is neither the direct effect of the current flow nor the primary electrochemical process taking place during overcharge.

ELECTRICAL ASPECTS

When the charging voltage V is applied to the terminals of the battery,

* It may be noted that in the example shown in Fig. 2 an anomaly occurs at the point labelled "D". The curves at this point seem to imply that the heating rate dropped for a short time after the battery reached chamber temperature. This obviously false indication is presumably due to the following factors: (a) chamber temperature in reality did not remain fixed at $49^\circ C$ but oscillated about this value as the heater cycled off and on and (b) the battery temperature was measured (as per specification CF-B-70) on a battery link, which probably lags the temperature in other parts of the battery.

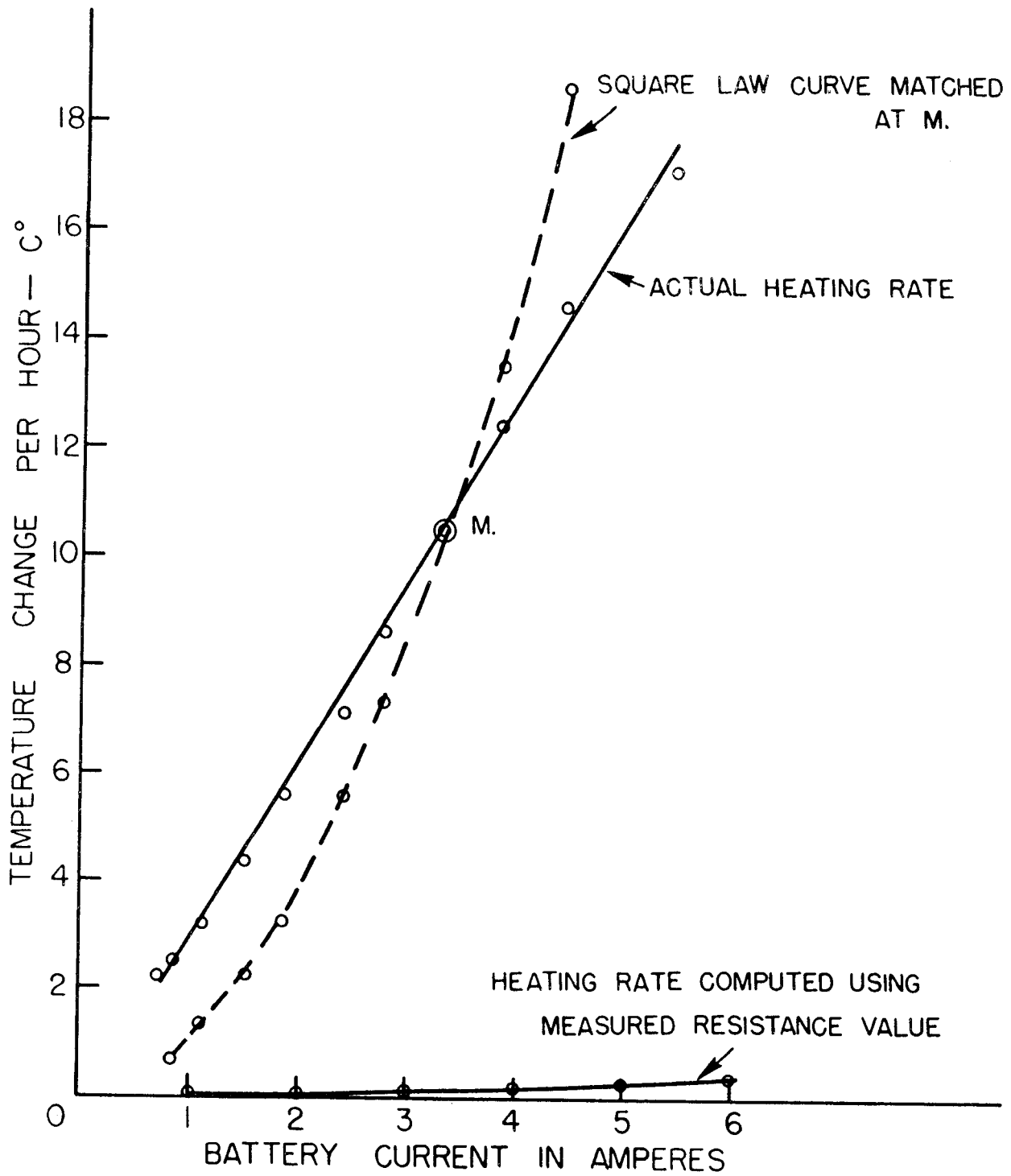


Fig. 3. Heating-Current Relationships.

charge current I flows through the battery as given by

$$I = (V - E)/r$$

where E is the back electromotive force of the battery and r is ohmic resistance of the battery.

The resistance is the resultant of various components in the current path. These may be divided into two categories, one composed of items in the metallic path (links, terminals, current collectors, active plate materials etc.), the other the electrolyte and electrolyte-soaked separator materials. The resistance of the metallic part of the path would be expected to exhibit the normal characteristics of most metals, that is, a positive temperature coefficient of resistance and no change dependent on current flow. The electrolyte portion, on the other hand, has a negative temperature coefficient of resistance and probably its resistance drops slightly as current increases (11). Because the changes in resistance in the two categories above are in opposite directions as the battery heats up, they tend to cancel each other. Thus the observation in the float charge experiments that very little change in resistance takes place should not be surprising (See Appendix I for details on resistance measurement).

Increases in current during float charge tests were of the order of a factor of ten. Obviously the primary cause of the increase cannot be the minor resistance changes that were observed.

The only remaining variable factor in the equation is E. It is of the same order of magnitude as the charging voltage V. For example, when the current in a test is 0.5 amperes, if one assumes 19 cells with an average resistance of 0.002 ohms and $V = 28.00$ volts, then E must be $28.00 - .5(.002)$ (19) = 27.98 volts. If E drops to 27.80 volts the current rises to 5 amperes. This change in current is representative of what occurred in the float charge tests. The above change in E may be expected to result from the change in temperature of the battery (12). Thus the electrical behaviour of the batteries during the float charge test is explained as the result but not the direct cause of the rise in temperature.

THERMAL RUNAWAY

If oxygen liberated at the nickel plate reaches and reacts with the charged cadmium plate, cadmium is converted to CdO and then to $Cd(OH)_2$. The latter is, of course, the discharged state of the negative plate material. Thus both the oxygen and the cadmium have reverted to their previous states

with no electrical output to the exterior. The energy of the charging current which produced the products before they reverted appears in the cell as heat.

In a float charge test, if the charge current has reached 5 amperes and 40% of the oxygen generated reacts with the cadmium, the heat produced raises the battery temperature at a rate of

$$\frac{(40\% \times 5A \times 28V \times 60 \text{ sec.})}{600 \text{ j} \times 19 \text{ cells}} = 0.3C^{\circ} \text{ per minute.}$$

This is consistent with the magnitudes observed. Auxiliary experiments were performed (see below) which gave confirming evidence that the above process did in fact occur.

Thus thermal runaway seems to result as follows. Overcharge produces oxygen at the nickel plate. Some of this oxygen reaches the charged cadmium causing heat producing reactions which raise the battery temperature. The increase in temperature reduces the back electromotive force which, with the constant charging potential, leads to an increase in charge current. This increases the magnitudes of each of the above steps in turn and gives rise to the runaway process.*

The cells under consideration are constructed with barriers such as cellophane which are intended to prevent oxygen from reaching the cadmium plate. Presumably in the tests of this study the barrier failed to serve this purpose effectively, perhaps as a result of deterioration of the material or of possible paths around the material, or both. A cell from each manufacturer was dismantled subsequent to the above tests to observe details relating to these matters. It was noted that three of the four manufacturers used cellophane. The cellophane was frequently broken, especially where bent around plate edges. Material used by the other one was found to be gas permeable. In all cases the wrapping configuration leaves the bottom edge and one side edge of each plate unwrapped. In two cases the last plate of the pack was cadmium and the outer sides of the pack were not covered by cellophane. In two cases the cell pack was bound vertically with a narrow strip of polyethylene; in one case the pack was bound horizontally; in one case the pack was not bound. No attempt has been made to study the effects, if any, of these factors on oxygen paths through the cells.

* If the thermal runaway process is permitted to proceed sufficiently far, secondary effects will, of course, follow. The electrolyte temperature rises to the boiling point giving increased rates of separator deterioration and excessive pressure. Internal short circuits may develop which further increases the temperature and possibly ignite the oxygen and hydrogen present.

CONFIRMATORY EXPERIMENTS

The following observations support the above interpretation of the thermal runaway process.

(1) A cell, previously subjected to the float charge tests, was fitted with temperature sensors on each terminal and with means for collecting and measuring the volume of gas emitted. It was placed on charge at a constant current of 5 amperes. After the overcharge period started the temperature remained relatively constant as the gas emission rate increased to about 50% of the theoretical maximum for that current.* Fig. 4 shows the behaviour subsequent to that time. The gas emission rate suddenly started dropping rapidly and in about half an hour was near zero. As the gas emission dropped the temperature of the negative terminal started to rise rapidly. The positive terminal temperature lagged behind and rose in a manner that would be expected to result from heating by conduction from the negative plate. (The reason for the relatively sudden drop in gas emission is unknown. It could, for example, be due to a sudden but slight warping of a plate which thus opened up a new path for oxygen flow. However, regardless of the cause of this fortuitous occurrence it served to dramatically illustrate the relationship between the drop in gas emission and rise of cadmium plate temperature).

(2) The volumes of gas emitted from numerous cells during overcharge for extended periods of time have been measured. It was noted that cells which emitted the theoretically expected volume did not heat up significantly. The contrary takes place in cells whose gas emission is low.

* 96485 coulombs passing through a fully charged cell produce one equivalent weight of oxygen and one of hydrogen. Hence, one ampere in one minute at room temperature produces in one cell

$$\frac{295^{\circ}}{273^{\circ}} \times \frac{60 \text{ amp. sec.}}{96485 \text{ amp. sec.}} \times \left(\frac{22.4\ell}{2} + \frac{22.4\ell}{4} \right) = 11.3 \text{ ml of gas.}$$

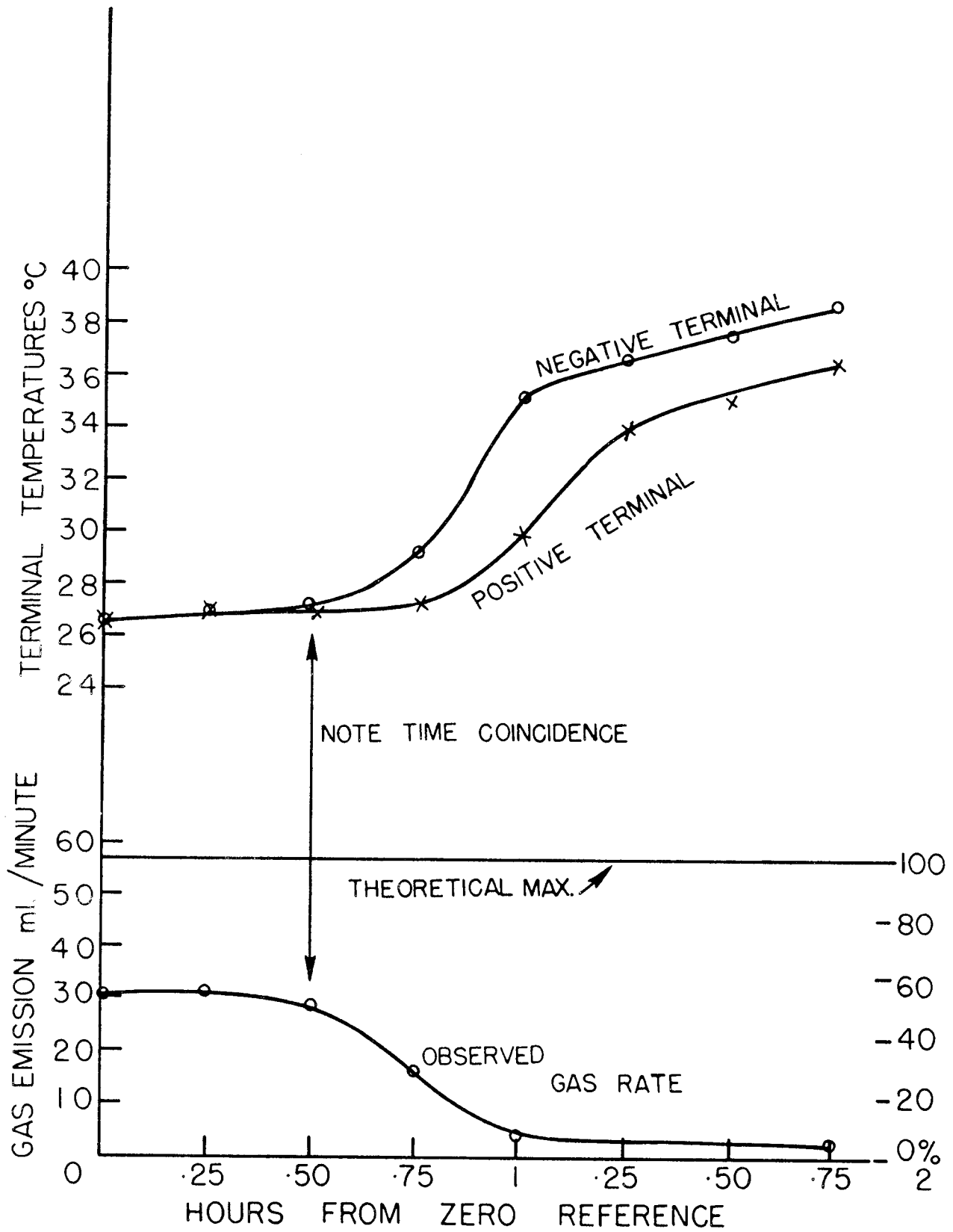


Fig. 4. Correlation of Gas rate with temperature rise.

MISCELLANEOUS OBSERVATIONS

(1) Titrations of the electrolyte before and after each float charge test indicated increases in the percentage concentration of carbonate. In part, of course, this is due to water loss by electrolysis and evaporation. However, as may be noted in Table II, the carbonate concentration increase greatly exceeds the KOH concentration change. Thus an actual increase in carbonate content has taken place. No attempt was made to determine the cause of the increase. However, it may be due to decomposition of separator material at elevated temperatures.

(2) During the early part of this study, attempts were made to assess the effect of carbonate concentration in the electrolyte on performance in the float charge test. However, any such effects were presumably masked by more significant factors and no conclusions were obvious. Since the pursuit of the main objective led in other directions no further work was done in this area.

(3) It was noted that the apparent cooling rates of batteries during the period immediately following overcharge, i.e. while gas bubbles were entrapped in the cells, were approximately one half of the cooling rate for the same batteries at other times. Presumably this is due to either reduced thermal conductivity within the battery, or to continued activity of oxygen at the cadmium plate, or both. It was noted also that the rates of cooling of the various batteries were roughly identical except for those manufactured by Manufacturer A. These cooled more slowly by a factor of nearly two. Similar behaviour may have been noted by others (13, 14).

RECOMMENDATIONS

The results of the above investigation call for recommendations in three separate areas: battery development, battery management and battery testing. Action was previously initiated in some of these (15,16,17,18,19).

TABLE II

Float Charge Test Effects on Electrolyte

Battery	Test	Duration in Hours	% KOH			% K ₂ CO ₃		
			Start	End	Change	Start	End	Change
A-1	1	2.7	30	31	3%	3.7	4.3	16%
A-1	2	9.3	22	23	5	8.6	11.0	28
A-2	1	4.3	30.5	30.5	0	2.4	3.0	25
B-1	1	8.7	34	34	0	.9	1.1	22
B-2	1	25.6	22	23	2	7.1	7.6	9
B-3	1	9.3	23.5	25	6	5.5	6.4	16
B-3	2	13.1	29.5	31	5	2.2	2.5	14
C-1	1	3.6	22	22	0	1.2	1.3	8
C-2	1	29.5	19.5	20	3	12	15	25
C-2	2	13.1	29	30	3	3.5	3.8	9
C-2	3	14.5	19	20	5	12	13	8
D-1	1	5.0	31	30	-3	7.2	8.5	18
D-2	1	12.4	34	33	-3	7.2	7.9	10

BATTERY DEVELOPMENT

If means could be found to prevent all oxygen from reaching the cadmium plates, a major source of thermal problems would be eliminated. Thermal runaway of batteries in service would presumably be nearly entirely eliminated. Furthermore, other improvements might also result. For example, failures due to short circuits resulting from "plating through" openings in barrier materials should be eliminated.

Efforts to prevent oxygen from reaching the cadmium plate should include both the search for more suitable materials and for wrapping techniques which do not permit oxygen to bypass the barrier.

BATTERY MANAGEMENT

The object of battery management in this context is to minimize the danger of thermal runaway on board aircraft with batteries of present design. Two procedures should materially reduce the probability of such occurrences. One of these is the screening of cells in the battery shop to exclude from service those which have deteriorated barriers. The screening can be done by measurement of gas emission during overcharge. The second procedure suggested is to minimize the generation of oxygen in batteries on board aircraft by restricting overcharge. This requires either the blocking of charge current from flowing through the battery after charging is completed, or the use of lower charging voltages.

The extent, if any, to which the above procedures may reduce the incidence of severe internal short circuits on board aircraft is not known. However, it seems logical to expect that screening as suggested above should reduce occurrences of short circuits which result from "plating through" severely damaged separators.

BATTERY TESTING

Hopefully battery improvements will eventually lead to the production of batteries which can readily meet the CF-B-70 requirements for the float charge test. However, until that time it is necessary to procure batteries which cannot do so. Advantages may therefore accrue from a revised version of the test. It should then be possible to better discriminate among available batteries and ensure that at least minimum requirements are met.

A modified float charge test could be designed to simulate a rigorous but realistic operational sequence. Such a sequence could, for example, subject the battery to an ambient temperature profile consisting of a preheat phase as in the battery compartment of an aircraft on the ground in sunshine and in a warm climate, followed by temperatures as experienced during flight. A discharge simulating ground inspection followed by high rate discharges equivalent in heat generation to engine starting routines could take place prior to the in-flight temperature phase. Constant potential recharge under conditions simulating aircraft practice could follow the high rate discharges. If short flights, i.e. those in which there is insufficient time for the battery to cool below its preheat phase temperature, are expected to be followed immediately by second flights, perhaps a simulation of the second sequence should be added to the test. An alternative procedure might be to carry out only a single sequence but to increase the preheat temperature to compensate for the second flight temperature differential.

In designing a modified float charge test it should be remembered that the significant objective is to determine whether or not thermal runaway will occur. However, the following factors should also be taken into account:

- (1) Since small changes in charging voltage can result in significant changes in current, reasonably small tolerances should be maintained on the test charging voltage.
- (2) Battery temperature measurements made on intercell connectors may not give true indications of internal cell temperatures.
- (3) Water loss by electrolysis is approximately 1 ml for every 3Ah of overcharge current. Tests that continue after the electrolyte level has been depressed excessively may lead to secondary effects which could mask the primary purpose of the test. Adequate supply of electrolyte for the intended use and maintenance profile as distinct from the float charge test, is, of course, also a requirement.

(4) The same single charging voltage applied to batteries of different capacities (and hence probably of different internal resistances) may give different current magnitudes so current limits should be specified separately.

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APPENDIX IBATTERY RESISTANCE MEASUREMENT

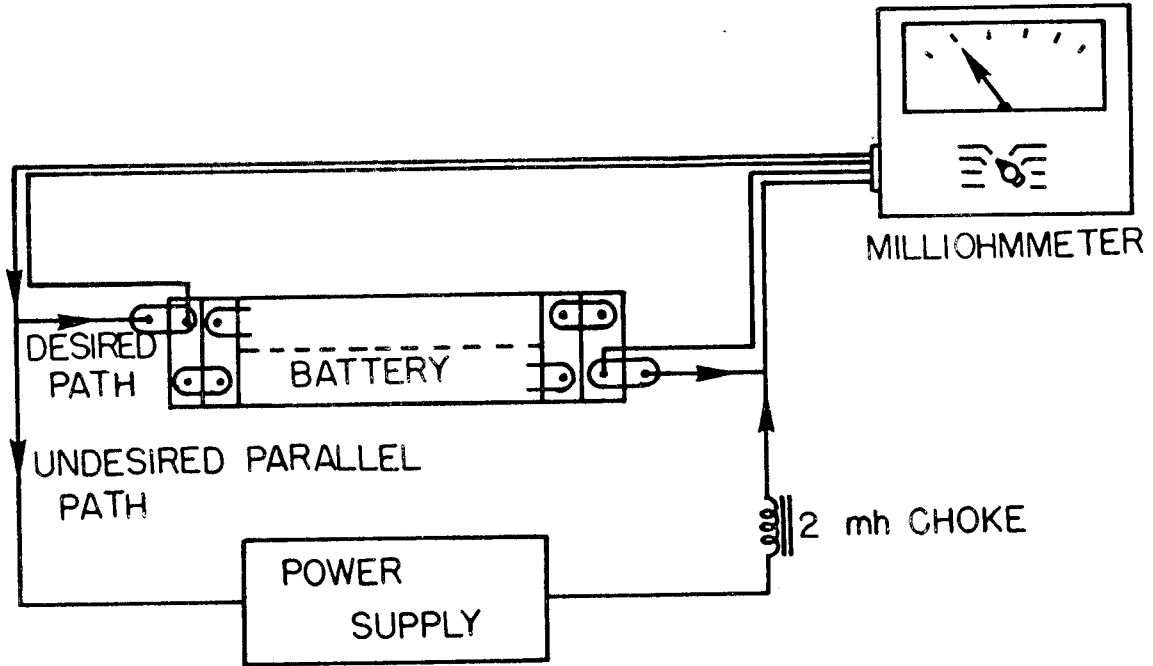
Two problems arise in making battery resistance measurements of the type involved in this investigation. One is connected with the effects of external circuits such as the charging circuit, which from the standpoint of the resistance measuring apparatus, may constitute a low resistance parallel load. The second problem relates to the presence of reactance and electromotive force as well as resistance between the battery terminals. Furthermore, the electromotive force varies with state of charge, current magnitude, temperature etc.

In this study resistance measurements were made with a Hewlett Packard Milliohmmeter (Modifications were made to the input leads to improve reliability of the connectors and to provide suitable terminations for the application). This instrument is an AC coupled device so the electromotive force problem is circumvented. Two leads provide a 1000 hertz constant magnitude test current. Two other high input impedance leads sense the voltage developed by the test signal (care was taken to ensure good electrical connections to the battery and the sense leads were connected to points inside" the signal circuit).

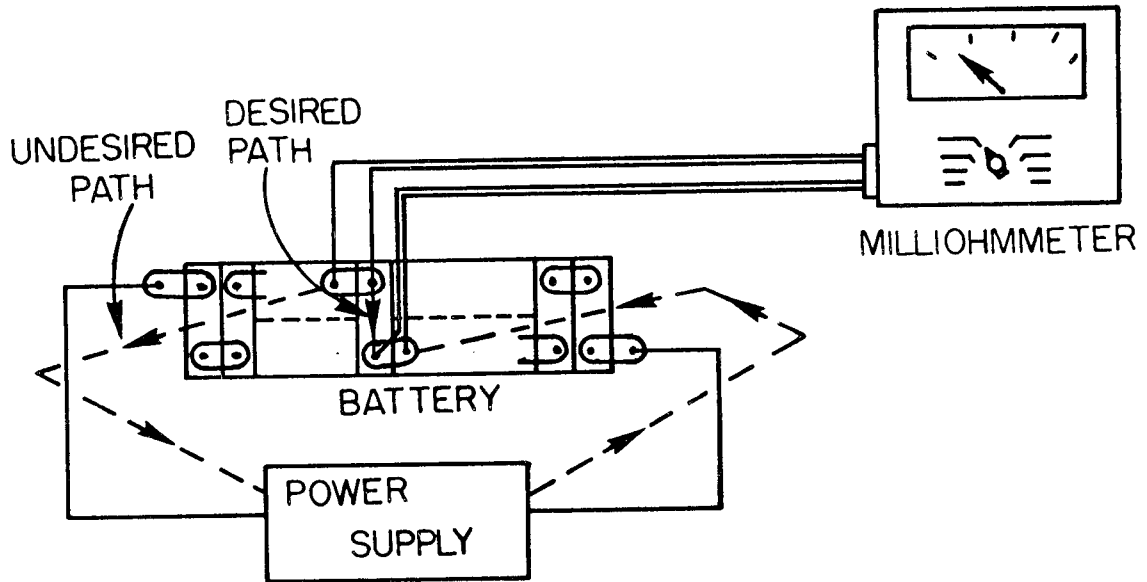
The instrument uses only that portion of the sensed signal which is in phase with the test signal. In this way resistance is measured in the presence of reactance. The accuracy of the device is claimed to be $\pm 2\%$ of full scale provided certain lead lengths are not exceeded. Since conditions during the float charge tests in this study made it necessary to exceed the specified lengths considerably, accuracy was degraded somewhat. However, auxiliary measurements indicated differences of less than 10% between measurements made with the long leads and with the normal ones. Hence it is assumed that the accuracy of measurements during float charge tests must be well within 20%. (It should be noted that errors in resistance measurement of a decimal order of magnitude would be required to cast doubt on the conclusions reached).

The problem of parallel circuits was treated in one of two ways depending on the details of the particular situation. When it was desired to measure the total battery resistance during the course of a float charge test, a 2.5 millihenry choke was placed in series with the power supply. This provides a reactance of over 15 ohms to the 1000 hertz milliohmmeter test signal so, compared to the battery resistance in the neighborhood of 0.04 ohms, the parallel path becomes negligible.

The second situation occurred when the resistance of only a single cell in the battery was monitored. In this case the remaining cells of the battery in series with the power supply constitute the parallel path. See Fig. 5. Since the resistance of the 18 cells in series with the power supply exceeds that of the single cell by more than a factor of 18, in the present context the effect of the parallel path may be ignored.



(a) CHOKE USED TO BLOCK PARALLEL PATH



(b) 18 CELLS IN PARALLEL WITH 1 CELL

Fig. 5. Parallel Paths in Resistance Measurement.

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<p>Manufacturers have been unable to supply nickel/cadmium aircraft batteries which could pass the float charge test specified in the Canadian Forces Specification CF-B-70. Battery behaviour under the conditions of the test has therefore been investigated.</p> <p>The batteries tested started into thermal runaway because oxygen generated at the nickel plate reached the cadmium plate and reacted exothermally with it.</p> <p>Recommendations are made for battery improvement, with respect to type of separator material and how it should be wrapped around the plates. Suggestions for modification of the float charge test are also made, so that it can be more useful in identifying those batteries which are best able to withstand floating at high temperatures. Suggestions for improved screening of defective cells and for limiting the overcharge on board the aircraft are made.</p>		
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KEY WORDS

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 Float Charge Test
 Thermal Runaway
 Separator Failure
 Overcharge
 Gas Emission Rate
 Battery Resistance

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