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TEST AND EVALUATION OF MK 37 TORPEDO BATTERIES

by

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ABSTRACT

The exercise and warshot batteries for the MK 37 torpedo were tested against the electrical specifications of the manufacturer. Both battery types failed to meet the minimum power requirements during the three-second, high rate (130 A) portion of the discharge. The warshot batteries performed as specified for the main part of the discharge test. Due to the limited number of test batteries examined it was not possible to estimate the cycle life expectancy for the rechargeable exercise battery.

Electrolyte levels within some cells of the exercise battery were found to decrease over a time interval of several months. Additional electrolyte should be provided as a routine servicing procedure. Some indication of imminent cell failure is provided by the open circuit cell voltage after at least a one day stand. Low open circuit voltage may be taken as sufficient reason for the replacement of the 4-cell monoblock in the exercise battery.

RÉSUMÉ

On a mis à l'essai des batteries de torpilles d'exercice et de torpilles à tête de combat MK 37 pour s'assurer qu'elles répondaient aux normes du fabricant. Les deux types de batteries n'ont pas débité l'intensité minimale exigée (130 A) pendant la pointe de 3 secondes de la décharge. Le rendement des batteries des torpilles à tête de combat a été conforme aux normes pendant la majeure partie de l'essai de décharge. En raison du petit nombre de batteries examinées, il ne fut pas possible d'évaluer la durée utile des batteries rechargeables des torpilles d'exercice.

Le niveau d'électrolyte dans quelques éléments de la batterie des torpilles d'exercice diminue au bout de plusieurs mois. Il faut donc le normaliser au cours de l'entretien courant. La tension à vide permet, aprés un repos d'au moins une journée, de déterminer si les éléments sont sur le point de lâcher. Une faible tension à vide peut être une raison suffisante pour remplacer le bloc de 4 éléments de la batterie de la torpille d'exercice.

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INTRODUCTION

The "MK 37 torpedo battery" is the power supply for the electrical systems in the modified MK 37 torpedo. The battery is made up of silver oxide-zinc cells operating in a strongly alkaline electrolyte (40% potassium hydroxide, aqueous solution). Its generic name which will be used throughout this report is the silver-zinc battery. A very compact construction is used in this torpedo application. In the "exercise" version, this consists of five separate and interchangeable modules each having four silver-zinc cells connected in series. There are therefore a total of twenty cells per battery. Depending on the battery application the number of plates in each cell differs so as to provide for nominal capacities of 12 Ah for the warshot battery and 18 Ah for the exercise battery. Although in principle the silver-zinc battery is rechargeable it is discharged only once when used in the warshot torpedo. Batteries for the exercise torpedo are recharged and the battery casing is consequently designed to be opened for routine servicing.

The purpose of the study described here was to test and evaluate both the exercise and warshot batteries according to the manufacturer's performance specifications and to estimate, in so far as it was possible, the life expectancy of the exercise battery (1). The manufacturer was Eagle Picher of Joplin, Missouri, U.S.A. This study was undertaken for the Director of Maritime Combat Systems, Underwater Weapons Section, DMCS-5.

EXPERIMENTAL

GENERAL DESCRIPTION OF BATTERIES

The exercise and warshot batteries are similar in outward appearance, the former being slightly larger, heavier and of greater capacity (see Table I).

TABLE I

Basic Data for MK 37 Torpedo Batteries

Battery Type	Length (cm)	Width (cm)	Height (cm)	Weight (kg)	Nominal Capacity (Ah)
Exercise	37.8	12.2	22.3	10.9	18
Warshot	37.8	12.2	20.3	9.1	12

Figure 1a is a photograph of the exercise battery enclosed in its metal battery box. A demonstration model displaying the inside of the warshot version is shown in Figure 1b.

The warshot battery is equipped with auxiliary apparatus contained within the sealed metal case. This consists of the electrolyte reservoir, the manifold and tubing for filling the cells with electrolyte and the activating mechanism which uses a small explosive charge (squib) to release the electrolyte from its pressurized reservoir. Warshot batteries are discharged only once and are not intended for further use once a warshot torpedo has been fired.

The exercise version of the MK 37 torpedo battery is similar in many respects to the warshot battery, but since it is intended to be repeatedly charged and discharged the casing is designed for opening to permit inspection and servicing. This is a 20-cell battery made up of five 4-cell monoblock units which are interchangeable. Figure 2 is a photograph of a four-cell monoblock showing four of the electrical terminals behind which are located the filling ports, one for each cell. After the prescribed amount of electrolyte has been added the filling ports are sealed by threaded caps having neoprene O-rings. These are designed to allow for controlled leakage of electrolyte in the event of excessive pressure build-up within the cell. Each electrochemical cell consists of five positive electrodes (silver oxide) and six negative electrodes (zinc); the positives and negatives individually connected in parallel to provide the required electrical capacity.

METHOD OF TESTING

Warshot batteries were tested by discharging them at their rated current load as specified by the manufacturer, Eagle Picher (2). Details will be elaborated below.

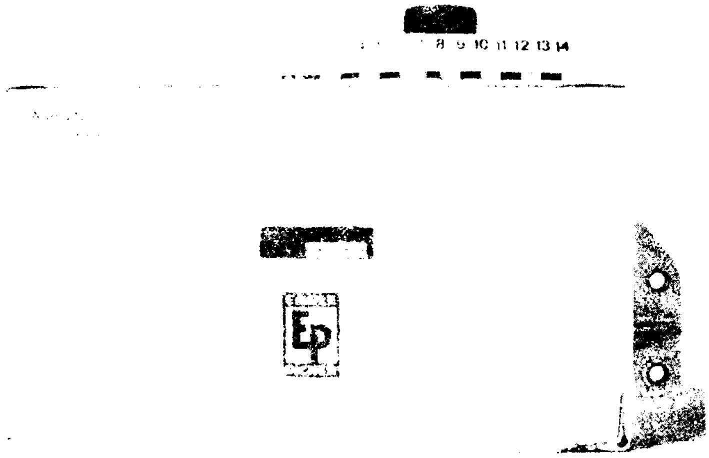


Fig. 1A: Exercise Battery for MK 37 Torpedo.

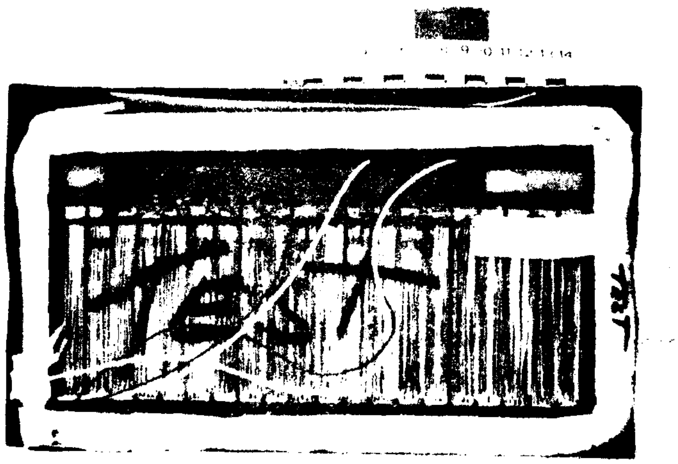


Fig. 1B: Warshot Battery for MK 37 Torpedo (demonstration model cutaway).

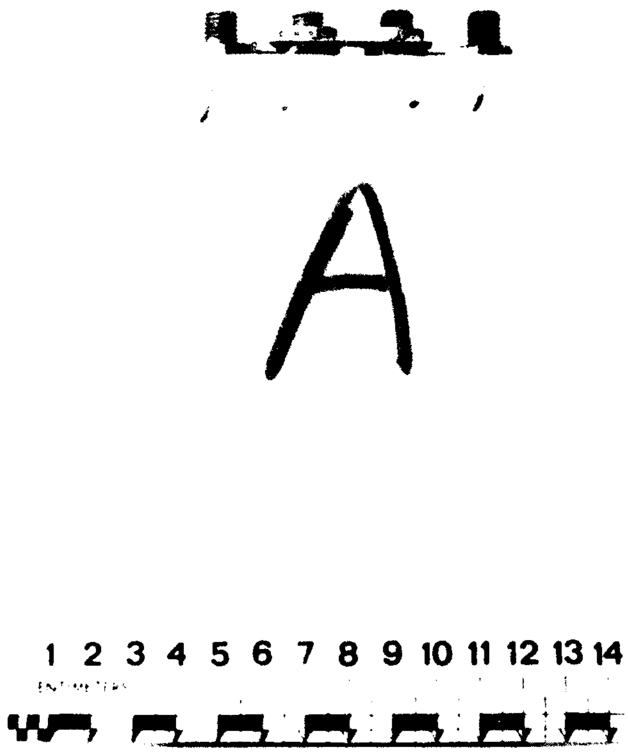


Fig. 2: Four-cell Monoblock unit of the exercise battery for the MK 37 torpedo.

The approach taken in testing the exercise battery was to simulate in the laboratory a pattern of charge and discharge cycling appropriate to the kind of use a typical exercise battery would be put to in operations with the Canadian Forces (1). The running time of an exercise torpedo varies from a few minutes to a maximum of twenty minutes, the average torpedo run being about ten minutes. There is frequently an interval of several weeks between the last recharge and the time when the battery is subsequently discharged. Following discharge a number of weeks may then elapse before the battery is returned to the workshop for charging. There is therefore a variable standing time after the battery is charged and another length of time during which the partially discharged battery stands before being recharged. To simulate such usage four charge/discharge cycles were established in which the open circuit (O.C.) stand periods following both charge and discharge and the amount of charge delivered by the battery were varied.

CYCLE I

- charge
- O.C. stand for 1 day
- discharge for 5 minutes
- O.C. stand for 1 day

CYCLE II

- charge
- O.C. stand for 1 day
- discharge for 15 minutes
- O.C. stand for 1 day

CYCLE III

- charge
- O.C. stand for 1 month
- discharge for 5 minutes
- O.C. stand for 1 week

CYCLE IV

- charge
- O.C. stand for 1 month
- discharge for 15 minutes
- O.C. stand for 1 week

Cycles I and II were intended to represent frequent usage of the battery, whereas cycles III and IV were similar to actual deployment in the Canadian Forces involving lengthy stand times.

Since the nominal capacity of the exercise battery is 18 Ah, the 5 minute and 15 minute discharges, (which are done at 38 A), represent only 17.6% and 52.7% depth of discharge, respectively. The main interest in carrying out these tests was to determine the effect on cycle life which could be attributed to the periods of time during which the batteries were on O.C. stand following charge or discharge.

TEST BATTERIES

Two warshot batteries were obtained, Serial #30 was delivered to DREO November 1974 and Serial #95 in January 1977. Both were stored in the laboratory under normal atmospheric conditions: 20°-23°C, ∿ 40% relative humidity.

Only one exercise battery could be obtained for cycle-life testing. This battery, Serial #13, was dismantled into its 4-cell monoblock units designated: A, B, C, D and E. There was therefore only one monoblock for each charge/discharge cycle test, and one spare. With only one test battery per cycle test it is obvious from the start that no information of statistical significance is obtainable in so far as predicting cycle life as a function of the variables imposed (i.e. depth of discharge and O.C. stand period following charge and discharge). The monoblock units were stored in the laboratory under the same conditions as stated above for the warshot battery.

ELECTRICAL TEST CONDITIONS

Electrical specifications for charging and discharging exercise batteries and discharging warshot batteries were interpreted from the engineering drawings supplied by Eagle Picher (2).

The full-size exercise battery is charged at a constant 2 A current until the emf reaches 39.95 V ± 0.05 V. For charging the 4-cell monoblock units the same current was employed (i.e. 2 A) but the voltage limit was taken as 7.99 V ± 0.01 V since each monoblock is one-fifth of a full-size battery.

The specifications call for two discharge regimes: (i) an initial high current rate followed by, (ii) the nominal 38 A rate. For the initial high rate discharge a full-size exercise (or warshot) battery is required to start-up a d.c. motor load at 130 A at 24 V for 2 seconds duration within 3 seconds of activation. The nominal discharge rate is a 38 A load requiring battery output of 2- V to 32 V for 19 minutes duration. Applying these to the 4-cell monoblock units the test conditions for the present work were defined as follows: Each 4-cell monoblock unit must be capable of discharging:

(i) at the initial high rate of approximately 130 A at 4.8 V for 2 seconds within 3 seconds of activation, followed by

(ii) a nominal rate of discharge at 38 A and 5.2 V to 6.4 V.

The time limits for the exercise battery discharge tests were set by the four established cycle schedules. The warshot batteries were required to discharge for a minimum of 19 minutes to produce 12 Ah electrical capacity.

All discharges were done using constant resistive loads calculated from the above electrical specifications. For the warshot battery tests at initial high rate of discharge (130 A) the resistance was 183.5 mohm and for the nominal 38 A rate the resistance had the value 744.8 mohm. Resistive loads were 33.7 mohm and 147.8 mohm for the high rate and nominal rate of discharge respectively in the case of the 4-cell monoblock units of the exercise battery.

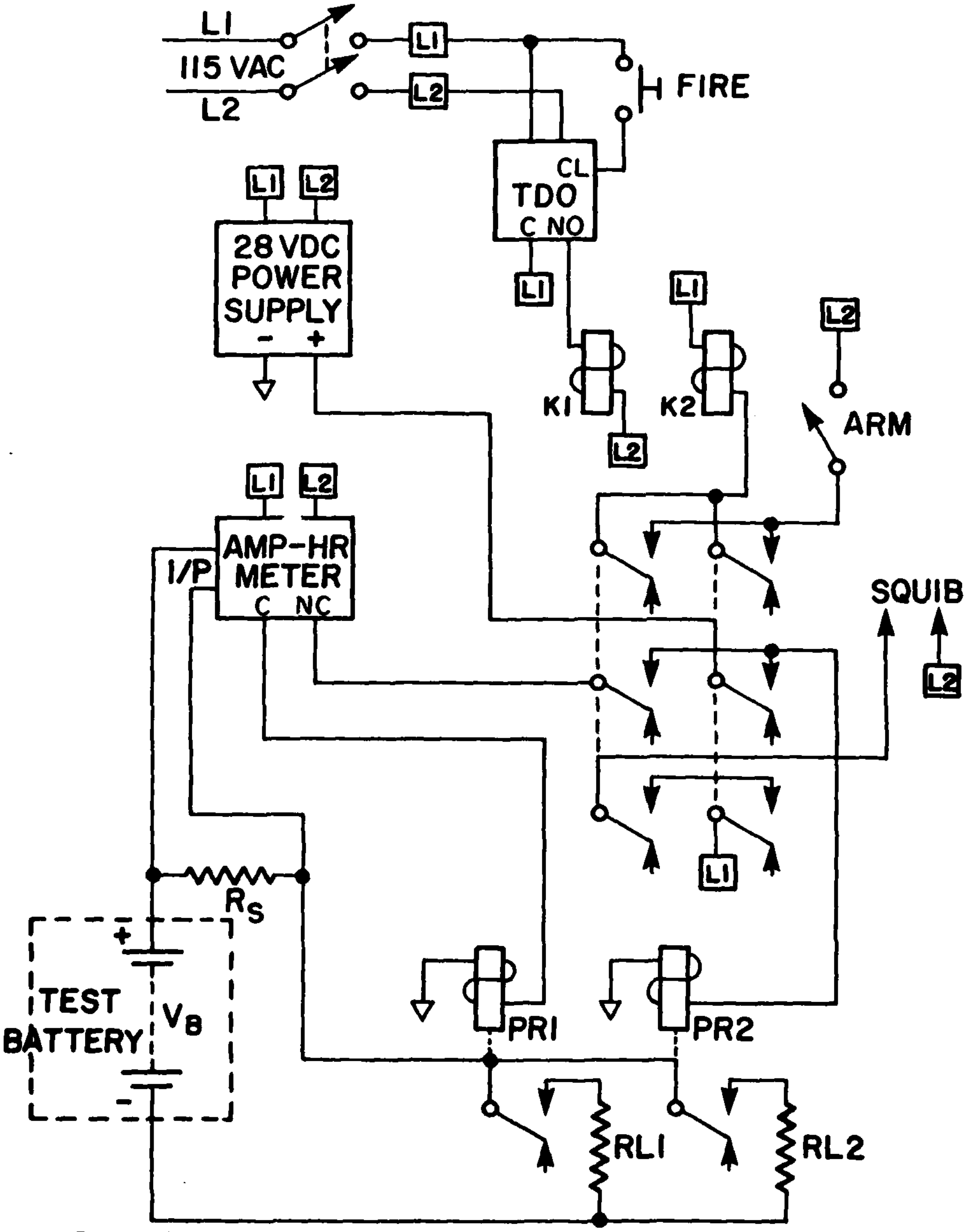
ELECTRICAL TEST CIRCUITS

For charging the 4-cell monoblocks of the exercise battery a power supply (Hewlett-Packard Harrison Laboratories, Model 6291A) was employed to provide a constant 2A current. The charging current was monitored by measuring the voltage drop across a shunt (2 A/50 mV) and the amount of charge passed in the circuit was recorded using a millivolt-hour meter (Gulton). A relay in the same instrument served to cut-off the charging current when the battery voltage reached 8.00 V. The 4-cell monoblock voltage, individual cell voltages and charging current were all recorded at 10-minute intervals.

For discharging exercise batteries (i.e. 4-cell monoblocks) and warshot batteries the circuit shown schematically in Figure 3 was employed. The resistors (RL1 and RL2) were made from Nichrome resistance ribbon cut-to-length to provide the required value of resistance for the particular experiment carried out. The circuit was activated by closing the "ARM" switch and pressing the "FIRE" push button. This activated the switching relays K1 and K2 which closed the power relays PR1 and PR2 thus putting load resistors RL1 and RL2 in parallel for the initial high rate discharge portion of the test. This initial load was controlled by the relay in the millivolt-hour meter and the time-delay-opening switch (TDO), which was pre-set to open following 254 Amp-seconds of discharge (i.e. approximately 130 A for approximately 2 seconds) or after 3 seconds. The remaining part of the discharge then took place with only RL1 in the circuit so that the current remained at approximately 38 A. The particular values of RL1 and RL2 for discharging both warshot and exercise batteries are given in Figure 3. To guard against excessive fluctuations in resistance caused by heating of the load resistors during current flow RL1 and RL2 were provided with forced-air cooling. For discharging warshot batteries the "SQUIB" (see Figure 3) was activated electrically (relays K1, K2 in Figure 3) causing electrolyte to be forced under pressure into the battery compartment. The "SQUIB" connection was not employed for exercise battery tests.

The voltage of the test battery (V_B in Figure 3) and the voltage drop across the shunt (R_S in Figure 3) were recorded continuously on a strip-chart recorder (Hewlett-Packard, Model 7100B). In addition, when 4-cell monoblocks were discharged the individual cell voltages were also recorded. During the initial high rate of discharge (lasting up to three seconds) the current and voltage were recorded at the rate of 10 readings per second.

Part of the test apparatus employed for the exercise battery monoblock units is shown in Figure 4. The test battery was secured in a wooden box seen left-front in Figure 4. The fan for cooling the load resistors is located just behind and to the left of the battery box. Warshot batteries were enclosed in large plexiglass boxes to give protection to equipment and personnel in the event of high pressure release of hot electrolyte during or following a discharge.



	WARSHOT BATTERY	4-CELL MONOBLOCK
RL1 (mΩ)	744·8	147·8
RL2 (mΩ)	243·5	43·6

Fig. 3: Schematic of electrical test circuit for charging or discharging warshot and exercise batteries.

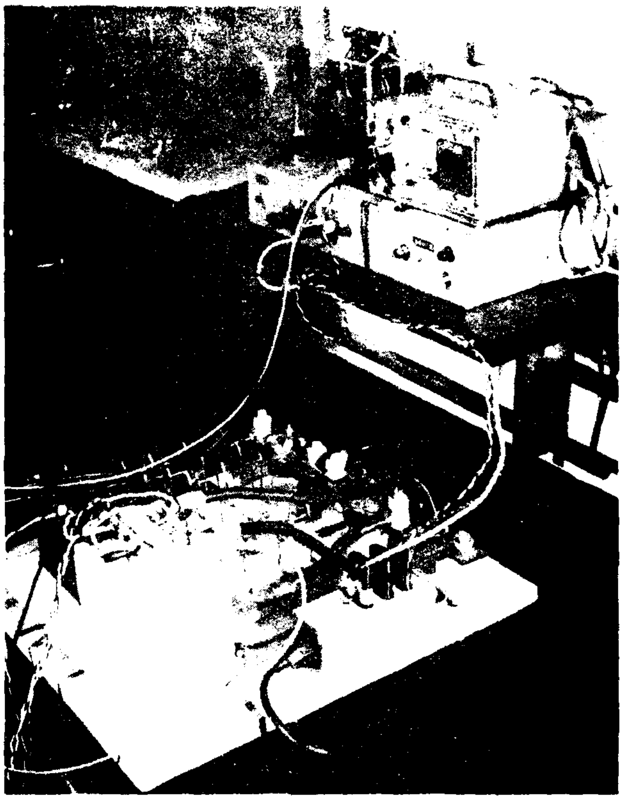


Fig. 4: Part of the experimental apparatus employed for testing monoblock units of the MK 37 exercise battery.

RESULTS

WARSHOT BATTERY TESTING

Battery serial number 30 was delivered in November 1974 and was discharged 30 May 1977. During the initial high rate part of the discharge the maximum current obtained was 119 A after about 3 seconds at 22 V, thus about 84% of the minimum specified power was delivered.

In the main part of the discharge the current varied from 37.5 A to 38.8 A with a corresponding voltage output of 28.0 V to 28.9 V. The charge obtained was 12.28 Ah at 19 minutes and the battery did not drop below 28 V output until after 25 minutes.

The second battery which was tested on 2 June 1977 had been delivered to DREO in January 1977. The initial discharge gave a maximum current of 126 A at 23 V after about 2 seconds. This corresponds to 93% of the minimum specified power.

The remaining discharge occurred within the voltage and current ranges: 27.7 V - 29.2 V and 37.1 A - 38.9 A, respectively. At 19 minutes into the test 12.29 Ah of charge had been delivered and the output remained above 28 V until nearly 28 minutes had elapsed.

In both discharge runs when the squib was fired the test chamber immediately filled with a reddish-brown vapour, most likely nitric oxide (NO_2) resulting from the nitrate-type explosive employed in this device. Towards the end of battery life, at about 28 minutes in each case, liquid appeared at the vent hole in the battery case. This was shortly followed by a stream of hot electrolyte and steam. Both of these emissions were adequately confined by the plexiglass box built around the test battery.

EXERCISE BATTERY TESTING

The results of cycling the 4-cell monoblocks are summarized briefly in Table II.

TABLE II

Cycle Tests on Exercise Battery Monoblocks

Charge/ Discharge Cycle	4-Cell Monoblock	Discharge Time (min)	O.C. Stand Following Discharge/Charge	No. Cycles Obtained	Time in Service (mo.)
I	A	5	1 da./1 da.	88	10
II	B	15	1 da./1 da.	46	6
III	C	5	1 wk./1 mo.	9	14
IV	D	15	1 wk./1 mo.	1	2
IV	E	15	1 wk./1 mo.	6	10

Monoblocks A, B and C were filled with electrolyte 26 March 1976 and after an open circuit stand for two days would accept no charge. Each monoblock was then discharged according to the selected cycle (see Table II) starting 30 March for A, 31 March for B and 20 April for test battery C. Monoblock D was filled 25 May 1976 and failed to discharge a second time due to a short circuit in one of its cells. It was noted that electrolyte levels were low in cells #2 and #4 which required addition of 10 ml and 3 ml respectively. This monoblock unit was returned to the manufacturer for their examination. In cycle IV the spare test battery E was used to replace D. It was filled with electrolyte 3 August 1976 and discharged for the first time 10 August.

Failure of a test battery, as indicated in Table II, column 5, was determined by the inability to produce 99% of the power prescribed by the specifications (i.e. 99% of 38 A x 5.2 V = 197.6 W). All tests were continued to exhaustion, that is, until the batteries were unable to deliver any power at all. For monoblocks A, B and E this amounted to a reversal of cell emf for one cell in each battery. Reversal of cell emf was detected during the 90th, 49th and 9th discharge for monoblocks A, B and E, respectively. Test battery C expired when the plastic casing developed a crack 18 days after the twelfth charge. Figure 5 is a photograph of the damaged unit.

The last column in Table II gives the length of time the test batteries were in service from the day they were first filled with electrolyte until their complete failure.

In the initial part of the discharge all monoblocks were capable of delivering 130 A for 2 out of 3 seconds after connecting the load. However, the voltage was always low, about 0.2 V less than the minimum required 4.8 V. Results typical of those obtained for the high rate discharge portion of the test are shown in Figure 6. These particular data were for the fourteenth discharge of monoblock B. The current and voltage curves are given for a time interval of 3 seconds after connecting the load. The load resistance

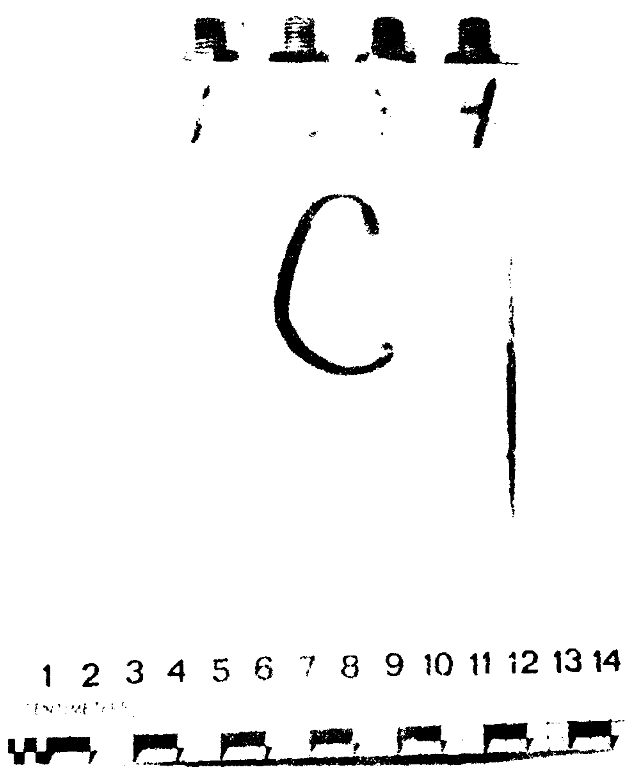


Fig. 5: Four-cell monoblock, Test Battery "C". Battery casing fractured following 18 days of open circuit stand after 11th charge/ discharge cycle.

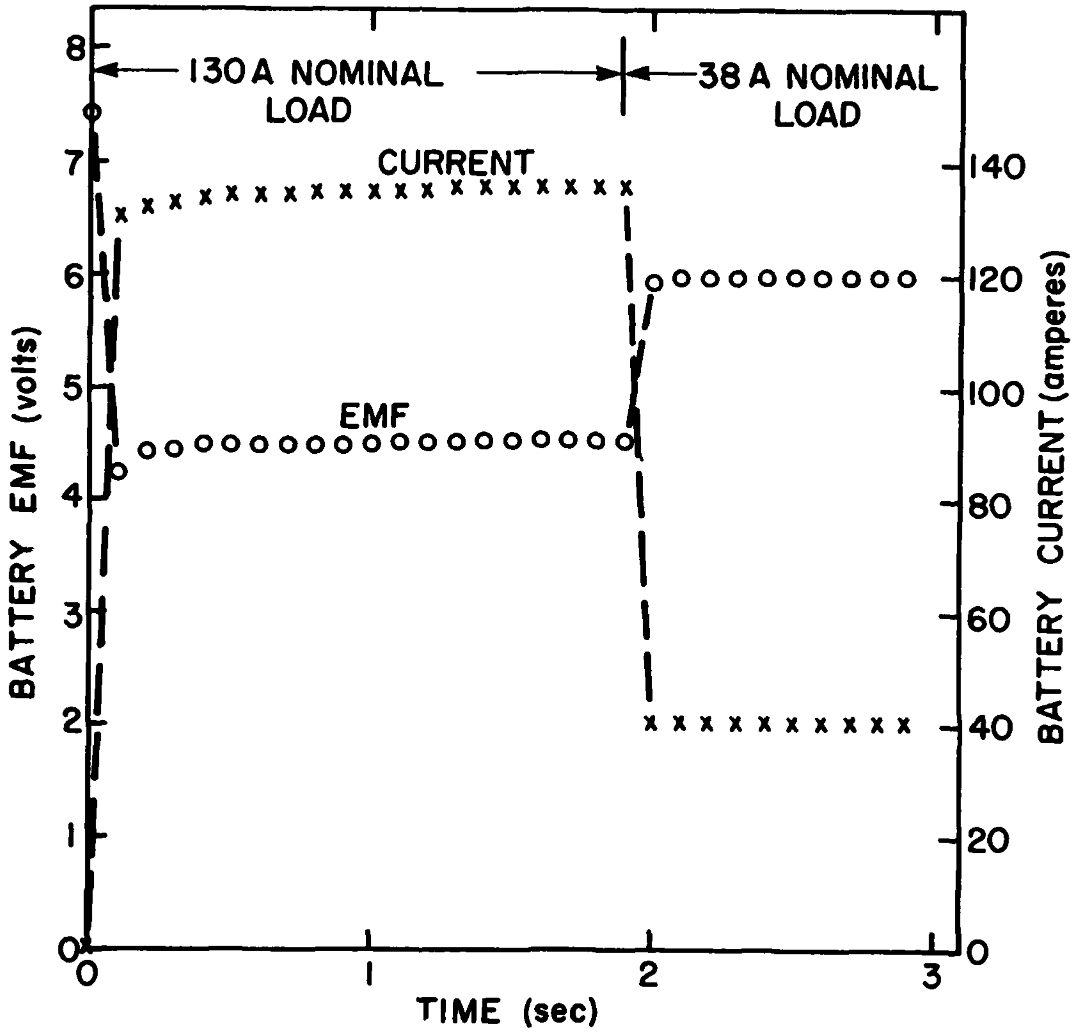


Fig. 6: Typical results for initial high rate discharge (130 A nominal) for a four-cell monoblock test battery. Zero time taken when load connected to battery terminals. Broken lines indicate discontinuity in recorded data when loads switched.

was constant throughout at 33.6 mohm. Since 130 A had been obtained for approximately 2 seconds (i.e. a charge of approximately 260 A sec) the test circuit switched from the 130 A load to the 38 A load at about 2 seconds. This accounts for the discontinuous increase in emf and decrease in current at 2 seconds in Figure 6.

DISCUSSION

WARSHOT BATTERIES

Both batteries performed as required for the nominal 38 A part of the discharge, giving between 27 V and 30 V for more than 19 minutes. However, for the initial part of the discharge, lasting up to three seconds after activation, the required 130 A could not be obtained. Since both the current and voltage fell below specifications, the batteries failed to perform adequately for this part of the discharge. This matter has been discussed with DMCS, but there does not appear to be a problem with the battery successfully starting-up the torpedo. It is therefore concluded that the manufacturer's specifications exceed the operational requirements (3).

The presence of both nitric oxide gas and hot, corrosive battery electrolyte could cause serious damage to many mechanical and electrical parts inside a torpedo. It is recommended that warshot batteries should not therefore be routinely employed as replacements for exercise batteries. This concern has been communicated to DMCS during the course of the testing project.

EXERCISE BATTERIES

Exercise battery monoblocks also failed in the initial high rate part of the discharge as did the warshot batteries. For the same reasons as given above this does not appear to be a serious problem.

A typical charge/discharge cycle is shown in Figure 7 for monoblock B on the forty-third cycle. This test included a discharge at 38 A (nominal) for fifteen minutes followed by a stand for one day, then a 2 A charge. The lower curve in Figure 7 is the main part of the discharge (i.e. at 38 A) and the open circuit voltage is indicated before discharge (7.44 V) and one minute after discharge (6.31 V). The vertical bar indicates the required voltage envelope: 5.2 V to 6.4 V. The rise in output voltage during the latter part of discharge can be attributed to increased temperature within

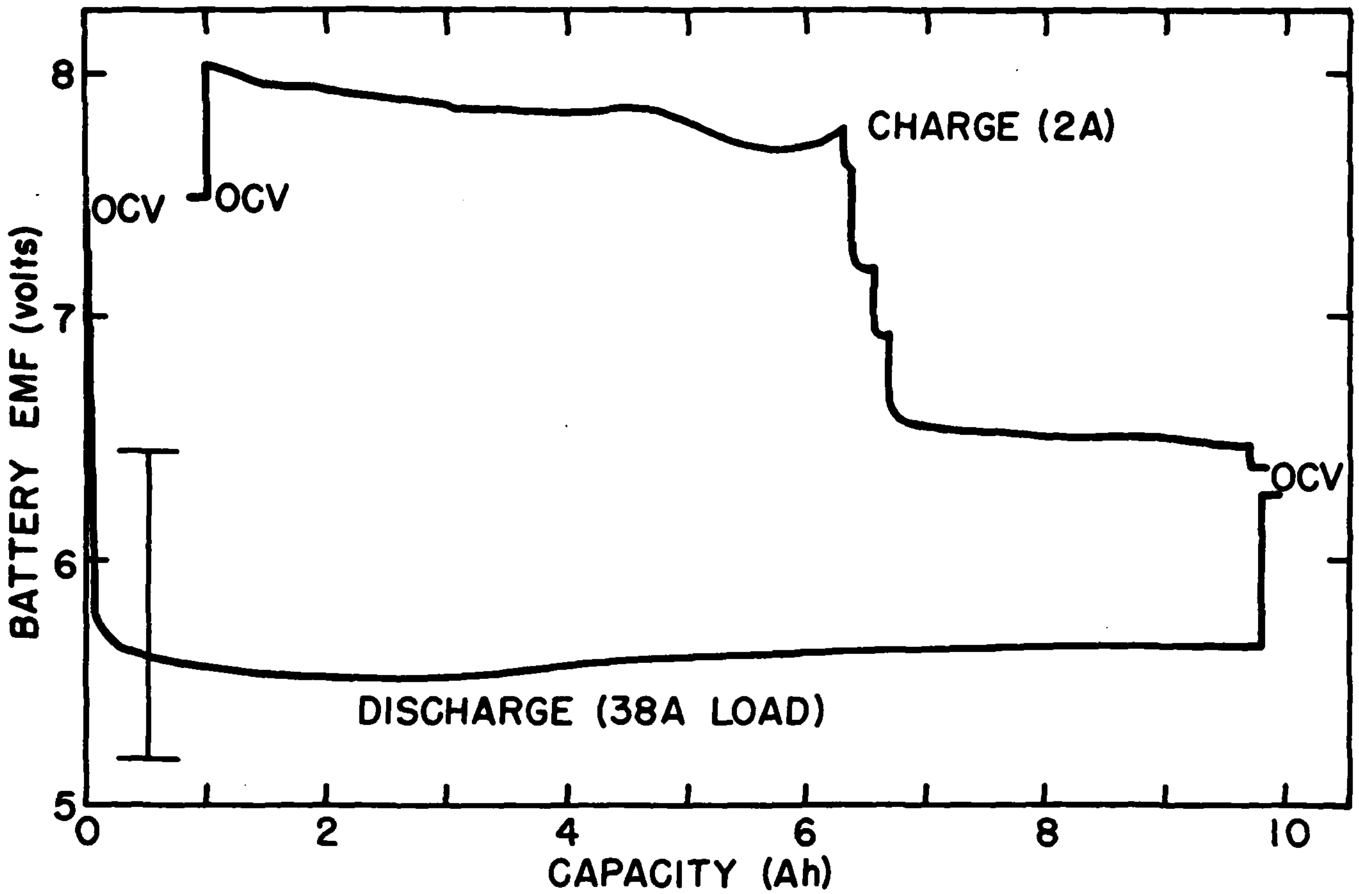


Fig. 7: Typical charge/discharg cycle for four-cell monoblock test battery. Example: 43rd charge and discharge of unit B, Cycle: 15 minute discharge, 1 day OC stand, 2 A charge, 1 day OC stand. Discharge curves begins at left of graph. Charge curve begins at right of graph.

the battery.

The charge curve shown in Figure 7 is in most ways typical for the exercise monoblocks, except for the amount of charge accepted before the cut-off of 8.00 V is attained. In the example shown the charge accepted is about one ampere-hour less than the charge delivered by the battery on the previous discharge. On other occasions the reverse occurred - more charge was accepted than delivered. The main reason for this phenomenon is the fact that for 15 minute discharges only half the nominal capacity is utilized. For 5 minute discharges only about 17.5% of nominal capacity is drained. The batteries therefore always have an excess of capacity after discharge so the quantity of charge given to the battery depends more on the shape of the curve as it approaches the specified cut-off of 8.00 V than it does on the state of charge. At between 6 and 7 ampere-hours in Figure 7 it can be clearly seen how each of the four cells becomes fully charged, indicating a small capacity difference between cells of a monoblock. These capacity differences were always quite small, less than one percent variation. The slow rise in battery voltage during the latter half of the charge curve represents completion of oxidation to silver oxide (AgO) with some slight amount of oxygen production occurring simultaneously.

The evolution of oxygen in the latter stage of charging may have contributed to a loss of electrolyte in various cells during the course of cycling tests. Test battery D was the most serious case of low electrolyte levels, but all monoblocks had to be given up to five millilitres of distilled water per cell after about three months of testing. On initial filling all cells took the prescribed volume of electrolyte (61 ± 0.5 ml) so it was unlikely that the initial filling procedure was responsible for low levels in some cells. Slow absorption of liquid by the porous separator materials and the positive (i.e. silver) plates could account for some up-take of electrolyte. It has been adopted now as routine practice by personnel servicing the exercise battery to regularly check electrolyte levels.

When a cell undergoes emf reversal as the cause of final failure it may possibly be predicted by monitoring the open circuit voltage (OCV) before the subsequent discharge is carried out. The OCV data for monoblocks A, B, C and E have been plotted versus cycle number in Figure 8. The data were obtained just prior to discharge and were normally 7.44 V ± 0.01 V.

Failure of the test battery to deliver 99% of the required power is indicated by "F" in Figure 8. Ultimate failure is notated by an "X". For A, B and E this occurred when one cell in each monoblock underwent emf reversal during discharge. Battery C failed due to splitting of the case. These data suggest that failure may be predicted by a low OCV occurring some few cycles prior to the event. Ultimate failure caused by emf reversal appears to be more closely defined by a low OCV (e.g. monoblock B). Although not a very reliable indication of failure the OCV if low should be used as sufficient reason for replacement of a monoblock unit in the exercise battery. It is interesting to note that in the three cases where cell reversal occurred it took place within 2 or 3 cycles of the failure of the battery to produce 99% of the required power.

It should be recognized that the cycle test results obtained in this study have no statistical validity for predicting battery life because there

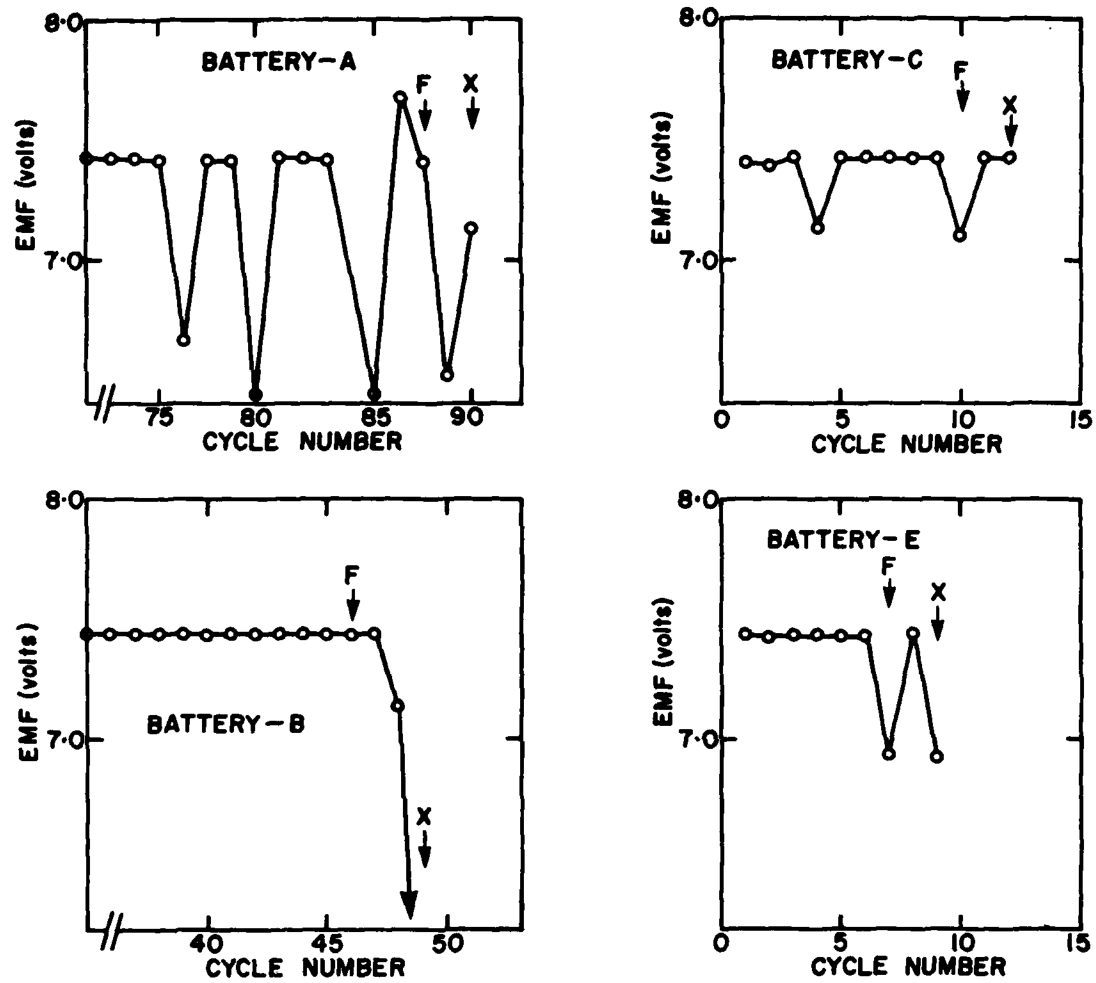


Fig. 8: Monoblocks A, B, C and E. Open circuit voltage data recorded prior to discharge. Cycle number given on abscissa. "F" indicates initial failure to produce 99% of minimum specified power. "X" indicates discharge cycle where ultimate failure to produce power occurred.

was only one test battery for each type of cycling programme examined. A minimum of five batteries for each cycle would have been sufficient for a statistically meaningful study. The only conclusive result obtained in these cycle tests was that the battery made up of the five monoblocks would have failed on the second discharge due to the development of a short in one cell of test battery D.

However, based on prior experience with silver-zinc secondary batteries, it is well known that batteries should be used as frequently as possible, with minimum stand periods following charging if maximum cycle life is to be obtained.

CONCLUSIONS

Due to the small number of test batteries examined in this study it is not possible to use the results to provide a reliable estimate of cycle life expectancy for the exercise battery. However, the open circuit voltage if found to be low prior to discharge should be taken as sufficient reason for discarding a monoblock unit and replacing it with a new one. The level of electrolyte in each cell should be monitored and fresh electrolyte added if needed. Exercise batteries should be used as soon as possible following charging and as a rule-of-thumb exercise batteries should be removed from service after a period of six months from the time of initial activation. This recommendation is based on general experience with silver-zinc batteries and does not result from the data obtained in this study.

Neither the exercise not the warshot batteries delivered the power required in the initial high rate (130 A load) of discharge. As noted, there have been no indications of failures of the batteries to start-up the torpedo, so it has been concluded that the manufacturer's specifications exceed the actual requirement. When the warshot batteries were activated nitric oxide gas was produced from the explosive material contained in the squib. It is recommended that exercise batteries not be replaced by warshot batteries for the reason that nitric oxide gas could cause severe corrosion to the interior of an exercise torpedo.

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3. Verbal communication with R.A. Spittall of DMCS-5 at CFAD Bedford, N.S., 5 October 1978.

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13. ABSTRACT

The exercise and warshot batteries for the MK 37 torpedo were tested against the electrical specifications of the manufacturer. Both battery types failed to meet the minimum power requirements during the three second, high rate (130 A) portion of the discharge. The warshot batteries performed as specified for the main part of the discharge test. Due to the limited number of test batteries examined it was not possible to estimate the cycle life expectancy for the rechargeable exercise battery.

Electrolyte levels within some cells of the exercise battery were found to decrease over a time interval of several months. Additional electrolyte should be provided as a routine servicing procedure. Some indication of imminent cell failure is provided by the open circuit cell voltage after at least a one day stand. Low open circuit voltage may be taken as sufficient reason for the replacement of the 4-cell monoblock in the exercise battery.

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