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Ronald J. Kovein & Martin T. Abell

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Benefits of a nickel-cadmium battery cycler

RONALD J. KOVEIN and MARTIN T. ABELL

National Institute for Occupational Safety and Health, 4676 Columbia Parkway, Cincinnati, Ohio 45226

Introduction

In the occupational health field, obtaining exposure data usually requires a battery-powered instrument. The instrument is likely to be a personal sampling pump, but almost always the power is provided by a battery of rechargeable, nickel-cadmium cells. If the instrument fails in the field because of battery failure, valuable resources are wasted, or worse, poor data is obtained. Maintaining battery packs in good condition is therefore required from both cost and quality standpoints.

All nickel-cadmium cells will eventually fail to provide their rated current capacities. A reversible failure is one where the cell can be restored to a serviceable condition; a permanent failure is one where the cell cannot be restored and should be replaced.⁽¹⁾ A defective cell can frequently be restored to full capacity by merely subjecting it to a series of deep discharges, each discharge immediately followed by a full recharge. A potential danger exists, however, during the discharge phase; if the discharge is too deep, then permanent damage to the cell may result. This is likely to happen in the absence of a properly designed battery cycler.

Two battery cycler models have been built at the National Institute for Occupational Safety and Health (NIOSH). Both use the basic circuitry of

A battery cycler that could prolong the life of nickel-cadmium batteries used in personal sampling pumps was described several years ago in the industrial hygiene literature. Cycling involves discharging a battery to a predetermined voltage level, then recharging at a fixed rate for a timed interval. The cycler evaluated here was fashioned after that earlier cycler, but has an improved recharge timer. Current capacity measurements of batteries during discharge have shown that cycling can improve the capacity of older batteries. Measurements on 17 used battery packs gave the following results: 5 improved substantially, 2 improved slightly, 9 were unchanged, and 1 actually deteriorated. Measurements on newer, unused battery packs showed there is no benefit to cycling them. **Kovein, R. J.; Abell, M. T.** Benefits of a nickel-cadmium battery cycler. *Appl. Ind. Hyg.* 1:29-33; 1986.

Myers,⁽²⁾ but the newer model has an improved recharge timer as described in the appendix. The older model cyclers were constructed several years ago specifically for MSA Model G pump batteries. These ten-station units are in use in several NIOSH Regional Offices. The newer model cyclers (Figure 1) have five independent stations, are smaller and simpler to construct, and have circuit boards that allow easy component substitution to accommodate different types of batteries.

To verify that using the cycler actually produces beneficial results, a preliminary study that could be performed in a short time was done. It is described in the Experimental section.

Cycler operation

The front panel of the cycler (Figure 1)

is organized into five columns, one for each cycling station. Each column consists of three momentary push-button switches, an LED, and a jack. A battery is connected to one of the jacks using a suitable patch cord and is automatically cycled by depressing the discharge switch for that jack. It discharges to a specific terminal voltage cutoff of ~0.9 V per cell, and then recharges at a high rate (1/10 of the rated ampere-hour capacity of the battery per hour). After 14 hours of high rate charging, the battery begins an indefinite period of low rate (trickle) charging.

While a battery is automatically switched to trickle charge after a 14 hour period of high rate charging, the low rate of charge can always be manually selected by the user before automatic switchover occurs. Conversely, timed high rate charging is also available on demand while the battery is on trickle charge. A discharge operation, however, cannot be overridden by depressing either the high or low rate charging selector. Nor can a discharge operation be initiated on any battery whose terminal voltage is below cutoff; instead, the cycler will make an audible "buzz" for as long as the discharge switch is depressed.

Experimental

To test the effect of using the cycler, 22 battery packs were cycled several times, and the capacity of each was

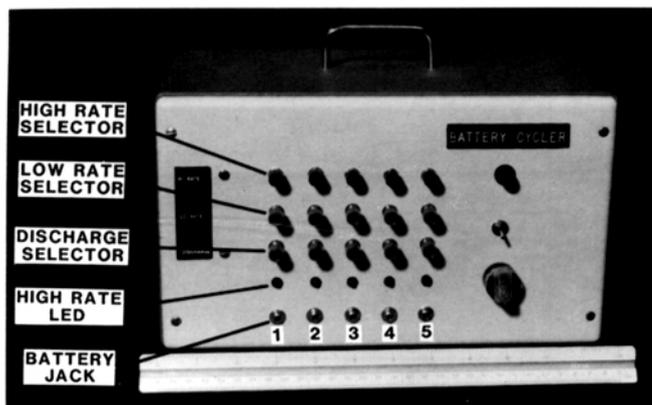


Figure 1—The five-station Ni-Cd battery cycler.

measured during discharge.

A cycle consists of a discharge to ~ 3.9 V for a 5 V battery, followed by 14 hours of high rate recharging. The batteries were all 5 V, 1200 mA·h battery packs of the type used in personal sampling pumps. They were all given a full charge before cycling.

Four sets of batteries were cycled at different times, the first two sets having five batteries and the other two sets having six batteries. The cycler unit accommodates five batteries, and an additional cycler board was run on a test stand for the last two sets. The batteries in the second set (Nos. 6 to 10) were new batteries that had been stored in a refrigerator for three months between delivery and testing. Some of the used battery packs were known to be three years old, but the exact history of all the packs was not available. The first set of batteries was cycled four times, the rest three.

The current data collected during discharge were plotted as a function of time. Figure 2 shows examples of discharge curves. The data were recorded using an analog-to-digital converter connected to an Apple IIe microcomputer. The microcomputer program determined the data collection sequence which can be summarized as follows: Readings of all the channels in use were taken at the end of each minute for ten minutes and then averaged and written to a file on diskette. This procedure was repeated continuously for 40 hours, long enough for a complete discharge cycle. Of the 240 data points recorded for each battery, only those occurring before the discharge current dropped to 10 mA (approximately 0.97 V per cell) were used for determining battery capacity. The 10 mA level was always reached just before the cycler circuitry switched to high rate charging. Each of the data points preceding the switch to charging represents the average discharge current in milliamperes during 1/6 of an hour. The sum of all these data points divided by 6 is therefore the capacity of the battery in milliamperes·hours for non-constant-current discharge.

Test results and discussion

The testing done in this work was an attempt to assess the effect of using the battery cycler; improvements in battery capacity were expected. The measurements of discharge current over time are depicted in the three graphs of Figure 2. The graphs shown are those for

two older battery packs (Nos. 1 and 22), and a relatively new one (No. 9). Each graph shows two curves, one each for the first and last discharges.

The graph for Battery 1 shows that the battery cycler cannot remedy all defective nickel-cadmium cells; severely damaged cells will never respond

favorably to treatment. Although the capacity of the battery pack was a respectable 1400 mA·h on the first discharge, the final discharge capacity was down 20% from that value. The problem could not be attributed to a faulty cycling station since the same station was later used for Battery 11 and Battery 17 with very different results.

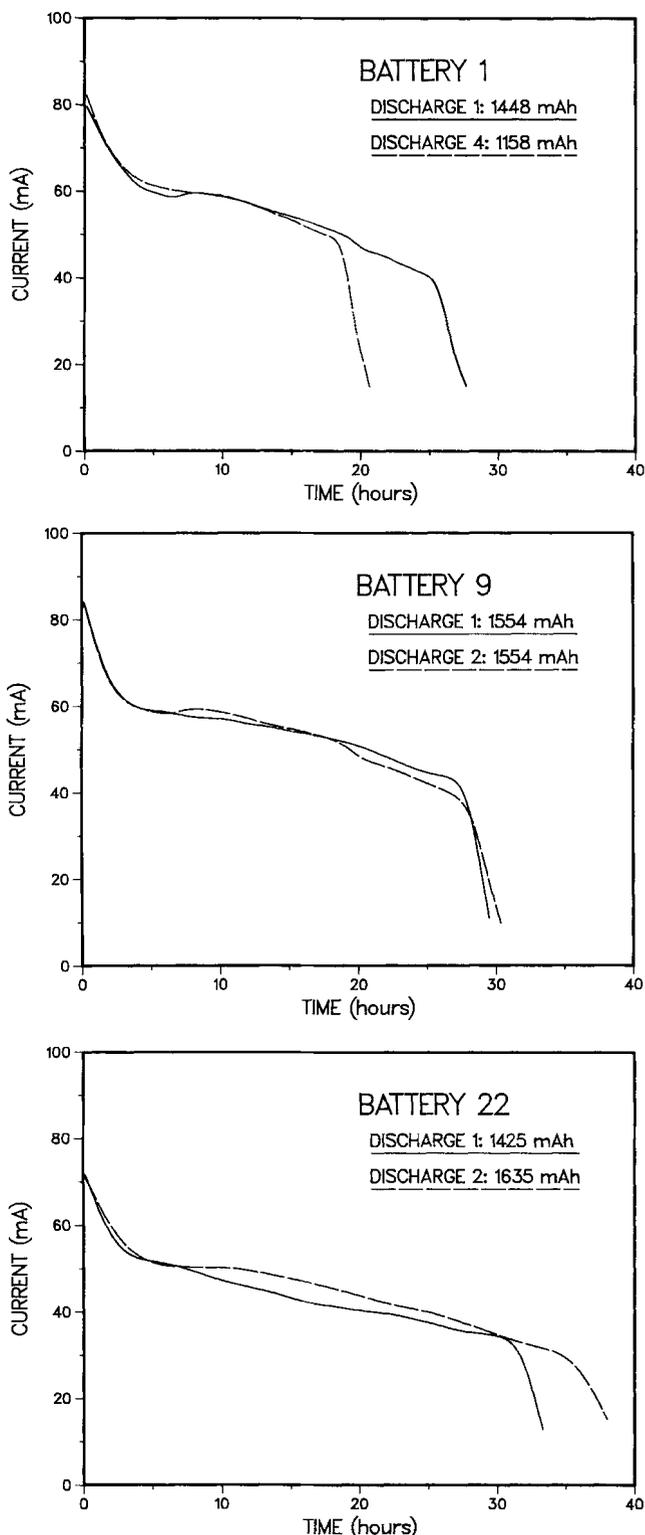


Figure 2—Typical discharge curves for Ni-Cd batteries during cycling.

The graph for Battery 9 shows that there is no advantage to cycling new batteries. None of the battery packs numbered 6 to 10 changed significantly with cycling. These batteries had been kept in a refrigerator for the three months between delivery and testing.

The graph for Battery 22 is an example of significantly improved capacity due to cycling. The remaining batteries, Nos. 2 to 5, and Nos. 11 to 21, could be put into three categories regarding their capacity changes: significant improvements, slight improvements, and little or no change. These categories roughly correspond to the following in terms of percentage of change: greater than +10%, between +5 and +10%, and less than $\pm 5\%$. Nine of these battery packs showed little or no improvement, but two showed slight improvement, and five (including Battery 22) showed significant improvement.

The batteries showing improvement are listed in Table I. Their capacity on the first discharge (reference capacity) varies, but the capacity on the final discharge usually falls in the 1400 to 1500 mA·h range. Note that capacity changes are usually most dramatic between the first and second discharges, but that some battery packs do not improve until the third cycle. Three batteries are not shown on Table I because, although they gained more than 5% capacity on discharge 2, they dropped back to 4% overall gain on discharge 3. A fourth cycle ordinarily showed no change and was therefore not carried out for most batteries. Candidate batteries that are most likely to benefit from cycling show depressions in their discharge profiles. Subsequent discharges will reduce or eliminate these depressions and the discharge time may be greatly extended.

Two of the batteries used in this test, excluding battery 1, would probably have failed if used in the field. A sampling pump in the field will typically require a total battery output of 1000

mA·h to collect a full 8-hour sample. Without cycling, battery 17 in Table I would have failed after 6.7 hours. And battery 13, though it began with 1030 mA·h capacity, would probably have failed near the end of the 8-hour period. After cycling, battery 17 showed a 49.8% increase in capacity, enough for 10.0 hours of continuous pump operation, and battery 13 gained enough for 10.6 hours of operation. Considering all of the batteries in Table I together, their average reference capacity was 1242 mA·h, or 9.9 hours of operation, and after cycling their capacity was 1473 mA·h, sufficient for 11.8 hours of operation.

The design of the battery cycler is such that discharging of battery packs is not done at constant current. This is apparent in Figure 2. Constant-current discharging is commonly employed for battery testing by the manufacturers. If a more stressful constant-current discharge rate has been used in this test, the observed capacities would have been closer to the manufacturer's value (1200 mA·h), and the first discharges of some of the weaker batteries may have ended much sooner. The gains in capacity shown by the batteries in Table I would probably not have decreased with constant-current discharging and may even have been more dramatic.

During this work, it was realized that any user of a battery cycler would like to know if the batteries being cycled will actually be reliable. The cycler itself can be used to indicate battery capacity. One user of a cycler does this by initiating discharges in the early morning and observing the LED's throughout the day. An LED that is turned on in less than 9 hours indicates a battery with serious capacity deficiency. Although this method is unsophisticated, it can be effective in identifying batteries at high risk of failure.

A more accurate instrument for measuring battery performance is currently

under development. This instrument will provide constant-current discharging for a variety of battery packs at several preselectable rates. The milliamperes·hour capacity of a battery under test will be continuously updated on a liquid crystal display until the battery reaches the preselected cutoff voltage. At that time, discharging is discontinued and the final capacity figure remains on the display. Such an instrument could also be used in conjunction with a standard charger to recondition batteries. Although similar instruments for measuring current capacity have been proposed,⁽³⁾ the design of this capacity tester is superior because it allows the selection of discharge current and voltage cutoff suitable for the battery packs commonly used in industrial hygiene equipment.

Conclusions

In spite of the limitations of this preliminary test (non-constant-current discharging and the use of battery packs of unknown history), there is strong evidence to support a routine cycling program. Two of the 17 used battery packs in this study would likely have failed sometime during their first eight hours of field use had they not been through the cycling process. Their failure would have resulted in lost data or, worse, inaccurate data. Five more of these batteries showed some improvement due to cycling. The capacity increase of these batteries demonstrates the benefit of cycling on a short-term basis. Additional justification for a routine cycling program may only come from a long-term study with control and test groups of battery packs. An increase in the useful lifetime of most Ni-Cd batteries is expected.

Although some battery users cycle them naturally through constant use, others have battery packs that sit idle for longer periods. For this latter group, the cost of construction of the five-station battery cycler (about \$400 and 60 hours) is relatively low compared to early battery replacement costs and the costs associated with the collection of bad data. Since unused batteries retain about 50% of their charge after 2 months, recycling every two months is reasonable and would allow a five-station cycler to service eighty battery packs.

Regular use of the battery cycler described here is meant to enhance battery reliability, and it can also be used to indicate battery fitness. An instrument

TABLE I
Capacity gain of selected battery packs

Battery Pack	Ref. Capacity (mA·h) (1st Discharge)	Capacity Gain (%)	
		2nd Disch.	3rd Disch.
#3	1365	1.2%	10.6%
#11	1312	4.4%	5.3%
#13	1030	29.3%	28.4%
#17	832	52.4%	49.8%
#18	1339	12.3%	12.9%
#19	1389	7.8%	7.8%
#22	1425	14.8%	15.2%

that accurately quantitates current capacity would also be highly desirable. The logical step would be to incorporate a current capacity tester into the design of the battery cycler so that the benefits of each could be realized both simultaneously and automatically.

Appendix: cycler circuit description

The circuit built into each of the five stations of the cycler is shown in Figure 3. As drawn, relay K1 is not energized, and the relay contacts are in the "recharge" position. Switches S1, S2, and S3 are the high rate, low rate, and discharge selectors described above. They are momentary-contact push-button switches in their normal positions. Whether the circuit is performing high rate charging or low rate charging cannot be determined from the schematic but only from a knowledge of which push buttons have been pressed. The circuit does provide the user with an LED indicator that is lit during high rate charging. Only that part of the circuit devoted to timing the high rate recharge is described here since the

rest of the circuitry is essentially that of Myers.⁽²⁾

The timing circuit allows the nickel-cadmium cells to recharge at a high rate for 14 to 16 hours before switching to a trickle rate. The timer here employs the XR-2243 (EXAR Integrated Systems, Inc., Sunnyvale, CA). Replacing the four cascaded 7490 counters⁽²⁾ with two cascaded XR-2243 long-range timers has eliminated the possibility of periods of charging shorter than 14 hours, especially if no provisions have been made to provide the 7490 counters with an automatic power-on reset feature. Two additional benefits include reduced power consumption (10 mW versus 1000 mW), and reduced circuit board area (two 8-pin packages versus four 14-pin packages).

One XR-2243 is capable of generating a time delay of $1024 RC$, where R and C are the external timing components. With the counter sections connected in series, the total count available increases geometrically rather than arithmetically. Therefore, the two cascaded timers will produce a total time delay of $(1024)^2 RC$. Referring to the

schematic diagram in Figure 3, the time base of U₆ is disabled by grounding pin 7 through R₂₂. The last stage output of U₅ is connected to the input of the counter section of U₆, pin 8. When +5V is initially supplied to the timing circuit by U₃, a trigger pulse (delayed in time for a $1.1R_{15}C_4$ duration) is simultaneously applied to pin 6 of U₅ and U₆, causing all of their internal counters to be set to "1." In addition, the trigger pulse activates the internal time base oscillator of U₅ so that, once triggered, U₅ will generate a squarewave at pin 3 that has a period of $T = 2(1024)R_{23}C_8$. Since the pin 3 output of U₆ will remain high until the rising edge of the first pulse arrives on pin 8, the network of R₁₄ and C₃ will limit the voltage level at the pin 4 input of the comparator to less than a volt for at least one $1024R_{23}C_8$ time interval. After that time, the output of U₆ will go low and remain low for the duration of the $(1024)^2 R_{23}C_8$ total time delay.

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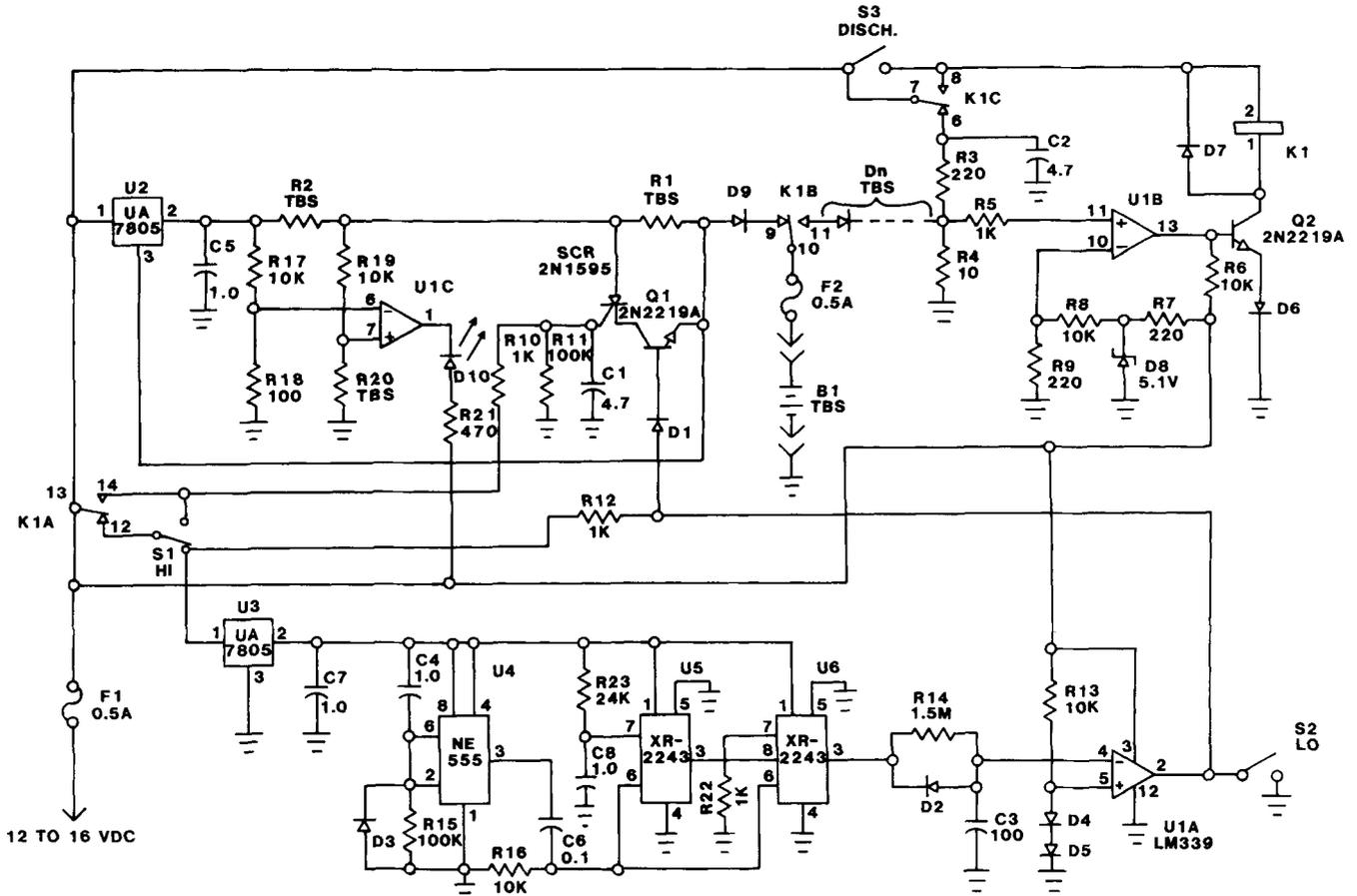


Figure 3—Schematic diagram for a single station Ni-Cd battery cycler. Relay K1 is in the "recharge" position. All capacitances are in microfarads.

A full report on the cyclor is available that gives a complete description of the circuitry including a parts list and printed circuit board layout. It also has the listings of the programs used for data collection. Request the report from the first author.

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Not too young to work. . .

Believe it or not, circa 1840, England coal mines: "In every district except North Staffordshire, where the younger children were needed in the potteries, the employment of children of seven was common; in many pits children were employed at six, in some at five, and in one case a baby of three was found working underground.

Such babies were sometimes taken down into the pits to keep the rats from their father's food.

The youngest children, both boys and girls, were employed as trappers; that is, they were in charge of the ventilating doors in the galleries, on the opening and closing of which the safety of the mines depended. Such a boy would sit in a small cell with a cord in his hand in darkness and solitude for twelve hours or longer at a time. The solitude was periodically interrupted while the trucks and the rats went by."

Reference: Hunter, D.: *The Diseases of Occupations*, p. 129. English Universities Press Ltd, London (1969).