APPENDIX A

NICKEL CADMIUM BATTERIES - TECHNICAL NOTES

1. All the battery chargers supplied by Grinel are so designed that by using them, the safety and long life of the batteries are assured.

2. Should Grinel battery chargers not be available, the following technical notes are offered so that the user may derive the maximum benefit from these remarkable batteries.

3. Each battery consists of 10 cells. The electrodes of the cell are made from sintered nickel mesh, the negative electrode impregnated with cadmium hydroxide and the positive electrode impregnated with nickel hydroxide. The electrodes are separated by a porous spacer, which is impregnated with the electrolyte, potassium hydroxide solution. During the charging process the nickel hydroxide $Ni(OH)_2$ at the positive electrode is converted to beta-nickel-hydroxy-oxide NiOOH and the cadmium hydroxide $Cd(OH)_2$ at the negative electrode is converted to metallic cadmium.

4. As soon as the cell is fully charged, a secondary reaction occurs. The electrolyte is decomposed, releasing oxygen gas. At low charging this gas dissolves in the electrolyte and travels to the negative electrode, where it combines with the metallic cadmium to form cadmium hydroxide and the process can continue indefinitely without physical release of excess oxygen.

5. In practice it has been found that if the capacity of a battery in ampere-hours (Ah) is C, then below 90% of full charge, the maximum current the battery may be charged with is

$$I_1 = \frac{C}{1 \text{ hour}}$$

Above 90% of full charge the rate must be reduced to a maximum of

$$I_2 = \frac{C}{10 \text{ hours}}$$

6. The battery used in this equipment is 5 Ah capacity and the two charging currents which may be used are:

$$I_1 = \frac{C}{1 \text{ hour}} = \frac{5}{1} = 5 \text{ amps maximum below 90\% charge}$$

$$I_2 = \frac{C}{10 \text{ hours}} = \frac{5}{10} = 0{,}5 \text{ amps maximum above 90\% charge}$$

7. While these nickel cadmium cells can be charged at 5 amps, extreme precautions must be taken to prevent overcharging. As explained in the previous paragraph, overcharging at a high rate will produce free oxygen and this can generate sufficient pressure to cause the cell to explode. Charging at a high rate from a constant voltage charge can also produce a second phenomenon - "thermal run-away". This can be caused at any time after the cell is 90% charged. As the cell approaches full charge the e.m.f. of the cell tends to drop slightly due to a small internal temperature increase caused by the charging current. This drop in e.m.f. will cause the charging current to increase, increasing the internal heat, further lowering the cell e.m.f. and thus further increasing the charging current. Unless the charge is terminated, this process will reach the stage where the complete destruction of the cell, with possible explosion due to boiling electrolyte, will occur.

8. From the foregoing it can be concluded that the safest method of charging nickel cadmium batteries is to charge from a constant current source at a rate not exceeding 0,5 amps. In order to fully charge a battery at 0,5 amps the charging must be continued for 12 to 14 hours. Overcharging can be permitted at this rate without damage to the cell. For optimum results the cells should be charged at an ambient temperature in excess of $50^{o}F$ ($10^{o}C$).

9. If for operational reasons it is necessary to charge the cells at rates in excess of 0,5 amps full precautions must be taken to ensure that overcharging does not occur. Even a few minutes overcharge at 5 amps can cause a cell to explode and in any case the oxygen produced by an overcharge is not quickly reabsorbed into the cell, causing a concentration in the cell electrolyte together with a reduction in capacity. If high rate charging is required it is advisable to use a special charging circuit which reduces the charging current to 0,5 amps or below as soon as the battery is 90% charged.

10. Alternatively, if the state of charge of the battery is known accurately before recharging is commenced, the time required to bring the battery to 90% charge can be calculated, after which time the charging rate should be dropped to the 0,5 amps. For example, take a battery that is known to be exactly half charged, i.e. 2,5Ah remain in the battery and 2,5Ah must be replaced. Up to 90% of 5Ah = 4,5Ah so our half-charged battery may have 2Ah (4,5Ah - 2,5Ah) replaced at 5 amps. The remaining 0,5Ah must be replaced at 0,5 amps. The first part of the charge will take:

$\frac{2Ah}{5A}$ = 0,4 hours or 24 minutes which will bring the battery up to 90% full charge. The Final part of the charge will take:

$\frac{0,5Ah}{0,5A}$ = 1 hour or 60 minutes

11. If the state of charge of the battery is not known the battery should be discharged through a suitable lamp load (a 12V 80W car bulb is suitable) until the battery voltage is 1,0V per cell (10,0V for the battery in this equipment). The battery will then be fully discharged and can then be charged for 54 minutes at 5 amperes, after which time the charging rate should be reduced to 500 milliamps at which rate, charging can continue indefinitely.

12. Cells in batteries can also be damaged during discharge if the discharge is to deep. The capacity of individual cells will vary slightly, consequently the cell with the lowest capacity will become fully discharged first. If discharge is allowed to proceed beyond this point the low capacity cell will be reverse charged. The reversal of one cell will produce a drop in the battery output voltage, but if the remainder of the cells in the battery are much greater in capacity the terminal voltage of the battery may still be higher than the normal end point and the reversal of one cell will not be obvious from a meter reading.

13. A certain degree of protection is built into nickel cadmium cells and short periods of reversal do not damage the cells, they will return to normal on recharging. However, deep reverse charging can permanently damage the cell. In the battery in this equipment additional protection is provided by silicon diodes placed across each cell which effectively short circuit any cell which becomes fully discharged. To avoid the risk of cell damage due to reverse charging, it is recommended that batteries should not be discharged beyond the point where the individual cell voltage is 1,0V.

14. The capacity of the battery is affected by the ambient temperature during discharge. At temperatures between $15^{o}C$ and $30^{o}C$ full capacity can be expected. At $0^{o}C$, 90% of capacity is obtained and at $45^{o}C$, 75% of capacity. Battery terminal voltages will be somewhat lower than those obtained at normal ambient as the temperature is increased or decreased.

15. Nickel cadmium cells will lose a part of their charge during storage. At normal ambient temperature an initially fully charged cell will retain 70% of its capacity after 30 days and 50% after 60 days. These periods can be extended by storing the batteries at lower than normal ambient, but not freezing, temperatures.

16. Finally, there is one point which may not be immediately obvious. Nickel cadmium cells are alkaline devices, consequently, exposure to acid fumes or, more seriously, contact with acid is to be avoided. If possible, separate charging facilities should be set up for alkaline batteries, but if the batteries have to be charged on a plant normally used for lead acid cells the top of the bench should be washed down with a weak solution of sodium carbonate in water before placing the alkaline batteries in position. Alternatively, the bench top can be covered with a sheet of P.V.C. which can easily be washed as required.

17. Recently, cells of 7Ah capacity have become available and these are now being used in some Grinel equipments. These cells may be charged to 90% of fully capacity at 7A, the remaining 10% being replaced at 700mA. Alternatively a 700mA charge for 14 hours will recharge a fully discharged cell.

18. The NiCd cells have their ampere-hour capacity marked on them and this must be ascertained before starting the charge. If it is not possible to check the capacity it should be assumed (for TR28 equipments) that this is 5Ah and the complete battery charged accordingly.