Verification methods of the secondary batteries capacity, the main power supply of the surveying instruments

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Abstract: *The progress of technologies implemented in modern instruments confronts with a big challenge: the higher and higher energy consumption. Most geodetic instruments are built on modular solutions, the most suggestive example being the total stations. Such a modern instrument incorporates multiple technologies in it: device to measure distances (EDM – Electro-Optical Distance Measurements), device to measure angles, electronic (laser) centering system, laser guidance system, servo motor system, electronic compensator, electronic micro-processor, etc. Each of these technologies is more or less energy consumer, requiring a modern battery with the capacity related to this consumption. In this article, the authors present some practical considerations related to primary and secondary batteries and also different methods to determine the capacity of such power supply.*

Keywords*: electronic total stations, primary batteries, secondary batteries, rechargeable batteries, instruments power supply, battery capacity*

1. INTRODUCTION

Electronics develops in much faster steps (so-called *Moore*'s law - performance in electronics doubles every 18 months) than battery technology. Although battery technology has evolved significantly, this progress is small compared to that of electronics. The battery technology has lower potential than electronic potential since the batteries requires chemical processes related to the structure of the chemical materials involved in their construction.

To illustrate the above with an example, we can say that although *Ni-Mh* rechargeable batteries began in 1985, they continue to be used extensively nowadays in the field of *GNSS* receivers and total stations (and obviously in the photo camera equipment, gadgets, etc).

Moreover, the performance of the *Ni-Mh* is not noticeable compared with the prior *Ni-Cd* batteries, but the latter are not in use anymore primary for reasons of environmental protection (its components being toxic to the environment).

There are two main types of batteries [1,2]:

1. Primary batteries – these batteries are so-called "disposable". As a general rule, they are more effective than secondary batteries, meaning that their efficiency is higher in functioning in time.

2. Secondary batteries (rechargeable batteries). Their efficiency is lower than primary batteries (because of the electrochemical processes that are executed cyclically in the secondary batteries case).

A battery is a device that converts chemical energy contained in the materials from which it is built into electrical energy through electrochemical reaction. A secondary battery is the battery that the electrochemical process can be reversed [1].

A battery consists of a series of basic electrochemical unit, called cells. A battery cannot exist without its cells. A battery is simply the sum of these cells connected in series or in parallel depending on desired voltage and current output and also the desired capacity.

A primary or a secondary battery with a small number of cells has a low capacity and hence a reduced operating time.

Performance of primary batteries is superior to secondary batteries because specific chemical modifications are performed cyclically for secondary batteries. However, primary batteries are usually more expensive (because they are disposable) and therefore the secondary batteries are the main source of energy for geodetic instruments.

It is preferable (where is possible) to purchase geodetic equipment that uses both classics primary and rechargeable batteries (*AA* or *AAA*) as classic usually means cheaper.

However it should be noted that a native battery is usually smaller, often more powerful and more comfortable to use even if it is more expensive overall. Ultimate decision should be made by correlating factors of convenience, ergonomics and ease of handling with financial ones.

For example, for a *Distomat* (*EDM* device used in measuring short distances), it is preferable that the power supply to be traditional batteries (primary or secondary). A native battery (battery specific to the manufacturer equipment) is generally more expensive and its replacement can be problematic and can have considerable costs even compared with the costs of the device itself.

2. CONSIDERATIONS REGARDING SECONDARY BATTERIES TYPES

A. Secondary Batteries Types

The main types of secondary batteries (used in geodetic instruments) are [2]:

a) Lead acid batteries
b) Nickel Cadmium (*Ni-Cd*)
c) Nickel Metal Hydride (*Ni-Mh*)
d) Lithium (*Li-Ion*)
e) Lithium-Polymer (*Li-Pol*, *Li-Po*)

Lead Acid Batteries

This type of secondary battery is important for geodesy because it can be used as an external source of energy for geodetic instruments as *GNSS* and electronic total stations [3]. In these cases, extreme care must be taken because the instrument voltage must coincide perfectly with the voltage of the external battery. This type of the external power supply must have protection circuits and should be performed and supervised only by an electronic engineer.

Ni-Cd (Nickel Cadmium) secondary batteries

Advantages:

1. Superior operating in low temperatures regime
2. Allow fast mode in the charging process
3. Relatively high numbers of charging-discharging cycles: 500 recharges (5-7 years of operation)
4. Relatively low sensitivity to the effect of overload

Disadvantages:

1. Memory effect. If this type of battery is only partially charged, the subsequent charges are effectuated only to the same point as previous charge. Several cycles of charging and discharging diminishing this effect, but the effect is not eliminated completely.
2. High cost relative to lead-acid batteries
3. High degree of environmental pollution due to chemical element Cadmium
4. Low storage capacity compared to other types of batteries
5. These batteries are sealed and therefore the defective cells are not replaceable

Due to the high levels of pollution from Cadmium element, this type of batteries has been replaced by *Ni-Mh* batteries. So there is the possibility of seeing this type of batteries (*Ni-Cd*) only in old instruments [2].

Ni-Mh Secondary batteries

In general the advantages and disadvantages of *Ni-Mh* batteries are very similar to *Ni-Cd* batteries:

1. Memory effect, although less than in the case of *Ni-Cd* batteries. However, the memory effect is present and can be counteracted by discharging the battery almost complete before a full charge.
2. High sensitivity to overload in charging process. Although permits speed charging, this type of secondary batteries is extremely sensitive to the effect of excessive loading. For quick charging, *Ni-Mh* requires smart chargers.
3. Higher energy storage in relation to the *Ni-Cd* batteries (in the same dimensions scenario) due to the metal hydride electrode that have higher energy density than cadmium electrode.
4. Few charging cycles in relation to the *Ni-Cd* batteries
5. High sensitivity to sudden drop in voltage
6. High degree of standardization. There are established classic formats for this type of battery*:* *AA*, *AAA*, and various combinations using *Ni-Mh* cells. This standardization also enables use of a wide range of chargers and therefore indirectly leading to reduced costs
7. Suitable for high temperature environments (environments where *Li-Ion* and *Li-Pol* can explode)

Note that these batteries are extremely sensitive to over-charging effect. In this respect special attention should be paid when using fast charging mode.

Lithium Ion (*Li-Ion*)

This type of battery replaced to a large extent even *Ni-Mh* batteries because of its advantages [4]:

Advantages:

1. Reduced memory effect
2. High-voltage relative to its size (in general has lower size than *Ni-Mh*).
3. These batteries also weigh about 30 % less (are lighter) than *Ni-Mh* batteries
4. Specific energy and energy density relative to its size
5. Low discharge rate
6. The "pollution" element is significantly reduced
7. Charging process can be done faster (supporting both "fast" and " ultra fast" charging mode)

Disadvantages:

1. Sensitivity to full discharge. Life decreases in such a discharging regime. It is therefore recommended to charge the battery at about 10% of its capacity (minimum value is 5%). Here the 200/1000 rule can be applied: if a battery has 1000 charging-discharging cycles, these can be preserved only if the battery is charged at > 5-10% and will have only 200 cycles if the battery is always completely discharged. According to this rule, virtually every complete discharge is wasting full 5 of charging-discharging cycles).
2. Low efficiency at low temperatures. Although, as compared with *Ni-Mh* batteries, the Lithium batteries are superior in performance in this aspect, as compared to *Ni-Cd* batteries still have problems in low-temperature operation.
3. Number of charges is "fixed". There is an obvious correlation between the lifetime and the number of loads in this type of battery.
4. Loading in "drip" mode may prove to be harmful for the *Li-Ion* battery.
5. Operational risk factor at high temperatures*:* risk of explosion. Although this element of risk is reduced compared with *Li-Po* batteries (see below), it still exists. This is another reason that *Ni-Mh* batteries are still widely used in various applications.
6. High production costs compared to *Ni-Mh* batteries. Nevertheless, the estimated cost of this type of batteries decline with its widespread.
7. Lack of standardization. *Ni-Mh* batteries became classic to a very great extent, which led to a standardization of this type of battery. *Li-Ion* batteries are still produced in various and different forms and dimensions, especially the native batteries (specific to every manufacturer). This prevents using of "universal" chargers - presenting in this respect a real limitation.

Lithium-Polymer (Li-Po) Secondary Batteries

This type of batteries is a forward technological step in relation to Li-Ion batteries. The main difference between them is that the electrolyte of lithium is not contained in an organic solvent (liquid material) but in a polymer compound (solid). This leads to lower cost of production and also the realization of these batteries in a wide variety of forms; the battery is more solid and a have a significantly higher number of charging cycles.

Aforementioned advantages are counter-balanced by some disadvantages relative to *Li-Ion* batteries:

1. Particular attention should be given to the over-charging process. It can lead to irreversible damage to the battery or even explosion.
2. Minimum amount of voltage must be respected in the process of unloading. Since the minimum value is exceeded, the battery may lose from its charge cycles and also cannot allow further charging to full capacity.
3. Their price is slightly higher (relative to *Li-Ion*). It requires also "smart chargers" to limit the overloading process.

3. VERIFICATION METHODS FOR CAPACITY OF THE SECONDARY BATTERIES

Battery capacity is provided by the manufacturers of surveying instruments usually as *mAh* or *Ah*. These values represents simply as long as the battery can provide some current consumption.

Thus, a battery with 2000 *mAh* capacity theoretically can provide current consumption of 2000 *mA* (*2A*) for one hour or a consumption of 500 *mA* (*0.5A*) for 4 hours.

The estimation in this form (*mAh*) is typically optimistic, because in high consumption regime, the time that this battery supplies power is shorter than expected.

A more accurate presentation of the capacity of a battery is in *Wh* form or *mWh*. This means that the battery can supply electric power for some time. For 6 *Wh* battery, at a *constant* voltage of 12 *V*, the battery can supply electric current of 500 *mA* (*1A*) for one hour, and an electric current of 1000 *mA* (*1A*) for a half hour.

Although this presentation (*mWh*) is more accurate as the one in *mAh* form, the battery capacity is usually also optimistic and based on the following assumptions:

a) Battery voltage is constant during consumption
b) The amount of current consumed during the battery testing time is small (0.1 or 0.2*C* - a tenth or two from the full battery capacity)
c) The current consumption is constant over time

Unfortunately, none of the assumptions listed above are not available in real life because of the following factors:

a) Battery voltage drops in the usage time until a threshold value, called the *cut-off* value [5] (the value at which the instrument software disconnects the battery)
b) The medium current consumption of the instrument is most of the time higher than the current used in the testing of battery capacity presented to the buyer
c) The power consumption is not constant because it depends on the device or active devices at one time or another. When measuring angles (angles mode), for example, a total station consumes more than in the stand-by mode but less than in the *EDM* mode

A more accurate way of presenting a battery capacity would be to submit (with battery) a table of the form presented in Table 1 [3].

7V Battery with 2100mAh capacity	
Consumption load value [mA]	**Capacity [mAh]**
210	2100
700	1700
1000	1500
2000	1200

Table 1 Secondary battery capacities at different levels of electric current consumption

Although this way of presenting works on the assumption of a constant voltage, fortunately it eliminates the other two hypotheses (low and constant current).

4. LOAD CONSUMPTION VALUES FOR SOME TOTAL STATIONS AND DIGITAL LEVELS

At disciplines within the Faculty of Geodesy in Bucharest [3], through specific electric arrangements, were connected geodetic instruments with measuring instruments and the values of consumption were monitored by the computer.

In Table 2 are different consumption values for various states of three total stations: a) standby mode, b) angle measurements mode and c) measurements of distances (*EDM*) mode.

Total station state	Topcon GTS 212	Leica 407	Leica 802
Start Time	360mAh	520mAh	1540mAh
Stand-By	80mAh	240mAh	280mAh
EDM measurements	360mAh	590mAh	1560mAh
Angle measurements	80mAh	340mAh	275mAh

Table 2 Consumption values of different total stations in various modes

From Table 2 it follows that the total station *TPS800* series, in *EDM* mode, consumes considerably more than the *TPS400* series. The conclusion is obvious: *TPS800* requires the large capacity batteries or some extra batteries.

In Table 3, the values presented are similar, but in this case for Topcon DL-100 series digital level. The maximum power consumptions is in the digital reading phase, as expected.

Digital Level state	Topcon DL-101C
Start Time	100mAh
Stand-By	70mAh
Digital Reading on Rods	360mAh

Table 3 Consumption values for Digital Level Topcon DL-101C

5. THE PRACTICAL WAYS TO ESTIMATE THE CAPACITY OF BATTERIES

Rigorous verification and monitoring of the battery capacity is achieved only by time integration through the values of voltage and amperage until the value of the *cut-off* voltage is achieved. Such an assessment is complicated and it takes both time and special electronic components (electronic loggers) [3].

Fortunately there are some practical ways that allow empirical evaluation of battery capacity, ways that involve a minimum of resources.

A. Secondary battery capacity estimation based on the values of load consumption

In this situation, if the values of load consumption are known, the total station *EDM* can be switched on continuously *EDM* measurements and the time when the total station reaches the *cut-off* voltage is noted (total station is switched OFF by itself). In this case, the consumer role is played by the continuous *EDM* mode [3].

Knowing for example that total station from TPS400 series consumes about 600mA for each measured distance (see Table 3), and assuming that continuous measurement was done in 3 hours, then the battery capacity will be C = 600mA x 3h = 1800mAh.

The disadvantages of this method are:

a) the battery capacity is determined at a high value of the electric current and therefore it is expected that the value obtained for the battery capacity to be pessimistic
b) continuous measurements of distances erode the quartz crystal and the emission diode of the total station. It is therefore recommended that this procedure be performed rarely, at each 6 months or even annually
c) the operator must be all the time near the total station to observe and note the total station running time. Fortunately, total station emits an acoustic signal at each measurement and therefore the time is relatively easy to monitor.

An alternative to using continuous *EDM* mode, and that eliminates all the disadvantages listed above is to put the respective battery to a constant (external) electric consumption. Of course, the user must have such electronic device (with variable consumption) or can use for consuming a device with constant current.

B. The relative estimation of secondary batteries capacity based on a reference value

In this case, are not known the actual battery capacity and the consumption value (of a component of the consumer), but it establishes a conventional reference value for the new and charged battery [3].

Example: a new and fully charged battery it is subjected to a constant power consumption (either the *EDM* continuous measurements or from any other consumer) and the time running under load is measured until the voltage falls below the threshold *cut-off* value of the voltage. This reference value will be the reference to subsequent determinations. Thus, a new battery can permit continuous measurements of distance for 3 hours, and after a year only 2 hours. This shows a decrease in battery capacity by 30% in one year.

This way of relative estimation not only allows the evaluation but also monitor the battery capacity over time. Thus, predictions can be made regarding the battery capacity by performing linear regressions, by reporting in time the battery capacity values.

The disadvantage of this method is that it cannot be calculated the numerical value of battery capacity but only it's original and initial condition - that is considered as relative reference for the future determination.

6. CONCLUSIONS

In the decision to purchase a geodetic instrument, an important role has to play its power supply. Elements such as battery type, the degree of battery replaceability, the charger type, or different consumption values of the instrument must decide the capacity of the battery and the number of additional batteries required by instrument.

The estimation of the battery capacity and also monitoring this battery capacity over time are other important steps. Thus, according to the behavior in time of the battery and its degree of wear, decisions can be made in advance to avoid unpleasant surprises in measurements processes in the field.

7. REFERENCES

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