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SIMPLE BATTERY QUALITY ASSESSMENT PROCEDURE

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Abstract

A circuit consisting of a resistor and battery was used to completely discharge an ensemble of dry cell batteries, and the number of batteries that failed in a given time were recorded (for five different brands of 1.5 V dry cell batteries, type R6 UM-3 AA size). This data was converted into Survival Probabilities as a function of time. Using the method of least-squares linear regression, estimates of the failure rate and mean-time-to-failure of each battery brand were extracted from the survival probabilities. The results indicate that supposedly equivalent batteries (from different manufacturers) have grossly different mean-time-to-failure and thus are of different quality.

***Keywords*: ** Failure rate, mean-to-time-failure, survival probability, Quality assessment

1. Introduction

Electrochemical batteries [1] are a convenient source of electrical energy especially as portable electronics becomes increasingly popular. Batteries have a long history with varied sizes and types that often depend on the energy demands and size limitations of the electronic system that use the battery. With the increasing popularity of mobile portable electronic systems, battery runtime [2] has become a key measure of battery quality. The operation of those electronic systems that use battery energy is often limited by the battery runtime; hence it is useful to be able to estimate battery runtime. With knowledge of battery runtime, it is possible to have a battery replacement schedule and to reduce system time-out (due to battery failure).

Dry cell batteries are a common type of non-rechargeable batteries used in electronic clocks, portable radios, remote control units, etc. Given the prevalence of dry cell batteries in Nigerian homes and the availability of various brands in the Nigerian market, we decided to study the battery runtime of this type of battery. Earlier studies, both experimental and theoretical, on battery performance compare the reliability of dry cell batteries [3] and consider electrical battery models capable of predicting runtime [4]. For every battery size and specification there are various brands in the market, from which one may choose. Ordinary, one may suppose that, the various brands are equivalent (that is, are of the same quality). But, experience has shown that some brands last longer than others. This work is motivated by the need to be guided in the choice of battery brand.

Here we consider mean-time-to-failure (the amount of time a product usually works until it fails) as a measure of runtime and an indicator of battery quality. We have estimated the failure rate and mean-time-to-failure of some brands of dry cell batteries, common in the Nigerian market. The estimates were deduced from experimental data on the continuous discharge of type R6 UM-3 AA size dry cell batteries.

2. Failure rate and Mean-time-to-failure

Failure rate and mean-time-to-failure are parameters that can be used to denote component (or system) runtime while in use, as a representation of component quality, determining its maintenance or replacement schedule. Ultimately, every component (or system) in use will wear-out. Thus the survival probability $S(t)$ of a component starts at unity, initially (at zero time, $t=0$) and decreases as time increases, eventually tending to zero as time tends to infinity. The survival probability of a component is deduced following the discussion of molecular collisions in kinetic theory [5, 6].

Consider an ensemble consisting of a large number N_o of similarly prepared components (say, batteries). The probability of occurrence of a particular event (say, failure) is defined with respect to this ensemble and is given by the fraction of

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components in the ensemble which exhibit the specified event. We desire the probability that a battery will continue in use for a time t, without failure; sometimes called, the survival probability *S(t)*

To compute the survival probability, *S(t)*, we observe what is happening to all N_o batteries in use. After a time t, some of them failed. Let *N(t)* denote the number of batteries that have not failed up to the time t. Note that *N(t)* is less than N_o

If we know that *N(t)* batteries have survived up to time t, then *N(t + dt)* the number of batteries which survive upto the time $t + dt$ is less than *N(t)* by the number of batteries dN that have failed in the small time interval dt. That is,

$$N(t) - N(t + dt) = dN \quad (1)$$

If there is equilibrium, then on average, nothing is changing with time. So N batteries waiting the time dt will have the same number of failures, as one battery waiting the time *Ndt*. Hence the number of batteries *dN* that will fail in the time interval dt is,

$$dN = \lambda N(t)dt \quad (2)$$

where λ is failure rate.

Re-writing *N(t + dt)* as *N(t) + (dN/dt)dt* following calculus, and using equation (2) to substitute for dN in equation (1) we obtain

$$-\frac{dN(t)}{dt}dt = \lambda N(t)dt$$

or,

$$\frac{dN(t)}{N(t)} = -\lambda dt \quad (3)$$

Assuming that the failure rate λ is constant, equation (3) can be integrated to give

$$\ln N(t) = -\lambda t + cons\tan t$$

or,

$$N(t) = N_o e^{-\lambda t} \quad (4)$$

Since N_o is the total number of batteries in the ensemble, which put to use at an arbitrary time $t = 0$, may fail at some time t in the future.

The survival probability, *S(t)*, is obtained by dividing *N(t)* by N_o, that is

$$S(t) = \frac{N(t)}{N_o} = e^{-\lambda t} \quad (5)$$

The survival probability is the probability that a battery survives for a time t without failure.

Now, the number of batteries which fail in the time interval dt at the time t, after an arbitrarily chosen starting time is given in equation (2). The time they spent before failure is, of course, t. Hence, the mean-time-to-failure (τ) (usually called relaxation time in kinetic theory) is

$$\tau = \frac{1}{N_o}\int_0^{\infty} t\lambda N(t)dt = \int_0^{\infty} \lambda t e^{-\lambda t} dt = \frac{1}{\lambda}\int_0^{\infty} y e^{-y} dy = \frac{1}{\lambda} \quad (6a)$$

Note that the value of the standard integral above is unity. Thus, the mean-time-to-failure for a component is

$$\tau = \frac{1}{\lambda} \quad (6b)$$

We shall estimate the failure rate (λ) and mean-time-to-failure (τ) of some dry cell batteries using experimental data.

3. Experimental Procedure and Result

A test circuit, consisting of a resistor connected to the battery, as shown in figure 1, was used to discharge the battery. The current (I) and voltage (V) readings were recorded at the start *t=0* of the experiment and, subsequently, at hourly intervals until a battery was completely discharged. A battery was considered to be completely discharged (and to have failed) when the ammeter and voltmeter readings were both zero. A small torch-bulb was used as resistor, and when a battery was completely discharged the torch-bulb did not give any light.

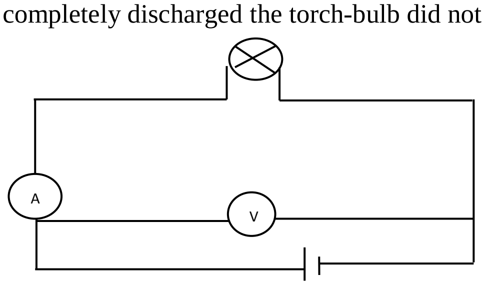

Figure. 1 Battery test circuit

Five different brands of 1.5V dry cell batteries type R6 UM-3 AA size were studied. The battery brands studied were Loncell, Matoma, PowerSuper, Tudor and Tunar Max. These battery brands are commonly found in Port Harcourt markets. Sixteen units of each battery brand were lasted. These batteries were new and not previously used. In the course of the experiment, which tested for seven hours, a fraction of the sixteen batteries failed. And after seven hours, all sixteen batteries failed. The number of batteries that failed (for each brand) at one-hourly interval are recorded in Table 1. This means that considering Tudor battery (for instance) the sixteen units survived for a time below one-hour, but by one-hour into the test one unit failed. And three units survived after six hours into the test, but all failed by the seventh hour.

Table 1: Failure Frequency

	Battery Brand	Time it takes a battery to fail (hours)						
		1	2	3	4	5	6	7
Number of batteries that failed	Loncell	4	2	3	2	3	1	1
	Motoma	3	2	1	4	1	3	2
	PowerSuper	4	2	2	1	3	2	2
	Tudor	1	2	4	2	3	1	3
	Tunar Max	2	2	4	3	3	1	1

4. Analysis and Discussion

To analyse the data in Table 1, equation (5) is used to calculate the survival probability values for each battery brand. These probabilities are given in Table 2. Note that in equation (5), N_o is sixteen and *N(t)* is the number of units (of a battery brand) that survived up to the time t. Hence the survival probability is the ratio of units (of a battery brand) that survived up to time t to the total number N_o At the start of the experiment $t=0$ all sixteen units of all the battery brands "survived", hence the survival probability at time $t=0$ is unity.

Table 2: Survival Probability

	Battery **B**rand	Time (hours)						
		0	1	2	3	4	5	6
Survival probability	Loncell	1.00	0.75	0.625	0.4375	0.3125	0.125	0.0625
	Motoma	1.00	0.8125	0.6875	0.625	0.375	0.3125	0.125
	Powersuper	1.00	0.75	0.625	0.50	0.4375	0.25	0.125
	Tudor	1.00	0.9375	0.8125	0.5625	0.4375	0.25	0.1875
	Tunar Max	1.00	0.875	0.75	0.50	0.3125	0.125	0.0625

We desire to extract the failure rate (λ) and the mean-time-to-failure (τ) from the above data, for each battery brand. Notice that equation (5) is an exponential decay function, the analysis is made simpler by linearing equation (5) thus:

$$-\ln S(t) = \lambda t \qquad (7)$$

Hence the failure rate (λ) is the slope of the line obtained on plotting *–In S(t)* against t. However, instead of extracting the failure rate (λ) from a graphical method, we have used the least square linear regression method [7,8] to calculate the failure rate (λ) via:

$$\lambda = \frac{N_o \sum_{t=0}^{6} (-\ln S)(t) - \sum_{t=0}^{6} (-\ln S) \sum_{t=0}^{6} t}{N_0 \sum_{t=0}^{6} t^2 - \left(\sum_{t=0}^{6} t \right)^2} \qquad (8)$$

Equation (6) is then used to calculate the mean-time-to-failure *(τ)* given the values of λ. The estimates of the failure rate (λ) and mean-time-to-failure *(τ)* for the five battery brands (calculated as mentioned above) are given in Table 3.

Table 3: Failure Rates and Mean-Time-to-Failure

Battery Brand	**Failure Rate (λ)**	**Mean-Time-to-Failure (hours)**
Loncell	0.4006	2.495
Motoma	0.2484	4.025
PowerSuper	0.2912	3.433
Tudor	0.2565	3.898
Tunar Max	0.3958	2.526

Observe from Table 3 that, of the five brands of 1.5 V dry cell batteries types R6 UM-3 AA size studied, Motoma exhibited the longest mean-time-to-failure of about 4.0hrs while Loncell exhibited the shortest mean-time-to-failure of 2.5hrs. Note that the estimated mean-time-to-failure is for continuous discharge of a battery, and as such the estimated times are appropriate in applications such as the use of a battery to provide electric energy in electronic clocks (or other such applications that require continuous electric energy supply). In application that require intermittent electric energy (such as in flash-lights) the runtime of the batteries used should be much longer than the above estimated times. Also, the data in Table 3, validates the common experience by users, that supposedly equivalent components (from different manufacturers) do not perform identically (and so may cost differently). The data shows that batteries of the same size have different runtimes; this does mean that they are of different quality.

5. Conclusion

We have used a simple battery test circuit to assess the quality of five brands of 1.5V dry cell batteries, type R6 UM-3 AA size, commonly found in Port Harcourt markets. Estimates of the failure rates and mean-time-to-failure of each battery brand have been deduced from experimental data obtained from an ensemble of each brand. The mean-time-to-failure has been considered as an indicator of quality of a battery brand. The results confirm that though the tested batteries were of same size, they exhibited grossly different qualities. Hence, in components replacement, one should note that while a component may fit/work, it may not last.

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