THE CARE AND FEEDING OF NICKEL-CADMIUM BATTERIES

Richard W. Cummings
Principal Electronics Technician

Biomechanics Laboratory
University of California, San Francisco and Berkeley
San Francisco, California 94143
Berkeley, California 94720

Batteries are increasingly being used as power sources for externally powered prosthetic and orthotic devices. Nickel-cadmium (NiCd) batteries are popular in such applications, probably because they represent the best compromise when such factors as price, weight, energy storage, and rechargeability are considered.

NiCd batteries are generally considered to be rechargeable hundreds or even thousands of times. It was therefore something of a surprise to receive inquiries from others in the prosthetics field concerning sudden, premature failures of NiCd batteries. Investigation indicated that the high failure rate was caused by a remarkably inappropriate charger. This short article is a presentation of the author's personal experience with NiCd batteries over the last five years. After some initial failures a charger has evolved which, for the last two years, has operated almost daily without problems of any nature.

These comments apply only to the "standard" sealed NiCd batteries, i.e., those with a 12- to 16-hour charging time (also often designated a $\frac{C}{10}$ charge rate). There are some NiCd batteries available which the manufacturers claim can be charged in a much shorter time. These batteries are not as common as those with the longer charging times; therefore, this article is concerned only with NiCd batteries with a 12- to 16-hour charging specification.

Long battery life depends upon proper charging; therefore the battery and its charger must be considered together and must be designed as a *system*.

Sealed NiCd batteries require a different type of charger from that used with the familiar lead-acid automobile battery. A lead-acid battery responds best to a charger which produces a constant voltage at its terminals. During charging, the lead-acid battery voltage rises, and with a constant voltage charger the charging current decreases as full charge is approached. The voltage of a lead-acid cell is a fair indication of its

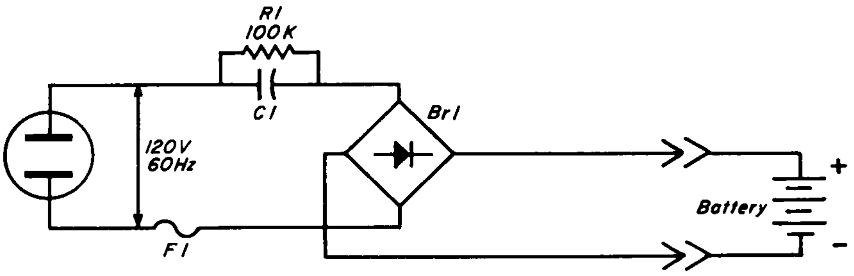


FIGURE 1.—Simple but dangerous charger circuit.

state of charge. The voltage of a NiCd battery is *no* indication of its state of charge, either during charge or during discharge, except at the very end of discharge. As the battery voltage does not change very much during charge, a small change in charger voltage can cause a large change in charging current. It is a characteristic of NiCd batteries that the voltage declines slightly as the temperature rises. Charging causes a temperature rise (charging is not 100 percent efficient), which results in a voltage drop which, with a constant-voltage charger, causes a current increase leading to a vicious circle of increasing temperature and current, which usually destroys the battery. Constant current charging eliminates this failure mode.

The first NiCd battery charger built by the author used the circuit shown in Figure 1. This is a *quasi* constant-current charger. The charge current is limited by the impedance of capacitor C_1 in series with the bridge rectifier and battery. Resistor R_1 is present to discharge the capacitor if it retains a charge after use. This charger performed well enough, but it is an extremely dangerous device since it has *no* isolation from the power line. However, it has been used successfully with very carefully designed double insulated instruments. The charging current is directly proportional to the capacitor size and to the line voltage. The capacitor usually is rather bulky since it must be designed to pass the required charging current. This type of charger is unsafe and unacceptable for use as a charger separate from the battery pack, and it should never even be considered as such.

The need for a charger separate from the batteries soon gave rise to the design shown in Figure 2. In this design the required isolation is provided by the transformer, and the current is regulated and quite constant with variations in line voltage or battery voltage—including the use of batteries with different numbers of cells.

Transformer T_1 reduces the line voltage, and bridge rectifier BR_2 converts this low voltage to a pulsating d.c., which is smoothed by capacitor C_2. The resulting voltage is applied through D_1 to the battery

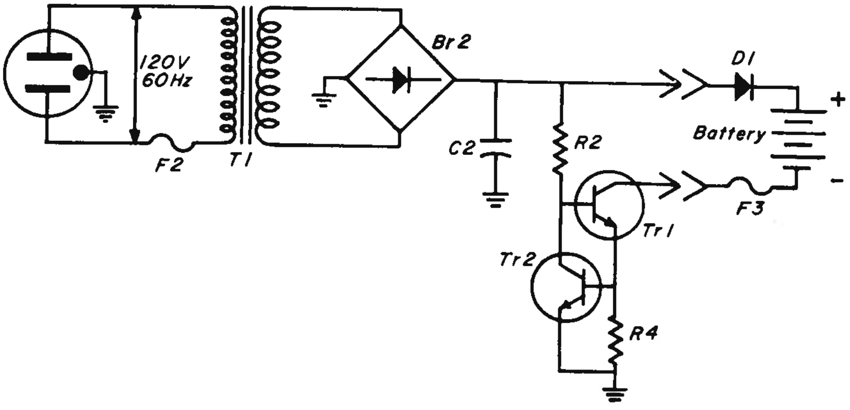


FIGURE 2.—Suggested charger circuit.

and through it to F_3 and Tr_1. R_2 furnishes current to the base of Tr_1 to cause it to conduct. When the current through the battery and through Tr_1 becomes large enough, the voltage across R_4 rises enough to turn on Tr_2 and cause it to divert base current away from Tr_1, thereby controlling the charging current. Diode D_1 prevents discharge of the battery when the transformer primary power is absent (blown fuse or plug removed from wall).

Three of these battery chargers have been built, each with slightly differing characteristics, and all have operated very well and without any known defects. One has the transformer primary switched and fused, so that it can be operated from a 220–260 v. or a 110–130 v., 50-Hz or 60-Hz, powerline. The charger has three selectable charge rates, 0.450 a., 0.100 a., and 0.045 a., and an ammeter to confirm that charging is actually occurring. This charger has been used in several countries to charge batteries in portable photographic and sound equipment. The greatest difficulty in using the charger has been finding adapters to convert the U.S.-type power-cord plug to the power outlets of the various countries where it has been used. The other two chargers have been designed for one charge rate and have also been very reliable. Figure 3 shows a charger that was built and tested, and the test results. Figure 4 presents some other possible charger designs.

For long, trouble-free, and most importantly, *safe* use of NiCd batteries it is recommended that all battery packs and chargers have the following characteristics:

1. The battery should be totally enclosed in a rigid, nonconducting vented case.
2. A fuse (F_3 in Fig. 2 and F_4 in Fig. 5) should always be placed inside this housing in series with the battery.

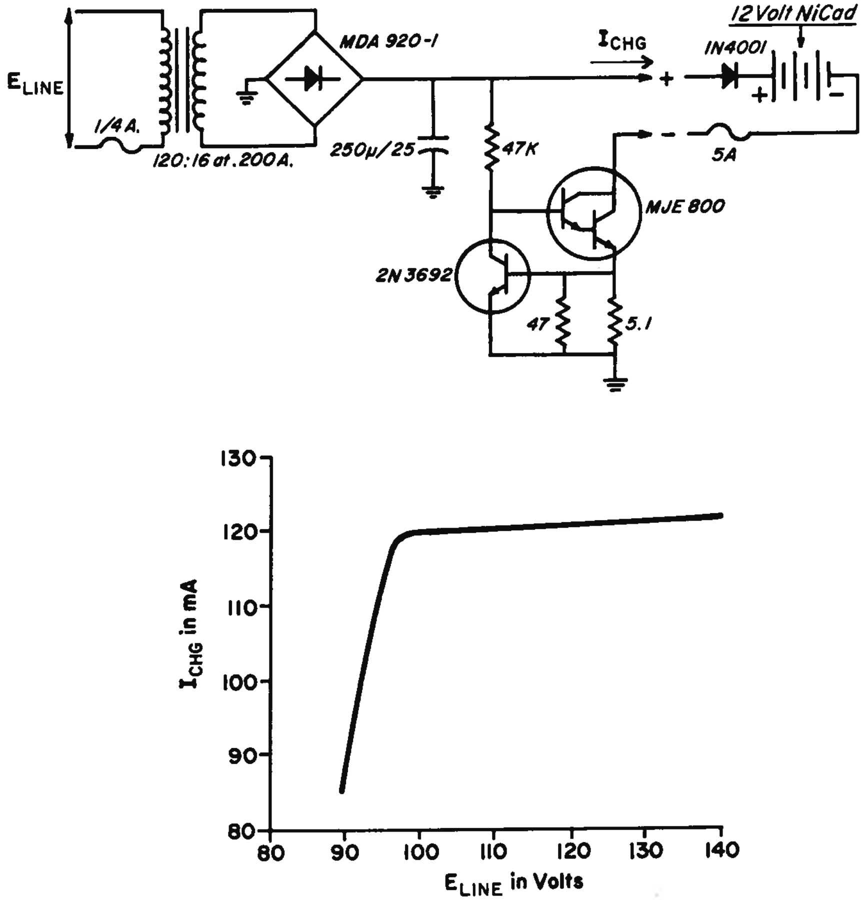
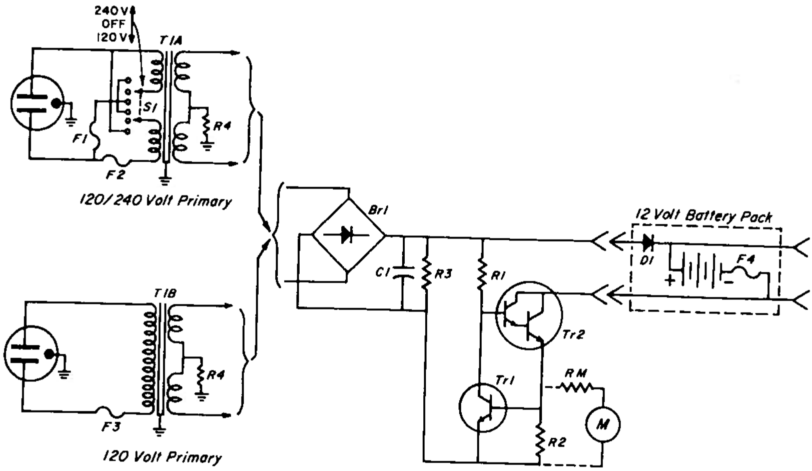


FIGURE 3.—120 ma. battery charger and measured performance.

3. A diode (D_1 in Fig. 2 and D_2 in Fig. 5) should be placed inside the battery case and in series with the charging connection.
4. The charging connection and the output connection should be separate and the connectors different.
5. An isolated charger designed for each battery pack should be available. This normally will be a constant current charger.

Recommendations 1 and 2 are primarily for safety. NiCd batteries can deliver, for a short time, currents large enough to cause considerable heat (the author ignited a small fire on his work bench once before he began fusing all NiCd battery packs).

The battery charging connection is normally exposed, and the diode of recommendation 3 prevents the discharge of the battery, not only through the charger but also through anything else placed across its



Br1	MDA920-1
D1	IN4001
R3	100K±20%,0.25W
M RM	Optimal charge current indicator 0.7V full scale
Tr1	MPS5172
R4	1K±20%,0.25W

	CHARGE CURRENT		
	0.45A	0.10A	0.045A
F1,F2,F3	0.25A	0.25A	0.25A
F4	20A	5A	3A
T1A*	DPC-16-640	DPC-16-260	DPC-16-75
T1B*	PC-16-640	PC-16-260	PC-16-75
C1	800µF, 25V	150µF, 25V	75µF, 25V
R1	6.8K±20%,0.25W	15K±20%,0.25W	30K±20%,0.25W
R2	1.2Ω±5%, 0.5W	5.1Ω±5%,0.25W	12Ω±5%,0.25W
Tr2**	MJE800	MPS-U45	MPS-U45

* Signal Transformer Co.,Inc.

** Tr2 must be mounted on a heat radiator of 2" x 2" x 1/16" minimum size with unrestricted airflow.

FIGURE 4.—Some suggested charger designs.

charging connections. Recommendation 5 has been discussed earlier and further explanations can be found in the attached bibliography (1–8).

In a properly designed system, NiCd batteries fail by slowly losing their ability to store energy. As the foregoing comments indicate, the charger, NiCd battery, their containers and connectors, and even the device powered by the battery, all should be considered as one system if optimum performance is to be obtained.

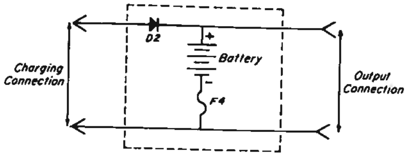


FIGURE 5.—Suggested battery pack configuration.

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