ELECTRO-CHEMICAL BATTERIES FOR GUIDED MISSILES

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Electro-chemical batteries owing to their simplicity and ease of stowage form one of the sources of electrical power inside a missile. However, all batteries are not suited for this application. This article describes the special features required of a missile borne battery pack and discusses the characteristics of various types of batteries available today in the world. Conclusions have been drawn as to the most suitable types of batteries for missile application.

Exploration of space through guided missiles and rockets has now assumed a great importance in all the technologically advanced countries of the world. In our country too, with the present tempo in the advancement of science, technology and industry, it is expected that missiles and rockets may assume their due place in the forseeable future. This, in fact, is evidenced by the series of space research rockets launched by the Indian Committee for Space Research (INCOSPAR) from Thumba launching pad in Kerala State and the three-stage high altitude sounding rocket launched by R & D Organisation of Ministry of Defence from Balasore sea range on the eastern coast.

Normally, a large variety of electrical and electronic components are located inside any missile to form parts of the various sub-systems such as guidance, control and instrumentation. Obviously for the operation of these components and sub-systems as a whole, a suitable source of electrical power located inside the missile is required. The selection of the source of power is governed by many factors.

Electro-chemical batteries, owing to their simplicity and ease of stowage, form an attractive power source for the purpose. Numerous types of batteries are commercially available in advanced countries but on account of certain special requirments, all types are not ideally suited for applications in missiles and as such a careful selection has to be made.

At present, only two types of batteries, namely Lead-Acid and Leclanche, are produced indigenously. Neither of them is much favoured for use in missiles. Therefore to live up to future requirements, it is high time to give a serious thought to the development and indigenous production of special batteries suited for missiles.

In this paper, an attempt has been made to bring out clearly the qualitative requirements of a missile battery and discuss the characteristics of batteries available in the world market. Various battery systems have been compared in respect of their performance, shelf life and other characteristics. Conclusions have been drawn to indicate batteries suitable for use in missiles.

FEATURES OF A MISSILE BATTERY

Missile batteries are invariably called upon to fulfill numerous stringent physical and electrical requirements mentioned below:

Electrical requirements

All missiles are single shot robots. Their time of flight is normally short and operational requirements impose the condition that they have instantaneous readiness. As such, the missile batteries are required for single shot applications of short duration only. Further, in the case of Reserve Batteries, since the electrolyte is injected into the battery only at the time of launching the missile, the activation time should not exceed a fraction of a second.

Weight and volume of the components located inside a missile must be minimum. This enables the missile to carry maximum payload with minimum of propulsive force. In addition to electrical power system, several other sub-systems such as propulsion, guidance, control and warhead have to be housed in the limited space available inside the missile. It is often found that after catering to the space needs of other sub-systems, the power supply unit has to be accommodated within the remaining odd-shaped space. Therefore, the individual cells required for the battery pack have to be small in size and light in weight so that the pack can be built to adopt any shape with ease. All this is possible only if the electro-chemical cells are small and possess high energy per unit weight and volume.

Since the missile battery is a single shot device, effort is always made to make full use of the total energy available from it. In view of the short application time, this is possible only if the battery is discharged at a high rate. Therefore, the missile battery needs to have specially treated electrodes so that they possess large active surface area without increasing the overall size.

The electronic and electrical components of the guidance and control circuitry of missiles are normally highly sensitive to voltage changes. As such, for their efficient performance, the regulation of the battery should be good. High internal resistance of the electro-chemical cells results in poor voltage regulation. For example, in the case of Leclanche cell, which has an internal resistance of the order of 0·2 ohm, a steep drop in terminal voltage is registered on closing the load circuit. Therefore, good regulation at high rates of discharge should be aimed at.

Physical requirements

Missile batteries are invariably expected to function satisfactorily over a wide range of temperatures. It may vary from +130°F to —4°F depending upon the season and place. Many battery systems while possessing good high temperature characteristics do not withstand low temperature environments and vice versa. But the missile battery should be such that its performance is not seriously impaired by temperature variations.

From the considerations of operational readiness and convenience of usage, it is a basic requirement that a guided weapon needs least attention and maintenance care, both while stored in depots and in the hands of the troops. To achieve this, it is necessary to ensure that the missile components do not deteriorate with time. Since the battery pack will at a later date form a major sub-assembly of a missile, it should have long storage life. Therefore, the requirement is for sealed type of batteries having a long shelf life.

The missile, during its flight, has to withstand considerable longitudinal and lateral accelerations. Especially during the boost phase when the optimum speed is achieved in the shortest possible time, very high accelerations are involved—say of the order of 15 gravities. Similarly, during flight and transportation, the batteries along with missiles are subjected to considerable vibrations and bumps. Further the battery is also required to withstand drop hazards as the technician at the time of assembly or replacement may accidentally drop it on the ground. To live up to these requirments, the battery should be rugged and the electrodes and containers should not be fragile. In achieving these features, however, the weight and volume of the batteries should not correspondingly increase. Particular attention should be given to the construction of electrodes where sintered plates are used.

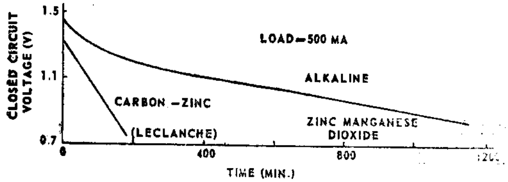
It may not be possible to satisfy all these requirments to a high degree at a time in any one battery system and as such a best compromise of these features has to be aimed at.

CELL TYPES AND THEIR CHARACTERISTICS

Now a brief survey of the various types of batteries available and their characteristics based on information extracted from various publications, will be presented under a broad classification of primary, reserve and secondary cells.

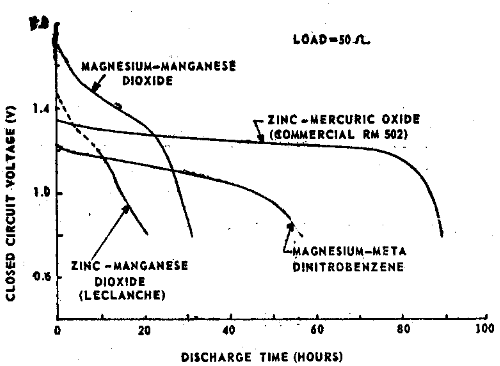
Primary cells—Among the primary cells, there are several types such as dry cell, wet cell, solid electrolyte cell etc. However, in view of its compactness and non-spillability the most useful primary cell for missiles is the dry type. Therefore, our discussion will be confined to the dry cells and only the important varieties such as Leclanche cells, Mercury cells and Magnesium cells. The data [1] pertaining to these cells are presented in Table 1. Their discharge characteristics[2,3] are given in Fig. 1.

Leclanche cells—These cells form the cheapest source of packaged electrical power. The electro-chemical system of the Leclanche cell consists essentially of a zinc anode, a carbon cathode and mixture of ammonium chloride, zinc chloride and manganese dioxide in the form of a paste spread between the electrodes. The century-old Leclanche cells have undergone considerable improvements in leak proofing, shelf life and miniaturisation and these are available commercially in a number of shapes, sizes, voltages and current ratings.



Their open circuit voltage varies from 1·5—1·65 V per cell and their nominal voltage is 1·5 V.

Except for their ready availability in the country, they are generally not favoured for specialised applications for the following reasons:—



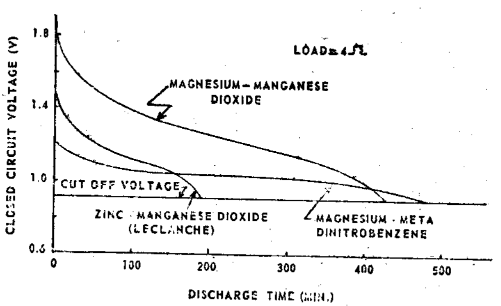


Fig. 1—Discharge characteristics of primary cells

(i) They possess short shelf life of about 6 months only.
(ii) They register steep drop in voltage when put on load [see Fig. 1(*a*).]
(iii) Their efficiency is generally low.
(iv) Their power to weight and volume ratio is very small.
(v) They possess high internal impedance which is further increased by polarisation at high rates of discharge.

These cells are normally unsuitable for operations at low and high temperatures such as below 32°F and above 100°F. They are designed to operate satisfactorily at about 70°F. For low temperature applications certain special electrolyte formulations are used in these cells and then they can operate upto 20°F.

Alkaline dry cells[1]—The alkaline dry cells are a further development of the Leclanche cell. The electrolyte used is potassium hydroxide instead of ammonium chloride. In addition, they differ in the manner of their construction. The discharge voltage of these cells also falls off but not as steeply as in the case of ordinary Leclanche cells [Fig. 1(*a*)]. Capacity of these cells does not vary to any great extent with current drain. The distinct advantage of the alkaline cells lies in their ability to operate with good efficiency even at high current drains. The internal impedance of these cells is comparatively low. The nominal voltage is 1·5 V.

At low temperature their performance is satisfactory. Their range of performance extends upto —40°F. At these temperatures they considerably exceed the performance of the best Leclanche type cells with special low temperature formulations[4]. The high temperature characteristics of these cells are also considerably better than those of the standard carbon-zinc cells.

Shelf life, which is the period under storage at a given storage temperature (normally 70°F) after which the battery retains 90 per cent capacity, is greater than the conventional Leclanche batteries.

Mercury cells—The Mercury cells, invented during World War II, appear to be the most significant dry cells developed in recent times. They consist of a depolarising mercuric oxide cathode, an anode of pure amalgamated zinc and a concentrated aqueous potassium hyroxide electrolyte. Their special features are: high capacity per unit volume and weight

TABLE 1

DATA ON PRIMARY CELLS

Type	Nominal voltage (V)	Capacity (Watt Hour/ lb.)	Capacity (Watt Hour/ cu. in.)	Operating temperature (°F)	Approximate shelf life	Remarks
Leclanche cell (conventional type)	1·5	2—3	0·2—2·5	30°—90°	6 months	For low temperatures special formulations are used.
Alkaline cell	1·5	47	2·2	—40°—160°	More than one year	
Mercuric oxide cell	1·35 & 1·4	51·4	4—8	50°—160°	—do.—	
Magnesium organic cell (Metadinitro-benzene)	1·5 (approx)	90	3·2	..	One year	

flat discharge characteristics, relatively constant ampere-hour capacity at various discharge rates, low internal impedance, more than a year's shelf life, good high temperature characteristics and a good resistance to shock, vibration and acceleration.

In this variety, two types of cells are available from commercial sources. One of these is specially used as a voltage substandard cell. Its nominal voltage is 1·35 V. The other type with a different formulation gives 1·4 volts and is used for general purposes. They possess a shelf life of more than a year.

They possess good high temperature characteristics. They can be used upto 130°F for long duration and even upto 200° F for few hours. However their performance at low temperatures is not satisfactory[4]. At about 32°F the cells give very little service. If the current requirement is of the order of a few milliamperes only, then it is possible to use them below 32°F.

In spite of several desirable features the mercury cells are not being used widely for civilian applications due to the high cost of mercuric oxide. For military purposes, they are commonly used and are produced commercially in a variety of sizes and shapes.

Magnesium cells—Magnesium as an anode material has attracted the attention of electrochemists for a long time due to its high electrode potential and high ampere-hour capacity. It is only recently that the problems connected with magnesium cells were nearing a solution. The cell consists essentially of a magnesium anode, an oxide cathode (such as manganese dioxide or bismuth oxide) or an organic cathode (such as *m*-dinitrobenzene) and an aquoeus electrolyte of magnesium bromide. Their special features are:—high watt-hour capacity per unit volume and weight, high electrode potential and a shelf life of about 15 months. The disadvantages of the system are: higher internal impedance in comparison to Leclanche cell, a delay in voltage build up and a sloping voltage-time discharge curve. However, the last mentioned handicap has been overcome to some extent in the case of magnesium-organic cell and magnesium-cupric oxide cell.

The open circuit volatge of manganese dioxide cathode cell is 1·8—2·0 V and that of the organic cell is 1·65 V. Their average operating voltages are 1·4—1·5 V and 1·15 V respectively. They possess good low and high temperature performance characteristics. The improved low temperature performance is due to internal heat generation during discharge. The magnesium-organic cell is only a recent development while other magnesium cells have since been commercially produced[5].

Reserve cells—Reserve cells are essentially primary cells, the difference arising out of the manner in which they are constructed. They are mainly used for making high energy and high rate discharge batteries of single shot applications and are generally designed to meet military specifications. Their advantages are:—highly active electro-chemical system possessing high power output per unit volume and weight, long shelf life and minimum

TABLE 2

DATA ON RESERVE CELLS

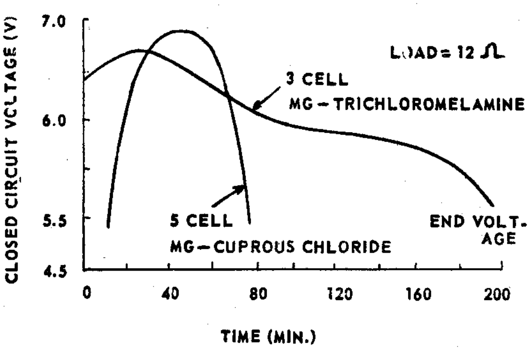
Type	Nominal Voltage (V)	Capacity (Watt hour/ lb.)	Capacity (Watt hour/ Cu. in.)	Operating temperature (°F)	Remarks
Silver oxide-zinc	1·5	25—56	1·3—3·8	0°—160°	
Magnesium-mercuric oxide	1·75	50	3·2	28°—85°	
Magnesium-silver chloride	1·5	20—80	upto 7·8	do.	Water activated battery

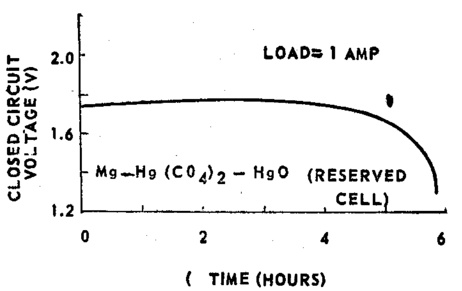
maintenance. The silver oxide-zinc reserve cell and the magnesium reserve cell, described below, find many specialised uses. The data[6] pertaining to these cells are presented in Table 2, and their discharge characteristics[3,7] are given in Fig. 2.

Silver oxide-zinc reserve cell— This cell is one of the major developments in recent times. Since it possesses very high energy it has succeeded in providing miniature batteries for military uses. It consists of silver oxide cathode, a zinc anode of large surface area and highly concentrated potassium hydroxide solution as electrolyte. The electrodes are separated by semi-permeable membranes.

The valuable features of these cells are:—highest watt-hour capacity per unit volume and weight, constancy of voltage at high power outputs, a very low internal impedance, and a long shelf life of about 5 years when standing dry[8]. The recent developments in these cells have resulted in leak and spill proof construction and the cells can be packaged in small sealed containers. The cell voltage under open circuit condition is 1·85 V and the nominal voltage is 1·5 V.

The battery is generally stored under a dry condition, *i.e.* with the electrolyte remaining separate. When electrolyte is added, the battery reaches its operating voltage in a short time. To attain rapid activation, automatic activation devices have been developed. These are of the vacuum and pressure types. In these systems, an electric pulse sets off a gas generating squib and punctures the chamber containing the electrolyte. The electrolyte is then forced instantaneously into the electrode surfaces either by high pressure of gas or by vacuum in the cell compartment. While considering a reserve battery, it is essential to note that the wet stand time (*i.e.* the life of the battery when allowed to stand wet with electrolyte) is proportional to the activation time. Mainly the wet stand time depends on the separator material which generally reacts with the electrolyte and causes short cirucuit in the cell. Since the thickness of separator material has to be reduced for requirements of rapid activation, the wet stand time correspondingly decreases.





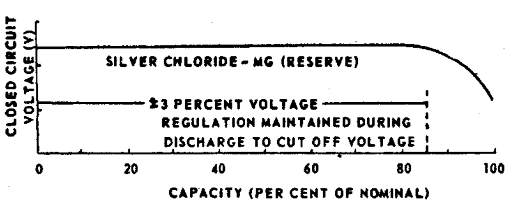


Fig. 2—Discharge characteristics of reserve cells

These batteries do not exhibit good low temperature performance. They are normally used upto 0°F but can also be used upto —20°F. The battery has to be correspondingly derated for low temperature performance. However, at very low temperatures of about —50°F, recourse has to be made to chemical or electrical heating of the battery. Batteries of this type have been made and operated from—65°F to+180°F by US Signal Corps Engineering Research Laboratories[9].

The silver oxide-zinc reserve system has a poor wet stand life of the order of a few minutes only. Recent trends are towards evolving a dry primary system with a long shelf life of a year or two. For the present the primary system that has been developed has a shelf life of one year.

The electrodes of a reserve cell are prepared out of a sintered material. These electrodes are brittle and it is not known as to what extent these will stand against shocks, vibrations and accelerations. However, US Signal Corps Engineering Research Laboratories have reported fabrication of silver oxide-zinc reserve batteries which have been successfully tested to withstand vibrations, shocks and accelerations.

Magnesium reserve cells—Magnesium reserve cells consist of a magnesium anode, a magnesium perchlorate electrolyte and an oxide or chloride cathode. Mercuric oxide and cupric oxide cathodes have been studied extensively.

The advantages of these cells are:—high capacity, high electrode potential, high anode efficiency, constancy of voltage under discharge, a long activated stand life and low cost. The performance obtained from mercuric oxide magnesium cells is comparable to other reserve systems [Fig. 2(*b*)]. Table 2 gives comparative figures [10]for all the three systems under discussion.

The silver chloride-magnesium reserve cells use silver chloride as cathode and are activated by saline water. Their attractive features are:—high capacity and excellent shelf life[4]. They are often designed for specialised applications such as torpedoes and sonars and are capable of withstanding shocks of air-to-sea impact when dropped from a height of 50,000 ft., vibrations of 10 g at 500 cps and large accelerations. The discharge curve is shown in Fig. 2(*c*).

These cells can be activated at temperatures ranging from 28°—85°F. They can also be activated at very low temperatures but to start with the output current is low. However due to self heating under discharge, voltage and current rise. Once activated, they can be discharged upto an ambient of —80°F. Their activation time is, however, large of the order of 10 sec[2]. Storage temperatures can range from —80° to 185°F.

Secondary cells—The chemical reaction in a secondary cell is reversible so that energy is stored during charging and released during discharging. These cells range from the

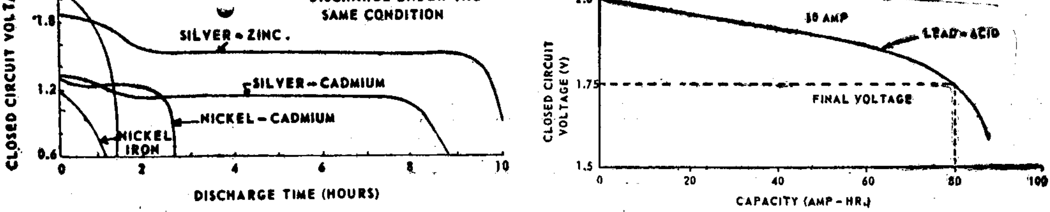


Fig. 3—Discharge characteristics of secondary cells

century-old lead-acid cell to the recently developed silver-zinc and silver-cadmium, cells. The characteristics of lead-acid, nickel-cadmium, nickel-iron, silver-zinc and silver-cadmium secondary cells are discussed below. The data[4] pertaining to these cells are presented in Table 3. Their discharge characteristics[3] are shown in Fig. 3.

Lead-acid cell—The lead-acid cell is a familiar piece of equipment. The active electrochemical system is a spongy lead anode and lead peroxide cathode with an electrolyte of dilute sulphuric acid. The nominal voltage is 2 V per cell. As the cell discharges under load, the terminal voltage of the cell drops gradually and then steeply. The life of the cell is seriously impaired if allowed to discharge below 1·75 volts. The discharge characteristic is shown in Fig. 3. The main drawbacks of these cells are:—low capacity per unit volume and weight and problems associated with their maintenance. Careful attention is necesary for charging and discharging them. The batteries made up of lead-acid cells cannot be sealed even though specially constructed tubular design and electrolyte retaining batteries have been produced for special uses. At low temperatures the capacity falls off proportionately. These batteries are designed to give service upto 0°F.

Nickel-iron cell—The active electro-chemical system consists of nickel hydroxide and nickel as positive plates and metallic iron, ferric oxide and mercuric oxide in powder form as negative plates with a solution of potassium hydroxide as electrolyte. The nominal cell voltage is 1·2 V. This cell is more rugged and can withstand even complete discharge and shorting of the electrodes. The ampere-hour efficiency is low. It has large cycle life but possess poor low-temperature characteristics. Its charge retention capacity is poor and it is bulky and heavy.

Nickel-cadmium cell—The nickel-cadmium cells have been in wide use for the past 20 years. They are made in two distinct forms: pocket type and sintered plate type. They differ from a nickel-iron-cell in that a cadmium anode is used instead of iron. They can be hermetically sealed because the gas generated during charging can be used up in reacting with cadmium in a suitably designed cell. They are characterised by their excellent life of many years and large cycle life[11]. They are commonly used in the sealed form as button cells for small electric gadgets. For space vehicles they are used in conjunction with a solar cell-charging unit. Their operating temperature ranges from a minimum of —60°F to a maximum of +115°F.

Silver-zinc cell—The silver-zinc secondary system consists of a positive silver electrode separated from the negative zinc electrode by a semi-permeable membrane. The electrolyte is concentrated potassium hydroxide.

TABLE 3

DATA ON SECONDARY CELLS

Type	Nominal Voltage (V)	Time for 50% capacity retention at 80°F (days)	Capacity (Watt hour/ lb.)	Capacity (Watt hour/ cu. in.)	Operating temperature (°F)	Remarks
Lead-acid	2·0	55	7—26	0·45—2·75	up to 0°	Wet cell
Nickel-iron	1·2	25	11—14	0·98—1·16	..	—do—
Nickel-cadmium	1·2	300	10—15	1·08	—60°—150°	Dry or Wet cell
Silver-zinc	1·5	..	25—56	1·3—3·8	—20°—165°	Wet cell
Silver-cadmium	1·1	over 2 yrs.	11—38	0·67—2·9	—do—	—do—

The nominal cell voltage is 1·5 V. The general features are similar to the primary cells discussed earlier. Average operating life is either about 6 months in activated state or 10—20 cycles, whichever occurs earlier. In the discharged state these batteries can be left alone without attention for long periods of time. In the dry state they can be stored upto 5 years at ambients ranging from —55°F to +100°F and can be activated by following a schedule of initial charging of about 24 hours. Operation of these cells is possible upto a temperature of —20°F as in the case of reserve cells. These cells can withstand high discharge rates and are not affected by altitude when sealed. They have been used widely for missiles and space vehicles[4]. Mariner II was provided with a silver-zinc battery for powering its electronic equipment.

The main drawbacks of silver-zinc system are its poor performance at very low temperatures and poor cycle life. Other features are most suitable for missile and space vehicle applications.

Silver-cadmium cell—The silver-cadmium system compares well with the silver-zinc system. However, the nominal cell voltage is only 1·1 V. Its capacity is less than the silver-zinc system but more than all the other. Its superiority lies in its ruggedness and very large cycle life. Silver-cadmium batteries are available commercially even though they are only of recent development. Sealed cells of this type have not yet been produced.

CHOICE OF A BATTERY

The development of electro-chemical cells has gone a long way from the simple Leclanche cells and lead-acid cells to the latest silver-zinc and silver-cadmium cells. The object of this paper is to consider them from the point of view of their application in missiles, and see which of them can meet their stringent requirements.

The lead-acid cells fail to come up to the requirements in several respects. From considerations of space and weight they provide the least energy and are, therefore, very bulky and heavy in weight. Their maintenance problems are manifold and they have charge retention characteristics of the order of a month. From the shelf life point of view also they will be unsuitable for the purpose of a missile battery.

The popular Leclanche dry cells also do not come up to the standard in several respects. They provide the least energy per unit volume and weight amongst the cell system available. Their shelf life of 6 months is too low and, therefore, such a missile borne battery will need frequent replacement constant attention and maintenance. Their discharge characteristics are generally unsuitable since as the cell discharges a large voltage swing has to be tolerated by the electronic equipment placed in the missile. Therefore, these cells can also be left out of consideration.

Nickel-iron secondary cells are considered to be better than lead-acid cells due to their ruggedness and large cycle life. They, however, suffer from two defects namely poor charge retention capability while in storage and low capacity per unit weight and volume. Therefore, this battery also does not satisfy missile requirements.

Alkaline dry cell is next to be considered. In comparison to Leclanche cells the several desirable features of these cells are:—good low temperature performance, large capacity and longer shelf life. However, the superiority is only marginal and other better cell systems are available.

The mercuric oxide primary cells possess very attractive features as listed earlier. They are nearly as good as the silver oxide-zinc system in respect of weight, but from volume considerations they appear to be even better (see Table 3). However, main limitation is their poor low-temperature performance. In this repsect the mercury cell is even inferior to the alkaline dry cell. Their other limitation is shelf life of about a year, which is considerably less than any reserve cell system.

Magnesium reserve cells and magnesium primary cells are the recent developments. From the point of view of obtaining a packaged ready source of electrical power lasting indefinitely, there is nothing more attractive than a reserve cell. But problems connected with the development of a suitable activation system and its effect on the reliability of the system as a whole have to be kept in view. However, it is seen that automatic activation systems have been successfully developed and tested in USA and UK.

The magnesium reserve cells can be based either on magnesium-silver chloride or magnesium-cupric oxide or magnesium-mercuric oxide system. Out of these, magnesium-silver chloride system possesses highest energy and is comparable to silver-zinc system [Fig. 2(*c*)]. They are rugged and can withstand a variety of environmental conditions. Their very low temperature performance is also satisfactory. With all these desirable features, the obvious drawback is the long activation time of about 10 seconds needed for these cells. This is quite unacceptable when viewed in the light of instant readiness required in the case of some missiles. However, when used on a long range surface-to-surface missile aimed at deliberate targets, this need not be a serious limitation because the cell can be activated in advance. These cells have a wide scope for us in some of the missiles depending on the individual application.

The magnesium non-reserve cells considered before, can be either mag-manganese dioxide or mag-organic cells. They possess a number of desirable features as listed previously. Their limitation lies mainly in the sloping discharge characteristic and limited shelf life. The former is to some extent compensated by the higher voltage of the cells to begin with but the latter remains a serious limitation.

The silver-cadmium secondary system has long cycle life and wet stand period and is very rugged. In these respects it is superior to silver-zinc system. However, for single shot applications we have in view, cycle life is not an important criterion. The capacity of silver-cadmium cell is less by about 40% and it has a lower operating voltage. In view of their ruggedness and cycle life they are used for satellites and space vehicles. However, there is no sufficient reason to prefer a silver-cadmium system over silver-zinc system for missiles.

The nickel-cadmium cells are inferior to silver-zinc system in respect of their capacities and discharge capabilities. However, from the points of view of cycle life and ruggedness they are preferred. Their low-temperature performance is superior to silver-cadmium and silver-zinc cells. As long as the desired low-temperature operation is not below —4°F silver-zinc and nickel-cadmium systems are at par.

Finally silver oxide-zinc primary, reserve and silver-zinc secondary cells can be considered. There has been a development effort in recent times to obtain silver oxide-zinc primary cell having shelf life of the order of two years. This effort has not met with complete success so far. At present they have been developed to have a shelf life of about one year. They exhibit good low-temperature performance and in this respect are superior to mercuric oxide cells.

The silver-zinc secondary system with a wet electrolyte possesses the same general features as the primary. For missile applications this system has the disadvantages of limited shelf life and frequent charging.

The last and the most important of these systems is the silver-oxide-zinc reserve cell. Such a reserve cell system is the ideal choice for the guided missile possessing all the attractive features of the silver-zinc system. It also has theoretically unlimited shelf life. The reported shelf life is about 5 years. The necessary automatic activation systems have been developed and are in use for guided missile application. To extend their low temperature performance, chemical or electrical heating is resorted to. Thus the lowest temperature at which they have been successfully operated is about —65°F. Activation time of a fraction of a second has already been achieved. As far as shock, vibration and acceleration go, this system withstands all the requirements, as reported by the U.S. Signal Corps Engineering Research Laboratory.

CONCLUSION

Amongst all the available types of batteries the pride of place belongs to silver oxide-zinc reserve battery by virtue of its high energy per unit weight and volume, capacity to discharge at high rate and long shelf life. However, the silver oxide-zinc primary battery now under development, may become most attractive provided a minimum shelf life of two years is achieved as that will do away with the complicated activation mechanism required in the case of reserve cells.

The next in importance are the sealed nickel-cadmium secondary cells. They possess excellent low-temperature characteristics and are rugged and can be sealed in resin. But their condition has to be checked often and they have to be re-charged when required. Similarly the silver-cadmium secondary cells can also be advantageously used for missile power packs provided they can be made spill proof or sealed type.

The mercuric oxide primary cells possess many desirable features from missile application point of view. They have a shelf life of one year or so. However, their performance at low temperature is poor.

Lastly, magnesium reserve cells and alkaline dry cells (primary) can also be considered for missile power packs. The magnesium reserve cells have long activation time and as such this point has to be borne in mind while selecting the same for a particular application.

From the foregoing it is concluded that reserve and primary silver-oxide-zinc, secondary nickel-cadmium and silver-cadmium, primary mercuric oxide, reserve magnesium and alkaline primary cells, in that order, are the most suitable electro-chemical systems for missile battery packs.

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