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Nickel-Cadmium Battery
Reconditioner

Assignment 61 501
MEL R&D Report 183/66
August 1966

By
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ABSTRACT

A device has been designed for automatically reconditioning a nickel-cadmium battery. Individual cell voltage detectors and/or a battery terminal voltage are utilized to determine when reconditioning is necessary. Reconditioning is accomplished by discharging each cell to nearly 0 volts, then recharging the battery at a small current. Controlled discharge of the battery is accomplished by individual cell shunting transistors and a battery current shunt transistor. Cell reversal is prevented by cutting off the battery dump current when a cell voltage reaches a low limit.

author

REFERENCE

(a) Potter, Nelson and Richard Morrison, "Two Level Voltage Limiter," Goddard Space Flight Center Rept X-716-66-7, Jan 1966

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NICKEL-CADMIUM BATTERY RECONDITIONER

1.0 INTRODUCTION

The U. S. Navy Marine Engineering Laboratory was requested by NASA (Goddard Space Flight Center (GSFC)) as part of Contract S-12730-G, Amendment 5 of 20 April 1965, to design and develop a device operating within a battery test system for automatically reconditioning nickel-cadmium cells. This report presents a description of the device designed to perform this task.

1.1 Development Task. When a nickel-cadmium battery is subjected to extensive cycling, degradation in the ampere-hour capacity of each cell occurs. Degradation takes place in the form of a "memory effect; i.e. after repetitive cycling of a nickel-cadmium to a given depth of discharge, the cell "remembers" this depth and will deliver only that amount of ampere-hour capacity, instead of its rated capacity. The number of cycles to which a battery may be subjected before the loss in ampere-hour capacity is critical varies among batteries of the same capacity, and with environment and depth of discharge. When the memory effect has taken place, it is indicated by a low battery voltage and/or a low cell voltage near the end of the discharge cycle. Previous tests on nickel-cadmium cells have indicated that the ampere-hour capacity of a battery can be restored by "bleeding" each cell down to approximately 0 volts and then recharging the battery at a current[1] that is very low (approximately C/10 current[2]).

The "memory effect" on each cell varies from cell to cell and results in cell unbalance in a battery Reconditioning removes this capacity unbalance by providing the cells with a common reference condition for recharging.

It is evident that reconditioning a battery pack of nickel-cadmium cells results in an extended life for the battery and provides for greater utilization of a battery's ampere-hour capacity. This greater efficiency would permit the use of a smaller ampere-hour battery pack for a given satellite payload

[1] Referred to as reconditioning
[2] C = cell capacity in ampere-hours; 10 = number of hours for charging

capability. The ultimate goal in developing this nickel-cadmium battery reconditioner, originally designed to operate in a laboratory battery test system, is adaptation to satellite power systems.

1.2 Problem Background. The method presently used to recondition nickel-cadmium batteries is designed to count the number of cycles to which a battery has been subjected and then automatically to discharge the battery by placing a load resistor across each cell.

The disadvantage of this method is twofold. First, since the number of cycles, and not a low voltage condition, is used to determine when reconditioning is to take place, the battery will be reconditioned irrespective of the state of degradation of the cells. Secondly, to prevent reverse charging of a cell, relays switch individual load resistors across each cell to discharge the battery. This requires relay contacts in series with each cell of the battery. The new nickel-cadmium battery reconditioner is a voltage detection device that utilizes a low voltage condition on the battery terminals or on a cell to indicate when degradation of the battery is such that reconditioning is necessary. Since the number of cycles to which a battery can be subjected before severe degradation occurs varies widely with environment, the voltage detection method is superior to the method of counting cycles. The use of transistors as a shunt load for each cell eliminates the need for relays and associated contacts to switch load resistors across each cell.

2.0 OPERATION

The following section provides a general description of the operation of the nickel-cadmium battery reconditioner and the battery test system it is used with. A detailed description of each circuit and its operation may be found in Section I of Appendix A. Section II of Appendix A is a detailed description of component. Section III contains the recommended adjustment and calibration procedure.

2.1 Functional Description. The nickel-cadmium battery reconditioner can best be described by the functional diagram shown in Figure 1. These functional units are: (1) battery under voltage detector and timer control, (2) cell voltage detector and control circuit, (3) battery current dump transistor, (4) individual cell-shunt transistors, and (5) a cycle number control. The orbit time control, shunt regulator, charger, and spacecraft load are shown to illustrate the relationship of the battery reconditioner to the rest of the battery test system.

The charger, spacecraft load, and shunt regulator are connected in parallel. Normally, the power from the charger is supplied to the battery and load during the daylight period of orbit. In the dark period, the battery supplies the power demands of the load. If degradation of the battery has taken place (loss of ampere-hour capacity), a low voltage condition on a cell or the battery will exist near the end of the discharge period. If the voltage of a cell or the battery falls below the respective preset limit, the battery is switched from the load to controlled discharge.

In controlled discharge, the battery-current dump transistor discharges the battery, and the cell-shunt transistors are biased "on" to discharge each cell. The current in the dump transistor is controlled by the voltage of the lowest cell of the battery. Cutoff is obtained when a cell reaches a preselected lower limit. This cutoff prevents reverse charging of that cell. The shunt transistors continue to deplete each cell of the remaining ampere-hour capacity, thereby assuring that the voltage of all cells will be reduced to near zero.

When the time control notes that sufficient time has elapsed for all cells to discharge, the timer removes the bias from the cell shunt transistors, opens the spacecraft load circuit, and places the battery in parallel with the charger and shunt regulator. The charger provides a constant current to recharge the battery to a voltage level determined by the shunt regulator, reference (a). Sufficient time for charging is preset into the timer control. When the battery is completely charged, the load is returned to the battery and charger. Normal cycling of the battery is resumed by the orbit time control with the battery reconditioner remaining in standby status. The cycle number control counts the number of cycles completed on the battery when a low voltage condition is reached. If desired, this device may also be used to switch the battery to controlled discharge after a preselected number of cycles has been completed.

2.2 Discussion. Since the initial purpose of the design of the nickel-cadmium battery reconditioner was to determine its feasibility through use in a battery test system, a number of parameters and operating conditions were made selective so that optimum conditions for system operation could be determined. These include the variable parameter adjustments which are: (1) battery low-voltage trip level (3 to 6 volts), (2) minimum cell voltage for zero-battery dump current (25 to 500 millivolts), (3) transistor-dump current (0.1 to 0.5 amperes), (4) cell shunt transistor current (50 to 750 milliamperes at 1 volt), and (5) sensitivity of dump transistor to control circuit. The following selective methods of switching to controlled discharge are provided: (1) low cell voltage, (2) low battery voltage, (3) cycle number limit, (4) low cell voltage or cycle-number limit, and (5) either low cell voltage, low battery voltage, or cycle-number limit. A means for bypassing the dump transistor, and using only the cell shunt transistors to discharge the battery, is also provided.

The added versatility obtained from these flexible characteristics allows this device to be used to obtain its own optimum operating conditions, as well as those for the battery pack. Although this instrument is designed for a 5-cell battery, the concept can be expanded to operate with any number of cells.

3.0 RESULTS

The characteristics obtained from a typical battery reconditioning operation are illustrated in Figure 2.[1] A 5-cell, 6 ampere-hour nickel-cadmium battery was being cycled in a battery test system. The cell voltage of four of the five cells was recorded. A low cell voltage on cell No. 1 is noted during discharge of the battery. At time T = 15 minutes on the graph, the reconditioner switched the battery to the dump transistor (Q_6) of Figure 1. The battery current through the dump transistor is reduced to approximately 0 as the voltage of cell No. 1 is reduced to a preset low limit. The remaining cells have their residual ampere-hour capacity removed by the individual cell shunt transistors (Q_5 of Figure 1). The area under the curves for each cell provides a graphic illustration of cell unbalance within the battery.

[1]Data obtained from GSFC, Greenbelt, Maryland

4.0 CONCLUSION

Two prototypes of the nickel-cadmium battery reconditioner have been built and delivered to NASA, GSFC, Greenbelt, Maryland. The first prototype was used to determine the feasibility of such a device, while the second one was built to serve as a model for production of the device. Photographs of the second unit are shown in Figures 3, 4, and 5.

The first prototype has been operating satisfactorily in a battery test system since December 1965. Results indicate that the voltage method of determining when a battery should be reconditioned is far superior to the number-of-cycles method.

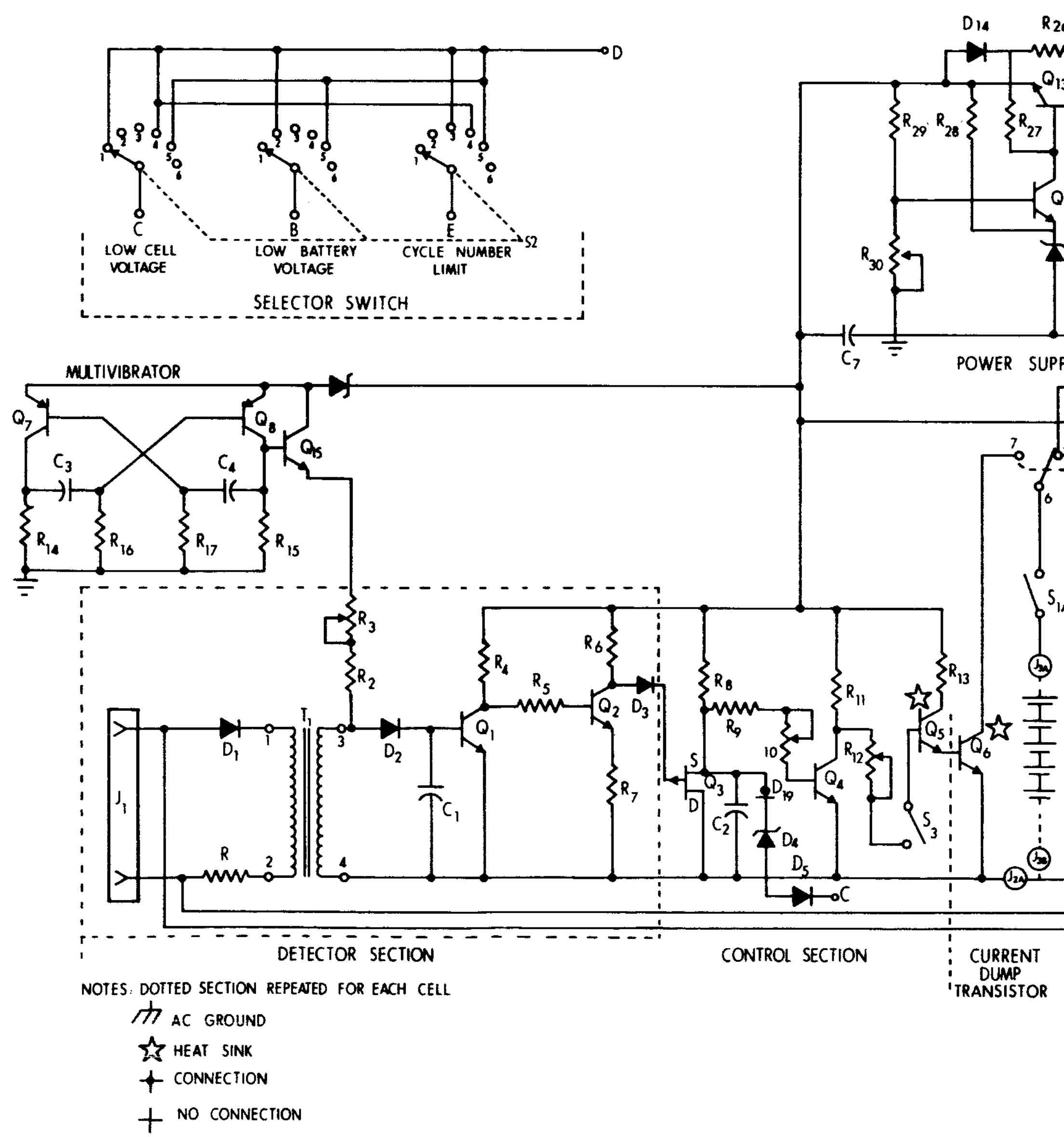
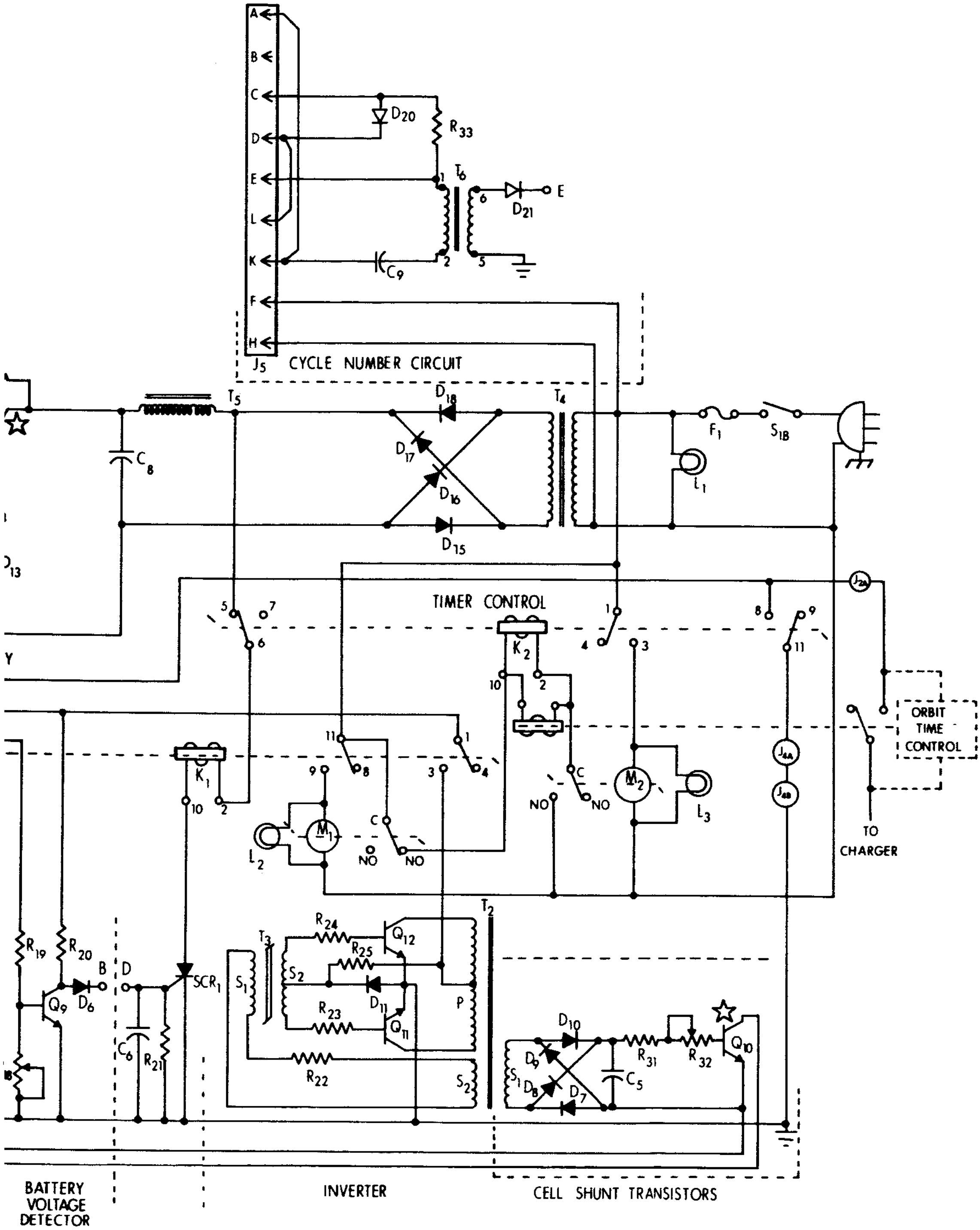


Figure 1-A - Nickel-Cadm



ADJUSTMENTS

R_{10} CUTOFF BAND ADJ	R_{30} POWER SUPPLY ADJ
R_{18} BATTERY VOLTAGE TRIP ADJ	R_3 DETECTOR CAL
R_{12} DUMP CURRENT ADJ	

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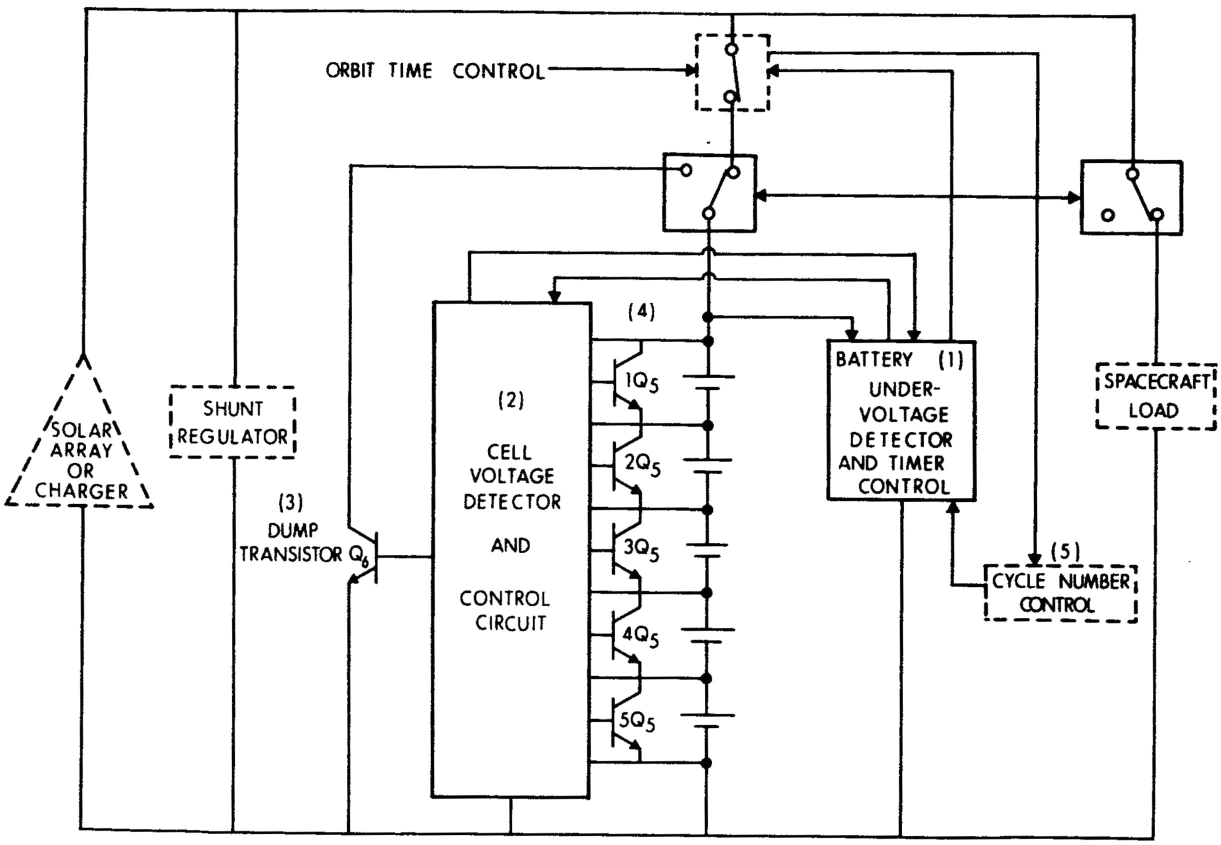

Figure 1
Nickel-Cadmium Battery Reconditioner System

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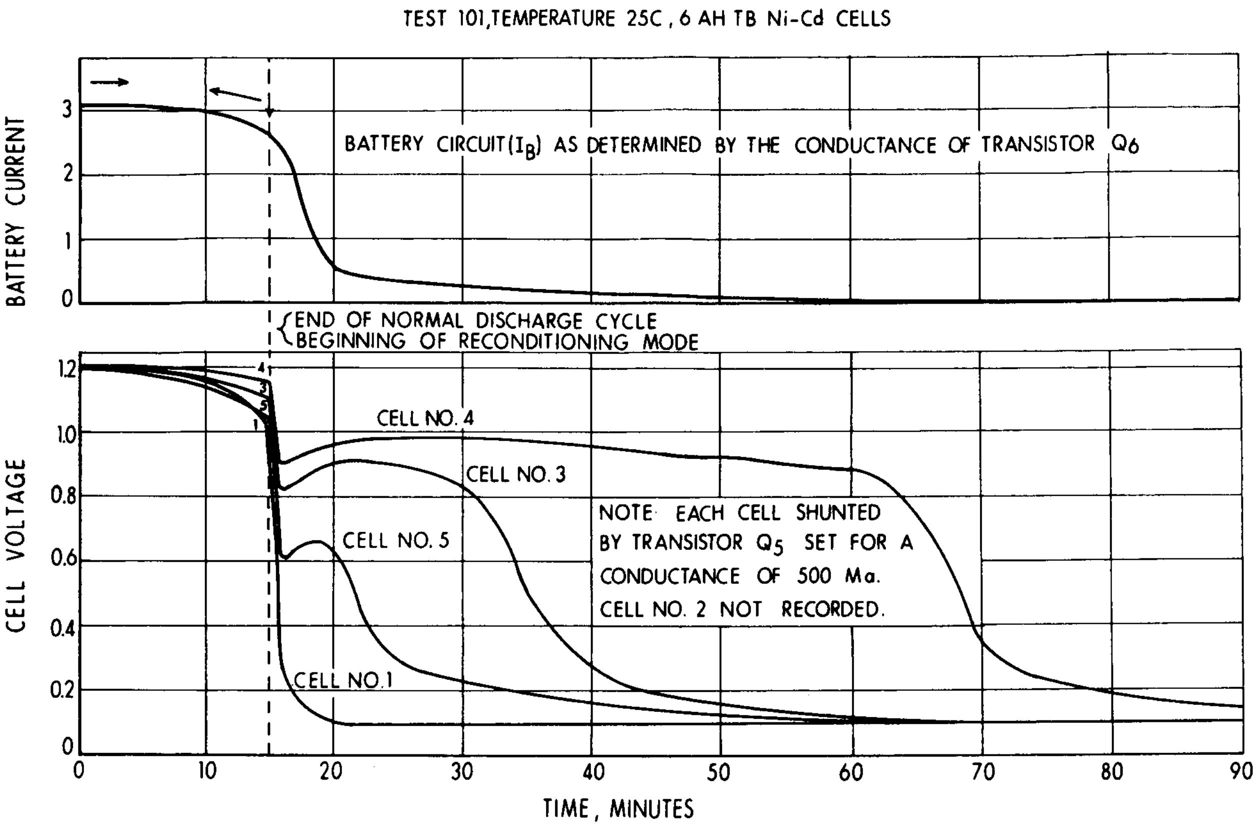


Figure 2
Characteristics of 5-Cell Battery Being
Discharged by Reconditioner

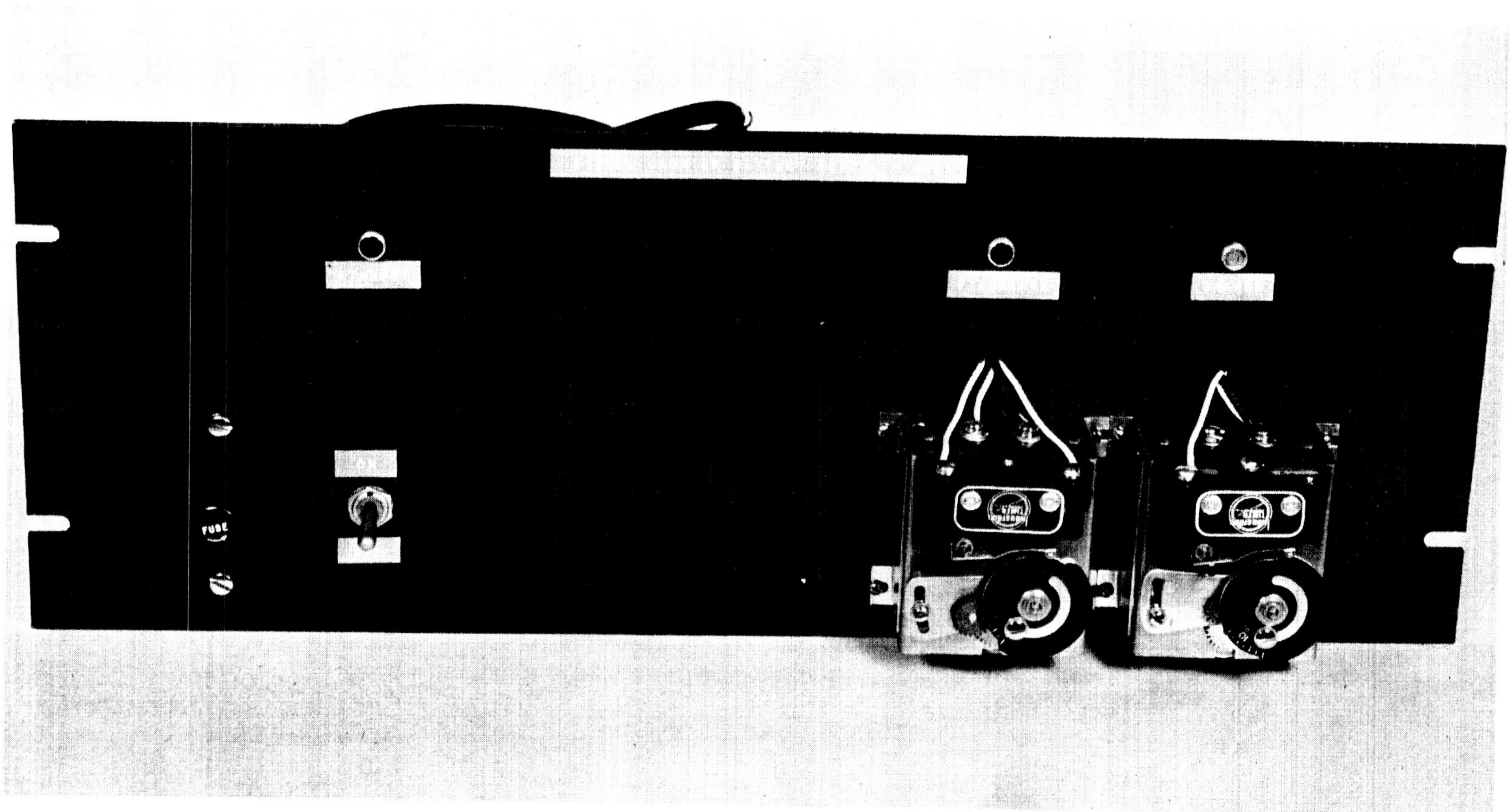


Figure 3
Nickel-Cadmium Battery Reconditioner, Front View

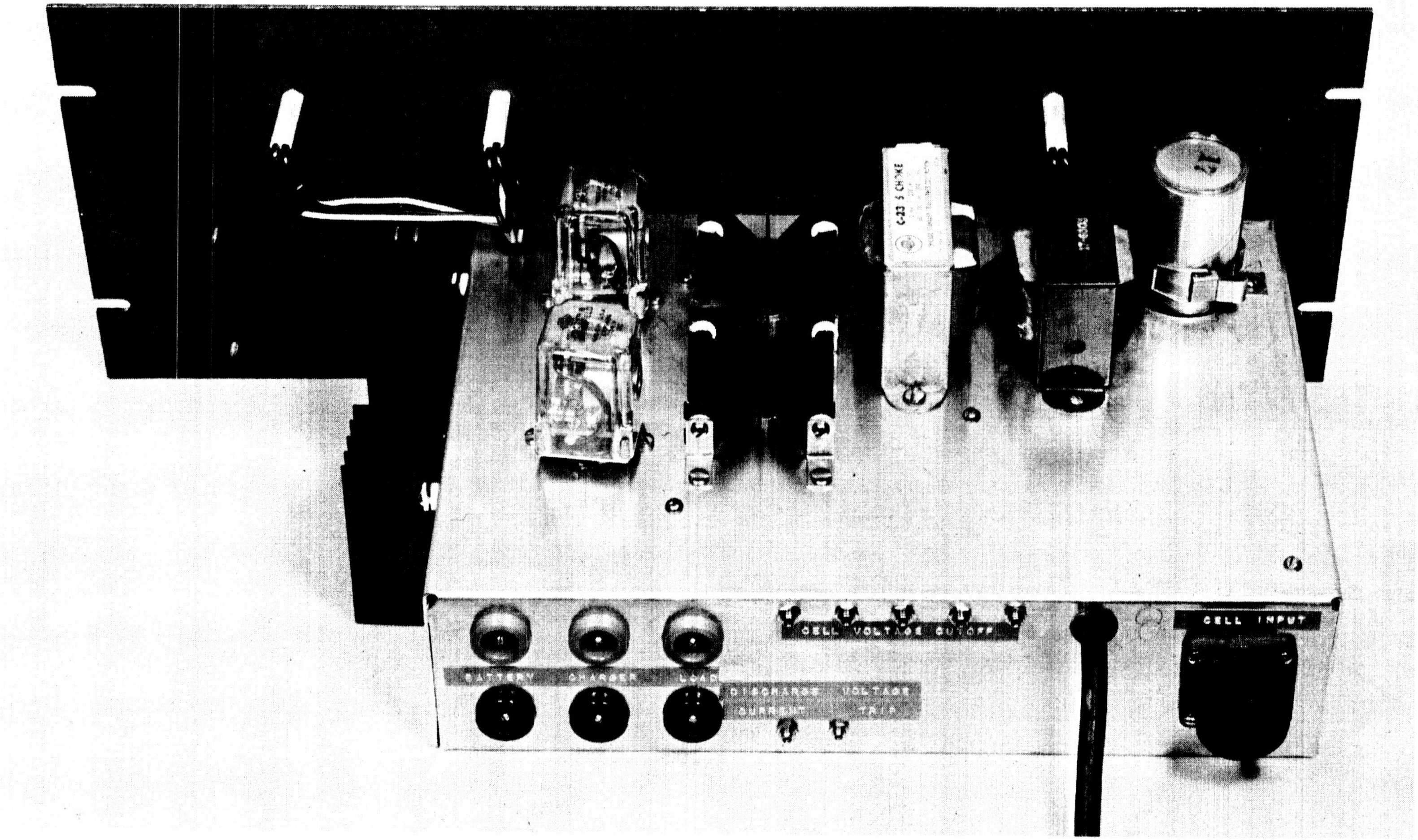


Figure 4
Nickel-Cadmium Battery Reconditioner, Top-Rear View

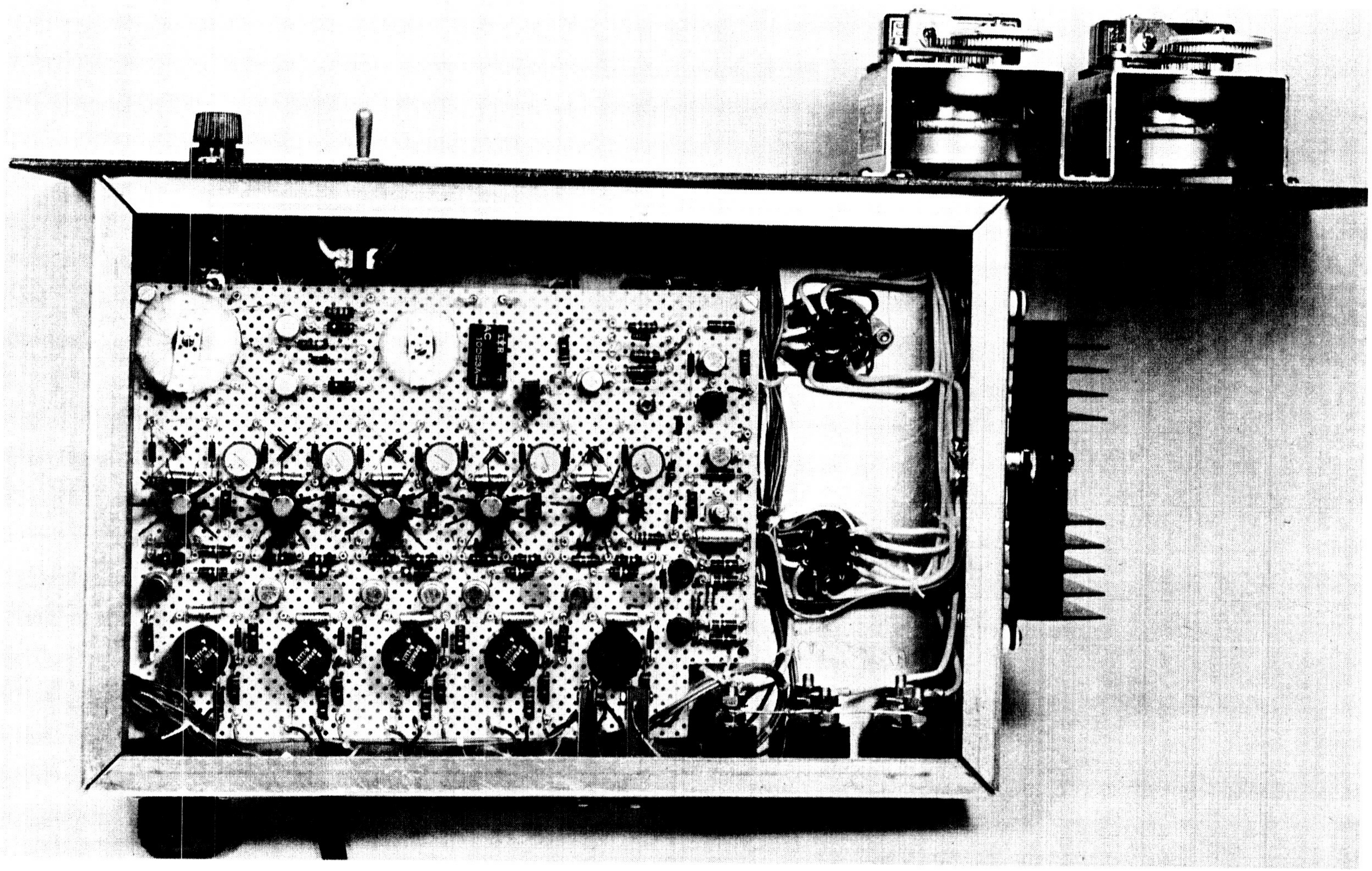


Figure 5
Nickel-Cadmium Battery Reconditioner, Bottom View

Appendix A

Operators Guide for Nickel-Cadmium Battery Reconditioner

Section I

Description

The reference characters used in this description refer to Figure 1-A. The battery terminal under-voltage detector consists of Transistor Q_9, Resistors R_{18}, R_{19}, and R_{20}. Resistors R_{18} and R_{19} form a voltage divider across the battery terminals, with the voltage drop ratio being determined by potentiometer R_{18}. This potentiometer is adjusted to provide saturation of Transistor Q_9 when the battery voltage is above the desired level (approximately 5 volts). If the battery voltage drops below this level, Transistor Q_9 comes out of saturation, thus providing an increasing voltage at its collector. Diode D_6 becomes forward biased, and allows the collector voltage to appear at Point B. Resistor R_{20} current limits Transistor Q_9 when in saturation and forms a voltage divider with Resistor R_{21} when Transistor Q_9 comes out of saturation.

The Silicon Controlled Rectifier (SCR_1) and Relay K_1 provide the switching action necessary to place the battery on controlled discharge. Switch S_2 provides an "or" connection from the low cell voltage detector, low battery voltage detector, and the cycle number counter to SCR_1. The wiring of this switch is such that a low cell, or low terminal voltage, or cycle-number limit, or low cell and cycle-number limit, or low cell and low terminal and cycle-number limit, will determine when the battery is to be placed on controlled discharge. When any one of these conditions exist, a signal appears at Point D, gating SCR_1 on and energizing the coil of Relay K_1, thus closing the normally open contacts associated with Relay K_1. Three functions are performed by these contacts: (1) The battery is placed across the Discharge Transistor, Q_6; (2) The 10 volts d-c supply is connected to the inverter circuit which biases the cell shunt transistors, Q_{10}, on; (3) The timer motor, M_1, is energized from the a-c line to start the discharge timer.

With the battery terminals shunted by Transistor Q_6, the battery discharge current is controlled by the bias condition set on Transistor Q_5 by Resistors R_{11} and R_{13}, and Potentiometer R_{12}. Since Transistor Q_4 is normally cutoff when all cell voltages are above the level set for detector control, the current available through Resistor R_{11} becomes the base current of Transistors Q_5 and Q_6, the collector-to-emitter current (battery current) of Q_6 is a direct function of base current of Transistor Q_5. Potentiometer R_{12} provides an adjustment for setting the maximum discharge current from the battery. Switch S_3 provides a manual control to prevent discharge of the battery by Transistor Q_6, when it is desirable to use only the cell shunt transistor for a load.

The individual cell voltage detector consists of Resistors R_1-R_7, Diodes D_1-D_3, Transistors Q_1 and Q_2, Capacitor C_1, and Toroidal Transformer T_1. This section is repeated for each cell. The square wave signal to drive each detector is provided by a conventional free-running multivibrator. This consists of Resistors R_{14}-R_{17}, Transistors Q_7 and Q_8, and Capacitors C_3 and C_4. Transistor Q_{15} provides for an impedance transformation between multivibrator and input to detector. The output of the multivibrator is approximately 500 cps, 5-volt square wave, referenced to ground. Diode D_{12} reduces the supply voltage to the multivibrator and may be used to shift the operating range of all the detectors.

Each cell is connected to the input of a detector, Resistor R_1 and Diode D_1. As a cell voltage decreases, the d-c current through Diode D_1 decreases, resulting in an increasing dynamic impedance of the diode. This change in dynamic impedance in the a-c side of Transformer T_1, which is part of the voltage dividers formed with Resistors R_2 and R_3. When a cell voltage at the detector input is high, the reflected dynamic impedance in the a-c side of Transformer T_1 is very small, thereby supporting little voltage drop across the windings. With no current available to the base of Transistor Q_1, it is in the cutoff region. As the voltage level at Point 3 increases (decreasing cell voltage), Diode D_2 becomes forward biased and allows energy to be stored in Capacitor C_1. An increasing voltage level on C_1 causes Transistor Q_1 to come out of cutoff and into the active region. The collector voltage of Transistor Q_1 is then a function of the voltage level at Point 3. The voltage at the detector input that determines when Q_1 comes out of cutoff can be set by Potentiometer R_3.

Since the voltage at the collector of Transistor Q_1 is high when the input to the detector is high (high cell voltage), an inversion is necessary in order to form an "or" connection to the control circuit. Transistor Q_2 with Bias Resistors R_5, R_6, and R_7 provide for this inversion. Diode D_3 from each detector forms the "or" connection to the input of the control circuit. With a high cell voltage at the input to each detector, all detector outputs are near zero.

The output of each detector is connected to the gate of the field effect transistor, Q_3, the input to the control circuit. As the output voltage of a detector increases, the voltage at the gate (and the source) of the field effect transistor, Q_3, increases to Bias Transistor Q_4 into the active region. The field effect transistor, being almost an ideal voltage control, prevents summing effect from the "or" circuit; i.e. the detector with the highest output voltage will be the controlling detector, irrespective of the lower voltage level of other detectors. Resistor R_8, and Resistors R_9 and R_{10} are bias resistors for Transistors Q_3 and Q_4, respectively. With Transistor Q_4 biased into the conducting state and eventually into the saturation region (as cell voltage decreases) Transistors Q_5 and Q_6 are gradually cutoff, thus reducing the current from the battery to zero. Resistor R_{10} allows the band of actual controlled cutoff to be adjusted for sharp cutoff, or a linear cutoff.

The output of field effect transistor, Q_3 is also connected to the gate of SCR_1 to provide for controlled discharge of the battery, if a cell voltage comes within the active region of the detector before an under-voltage condition occurs on the battery. This prevents a cell from being reversed charged. Field effect diode, D_{19}, is a current limiting diode to prevent loading the output of Transistor Q_3, while zener Diode D_4 provides a d-c level shift to compensate for the off-set voltage at the source of the field effect transistor, Q_3. Diode D_5 is part of the "or" circuit to SCR_1 and prevents interaction from other circuits feeding the "or" connection.

To use the cycle number counter to switch the battery to control discharge, it is necessary to obtain a signal from a set of normally open-normally closed contacts within the counter. Resistor R_{33}, Transformer T_6, and Capacitor C_9 form a pulse shaping network that operates from the counter power supply. Upon completing a predetermined number of cycles, the counter resets and a pulse appears at the "or" connection, formed by Diodes D_{21}, D_5, and D_6. With Switch S_2 in Position 3, 4, or 5, SCR_1 will be energized, switching the battery to control discharge. Diode D_{20} is an arc suppressor to protect the contacts of the counter.

The circuit to drive the individual cell load transistors consists of an inverter, a rectifier, and shunt transistor for each cell. The inverter consists of Transistors Q_{11} and Q_{12}, Resistors R_{22}-R_{24}, Transformers T_2 and T_3, and Diode D_{10}. This is a conventional two-transformer inverter with the exceptions of Diode D_{10} and Resistor R_{25} which were added to ensure a positive start when power is applied. The secondary of Transformer T_2 consists of five separate windings (one for each cell) so that complete isolation is maintained between cells. The bridge rectifier, Diodes D_5-D_8, along with Capacitor C_5 provides a d-c voltage from the inverter to drive the cell shunt transistor. Resistor R_{24} is a current limiting resistor, while Resistor R_{25} provides for adjustment of cell discharge currents (50 to 750 ma) by controlling the bias current of the shunt transistor. Each shunt transistor discharges its respective cell to approximately 0 volts. The improtant characteristic of Transistor Q_{10} is one having a low saturation voltage. A switching-type transistor serves this application very well.

After sufficient time has been allowed for all cells to be completely discharged, the mechanical actuated switch associated with Timer M_1 closes the normally open contact and applies the a-c line voltage to the coil of Relay K_2. The contacts associated with Relay K_2 perform three functions: (1) de-energizes the relay coil, K_1 (all contacts return to normally closed position); (2) opens circuit-to-battery load; (3) starts the charge period timer, M_2, and energizes Relay K_3 to bypass orbit time control. The battery is now charged at a current rate determined by the setting of Timer M_2. At the end of the charge time, the relay coil of K_2 is de-energized and the battery is returned to normal cycling. Standby status is maintained as long as Switch S_1 is on with the mode of operation being determined by the position of Switch S_2.

A 115-volt, 60-cps a-c voltage is required to operate this instrument. Timers M_1 and M_2, and Relays K_2 and K_3 are energized directly from the line of voltage, while Relay K_1 is operated from the output of the bridge rectifier. The d-c power supply consists of a bridge rectifier, Diodes D_{15}-D_{18}; a filter, Choke T_4 and Capacitor C_8; and the series voltage regulator, Resistors R_{26}-R_{30}, Diodes D_{13} and D_{14}, and Transistors Q_{13} and Q_{14}. The 115±10 percent line voltage is converted to 10 volts ±1 percent d-c and is regulated for a 100 percent load charge.

Section II

Parts List

Nickel-Cadmium Battery Reconditioner

R_1	3.3K[1]	
R_2	4.7K	
R_3	25K	1/4-watt, 25-turn potentiometer, wire wound (panel mount)
R_4	10K	
R_5	510K	
R_6	10K	
R_7	2.2K	
R_8	5.6K	
R_9	33K	
R_{10}	25K	1/4-watt, 25-turn potentiometer, (circuit board)
R_{11}	1K	
R_{12}	50K	1/4-watt, 25-turn potentiometer, carbon or metal film (panel mount)
R_{13}	47Ω	2 watt
R_{14}, R_{15}	10K	
R_{16}, R_{17}	47K	
R_{18}	2K	1/4-watt, 25-turn potentiometer, carbon or metal film (panel mount)
R_{19}, R_{20}	10K	
R_{21}	2.7K	

[1] K = thousand

R_{22}	2.7Ω	
R_{23}, R_{24}	22Ω	
R_{25}	5.6K	
R_{26}	560Ω	
R_{27}	430Ω	
R_{28}	620Ω	
R_{29}	560Ω	
R_{30}	2K	1/4-watt, single-turn potentiometer, carbon, (circuit board)
R_{31}	100Ω	
R_{32}	2K	1-watt, single-turn potentiometer (IRC series 100)
R_{33}	200K	All resistors 1/2 watt 5 percent unless otherwise noted

Capacitors

C_1	10 mf[1]	10-v dc	(Sprague Type 150D)
C_2	33 mf	20-v dc	
C_3, C_4	.033 mf	20-v dc	
C_5	22 mf	15-v dc	
C_6	10 mf	10-v dc	
C_7	68 mf	20-v dc	
C_8	1500 mf	25-v dc	
C_9	1 mf	200-v dc	

[1]Abbreviations used in this text are from the GPO Style Manual, 1959, unless otherwise noted.

Transistors

Q_1	2N338
Q_2, Q_4, Q_{14}	2N1613
Q_3	2N2609
Q_5, Q_{13}	2N1720
Q_6	164-04 (Westinghouse)
Q_7, Q_8	2N1303
Q_9	2N1302
Q_{10}, Q_{11}, Q_{12}	2N2192A
Q_{15}	2N1308

Diodes

D_1	1N191
D_2, D_3, D_5-D_{11}, D_{21}	1N457
D_4	1N751A
D_{12}	2N2192A
D_{13}	1N752
D_{14}	1N746
D_{15}-D_{18}	1N4002
D_{19}	MCL 1300 (Motorla)
D_{20}	1N4005
SCR_1	2N2324

Transformers and Chokes

T_1	Spraque Electric Co. R1111
T_2	Core, Arnold Engrg. Co. 5504D-1 Primary (2) 47 Turns Bifilar, No. 27 wire Secondary (S_1) (5) 15 Turns, No. 34 wire Secondary (S_2) (1) 15 Turns, No. 34 wire
T_3	Core, Arnold Engrg. Co. 5515D-1 Primary (1) 50 Turns, No. 34 wire Secondary (2) 35 Turns, Bifilar, No. 34 wire
T_4	Filament Transfer Primary: 117 volts, 50/60 cps Secondary: 26.5 volts, center tapped at 6 amp (Knight No. b-K-48HF)
T_5	Choke 2 H[1] at 200 ma 60Ω d-c resistance (Stanco No. C-2325)
T_6	Pulse Transformer, UTC H-51

Relays

K_1	Potter and Brumfield, KRP 14 DG, 24-v d-c Coil
K_2	Potter and Brumfield, KRP 14 AE, 115-v d-c Coil

Timers

M_1, M_2	Industrial Timer Corporation, Model CM 10

Lights

L_1, L_2	Leecraft, No. 36EN2111 RED
L_3	Leecraft, No. 36EN2113 Amber

[1] H = Henry

Connectors

J_1	Amphenol, No. MS 3102A-20-33S, with mating plug
J_2-J_4	Superior Electric Co., No. RP25GR (3)
J_5	Amphenol, No. MS 3102A-28-14P, with mating socket

Switch

S_1	DPST - Toggle, 10-amp contacts
S_2	3 pole - 5-position; nonshort
S_3	SPST Toggle

Heat Sink

Wakefield	No. NF 209	(5)
Wakefield	No. NC 403K	(1)
Wakefield	No. NC 301M	(2)

Power Cord

Belden N	17408-S, 3 wire, 8 ft

Section III

Adjustment and Calibration Procedure

Note: It is recommended that all adjustment procedures be read before proceeding with individual adjustments.

The following instruments are necessary for adjustment and calibration:

1 - Multirange voltmeter (digital voltameter preferred)

2 - Power supply; 0-5 volts, 0-750 milliamps

3 - Power supply; 0-10 volts, 0-5 amperes

4 - Ammeter; multirange clip-on, 5 amperes maximum

A. Power Supply Voltage Adjustment

1 - Plug instrument in ac (115 volts, 60 cps) and place Switch S_1 in "on" position.

2 - With a voltmeter across Capacitor C_7, adjust Resistor R_{30} (on circuit board) for 10 volts on meter.

B. Battery Low-Voltage Trip-Level Adjustment.

Note: Complete A above before preceeding.

1 - Set cams on Timer M_1 and M_2 at beginning of lobe (cams rotate clockwise).

2 - Set Selector Switch S_2 to "low battery."

3 - Connect power supply to battery terminals and set voltage to desired trip level.

4 - Adjust battery voltage trip adjustment screw (R_{18}) until Relay K_1 is energized (discharge light comes on).

5 - Reset of Relay K_1 may be accomplished by moving the cam of Timer M_1 to it's flank.

C. Battery Dump Transistor Current Adjustment.

Note: Complete A and B above before preceeding.

1 - Place cell detector (J_1) inputs in parallel and connect to approximately 2-volt power supply.

2 - Place dump transistor switch (S_3) in "on" position.

3 - Adjust dump current adjustment screw (R_{12}) for desired current. A clip-on ammeter may be used to measure this current.

D. Minimum Cell Voltage for Zero Dump Current Adjustment.

Note: This procedure may be a continuation of C above.

1 - Connect one detector input to a power-supply voltage set at the level desired for zero dump current. (The other detectors are in parallel across the 2-volt supply.)

2 - Set cutoff band adjustment screw (R_{10}) at midrange of adjustment. This may be varied to obtain desired cutoff band in conjunction with the following steps:

(a) Adjust the detector calibration screw, corresponding to the detector connected to the variable power supply for zero dump current using a sensitive ammeter (clip-on type) to indicate zero current.

(b) Vary the input to the detector and adjust cutoff band adjustment until desired "active" band of detector control over transistor dump current is obtained.

(c) Repeat Steps (a) and (b) above for each detector until all 5 detectors are calibrated.

E. Individual Cell Discharge Adjustment.

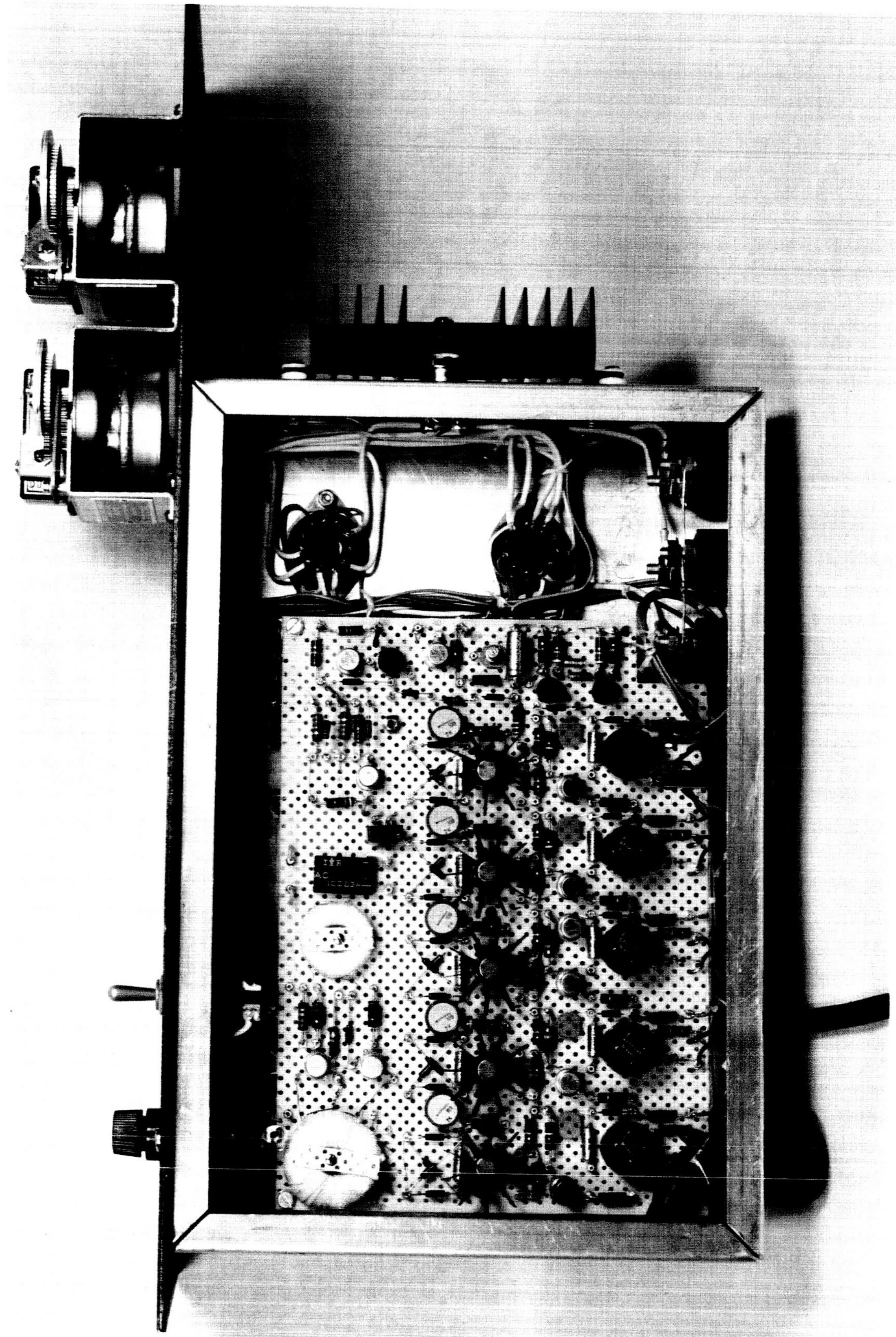
Note: This adjustment may be made in conjunction with D-1 above.

1 - Set the voltage input to the single detector to 1 volt.

2 - Connect a clip-on ammeter on a lead to the detector input for current measurement.

3 - Adjust Potentiometer R_{32} (on circuit board) for corresponding detector to obtain the desired current level to be shunted by the individual cell shunt transistor.

4 - Repeat Steps (1), (2), and (3) above for all five detectors or shunt transistors.



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13. ABSTRACT

A device has been designed for automatically reconditioning a nickel-cadmium battery. Individual cell voltage detectors and/or a battery terminal voltage are utilized to determine when reconditioning is necessary. Reconditioning is accomplished by discharging each cell to nearly 0 volts, then recharging the battery at a small current. Controlled discharge of the battery is accomplished by individual cell shunting transistors and a battery current shunt transistor. Cell reversal is prevented by cutting off the battery dump current when a cell voltage reaches a low limit.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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