

STORAGE BATTERIES

G. SMITH



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STORAGE BATTERIES

INCLUDING OPERATION, CHARGING
MAINTENANCE AND REPAIR

G. SMITH, A.M.I.E.E.

Assistant Engineering Manager
Chloride Batteries Limited



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PREFACE

THE development of modern industry and the desirable increase in national productivity depend to a large extent on an expanding and efficient electricity supply industry.

To this end, new and larger power stations, of conventional and nuclear design, are being built to satisfy increased electrical load demands, which have doubled in the last ten years.

The electricity supply and storage battery industries have been closely associated since the earliest days of direct-current power stations. Then, very large storage batteries were an essential part of the power plant, providing electrical power which was switched on to the system either to supplement or take over generator loads during periods of heavy and light working.

Changes from d.c. to a.c. generation and the growth of the national grid system have altered the demands made on storage batteries. Batteries of very large capacity are no longer required, but because of the complexities of high-voltage a.c. generation and distribution many more smaller batteries are used for a wide variety of duties.

Improved standards of living have created a large increase in the demand for telephones and all kinds of motor-cars and road vehicles—none of these can work without a storage battery. Other forms of transport, by air, rail and sea, rely on batteries for vital standby power. The replacement of steam locomotives by Diesel and Diesel-electric locomotives has increased the demands on the battery, which must now supply very high electrical power for starting large Diesel engines, in addition to lighting loads.

Extensive building projects for new towns, schools, hospitals, large stores, places of entertainment, etc., demand storage batteries for maintaining emergency services during power failures. Industrial efficiency is closely related to improved standards of material-handling relying largely on battery-electric powered trucks for transport and stacking duties.

The adaptability and reliability of storage batteries as sources of electrical power have made them an essential part of most industries throughout the world. Yet, in spite of their widespread use, batteries remain to many people the black box of mystery and magic. The black box conceals not one but many designs, each with some special built-in characteristic to enable a particular battery to give optimum performance for a particular duty.

For each operation or duty there is the right type of battery, and correct charging and maintenance procedure to ensure the longest possible trouble-free life. A little knowledge of how a storage battery works, and the simple maintenance required for maximum service, will almost certainly save time, money and frustration.

This book has been written in the hope that it will provide guidance in the choice, operation and maintenance of the various types of battery available.

G. S.

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G. S.

PRINCIPAL SYMBOLS AND ABBREVIATIONS

Quantity	Symbol	Unit	Abbr.
Capacity; (rated or nominal)	C	ampere-hour	Ah
Current	I	ampere	A
		milliampere	mA
Electromotive force (e.m.f.) .	E	volt	V
Energy	W	watt-hour	Wh
		kilowatt-hour	kWh
Frequency	f	cycle per second	c/s
Power	P	watt	W
		kilowatt	kW
Resistance	R	ohm	Ω
		megohm	M Ω
Time	T	second	sec
		minute	min
		hour	hr
Voltage	V	volt	V

Specific Gravity. Differences between readings are often expressed in *points*. Thus 1.280 — 1.250, or 0.030, is 30 points.

INTRODUCTION

Primary and Secondary Cells

VOLTAIC CELLS store chemical energy which is converted to direct-current electrical energy during discharge. They are divided into two classes, the *primary cell* and the secondary cell, accumulator or *storage cell*.

The chemical reactions in storage cells are reversible: after discharge such a cell can be restored to its original chemical condition by passing an electric current through it in the direction opposite to that of discharge.

For all practical purposes the chemical reactions in a primary cell are irreversible: the generation of electric current consumes materials which cannot be replenished by recharging.

A *battery* consists of two or more voltaic cells connected together. The storage batteries described in this book are the types most widely used for commercial purposes, namely *lead-acid* batteries and alkaline batteries of the *nickel-cadmium* and *nickel-iron* types.

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CHAPTER 1

FUNDAMENTALS OF THE STORAGE BATTERY

THE storage of electrical power remains one of the greatest challenges to modern science. For most practical purposes electricity can be used only as it is generated. When the machine generating electricity at the power station stops, the wires linking power station and consumer become "dead" and no longer pass electricity.

There are, however, various systems and devices for converting electrical energy to some convenient form of stored energy for reconversion to electrical energy when required. Recently, hydro-electric pump storage stations have been built which utilize spare electrical power for pumping water to high-level reservoirs. The stored water is used later to drive turbines for producing electricity during periods of peak loading.

Since the earliest days of electrical power supply, storage batteries have been widely used to meet lighting and power demands during failure of mains supply, or to provide electrical power for equipment used away from the main electricity supply.

In the storage battery, electrical energy is stored as chemical energy which is converted to electrical energy, instantly and silently, and without the necessity of any moving parts, merely by closing a switch. The lead-acid battery is the type of storage battery which is most widely used, and the reasons for this will be explained in later chapters.

The necessity for storing electrical power may appear perplexing to the layman, who may have heard on many occasions that electricity exists everywhere and in everything. This is true, but electricity exists in atoms containing positive and negative electrical charges, which under normal conditions are balanced so that there is no movement of electrons within the material to produce an electric current. An electric current is therefore produced when the balance of electrical charges within atoms of the material is upset by some outside influence causing electrons to pass from one atom to the next.

With certain substances such as metals the electrons move freely, once their movement is started by the outside influence. This ready transfer of electrons is in fact an electric current in the metal conductor, and as many electrons are expelled at the one end as are

accepted at the other end of the conductor. One simple method of starting the transfer of electrons, or flow of electricity, in a conductor is to connect a source of electromotive force, such as a storage cell or battery, across the ends of the conductor.

Electrical Power from Lead-Acid Storage Batteries

The rapid development of electric lighting about 1880 and the improvements made in dynamo designs for generating direct current led to the creation of central supply stations in most cities and large towns. The new supply stations required storage batteries for—

- (a) Maintaining the small outputs at night time when the engines which drove the generators were shut down.
- (b) Maintenance of supply during breakdowns.
- (c) Load sharing during periods of maximum demand.

By 1900, the widespread demand for batteries for such purposes as lighting, propulsion of road vehicles, boats and tramcars, operation of telephone exchanges, etc., prompted the growth of various battery works and the foundation of the battery industry.

In 1911 the invention in America of the electric starting system for motor-cars created a demand for many more car batteries of increased power. Today the demand for motor-car and vehicle batteries amounts annually to several millions, and accounts for more than 80 per cent of the lead used in the battery industry.

From those early days the demand for batteries for all kinds of duties has steadily increased, whilst the last twenty years have seen a rapidly growing demand for batteries for specialized uses.

The electrical devices and equipment used in the Second World War required portable battery power in unprecedented designs and numbers. Light-weight batteries were required for aircraft, portable radios, telephones and transmitters. High-capacity heavy-duty batteries were required for tanks, army vehicles and assault craft. Special batteries of unique design were made for the destruction of enemy magnetic mines, for submarines of conventional and miniature size. Safety on land and sea was served by batteries designed to provide lighting in air-raid shelters, hospitals, public buildings, ships and lighthouses. Lifeboats carried radio transmitters worked by batteries designed specifically for that duty. In the munition factories, down the mines, on the docks, thousands of battery-propelled trucks of all types worked round the clock, speeding up the manufacture and transport of vital munitions and supplies.

Since the war the change-over and expansion of industry, together with an ever increasing rise in the standard of living, have created a

tremendous demand for electrical power. Attempts to satisfy this have been made by the building of numerous power stations, including several using nuclear fuel. Even these huge power plants require storage batteries for standby duties during an emergency or breakdown. The maintenance of essential services by battery power during an emergency is particularly vital in the nuclear power stations.

Stationary batteries have also played a very important part in the development of automatic telephone exchanges, and the British Post Office operates more battery power than any other user. Many more batteries will be required for the vast conversion and expansion schemes which are still proceeding in this field.

The need for portable or localized power has also greatly increased. The number of battery-operated industrial trucks and vehicles in Great Britain has increased from 25,000 to 90,000 in the last 10 years: the number of motor vehicles, each requiring a battery, multiplies year by year.

Improvements in Lead-Acid Storage Batteries

In all applications the battery has proved to be reliable and has frequently given good performance under adverse conditions and with indifferent maintenance. Much of the success of modern batteries lies in the research carried out since the war, resulting in improvements in battery components and production of designs suited to various operating conditions.

Battery life has been extended by the use of improved grid alloys, container and separator materials. Performance under widely different temperature conditions has been improved by new process methods and blending of the oxides with new additives. The energy outputs per unit weight and volume have increased by 30 per cent in the batteries designed for traction purposes. The modern car battery gives 20 per cent more energy per pound than that of 10 years ago. Modern stationary batteries for emergency duties in power stations, large stores, etc., give $2\frac{1}{2}$ times the output for the same volume compared with those made 20 years ago.

Modern dry-charged batteries can be stored dry for a period of 2 years, and still give at least 75 per cent of nominal capacity when activated by adding sulphuric acid.

History and Development of the Storage Battery

Much of the experimental work which led to the development of the lead-acid battery was carried out by Gaston Planté in 1859. Earlier, other scientists, the most notable being Gautherot, De la

Rue, Ritter, Grove, Faraday and Sinsteden, had each made some contribution to the discovery of the ideal reversible reaction, which in its practical form is the fundamental principle of the storage battery.

PLANTÉ (FORMED) PLATES

The earliest cell made by Planté consisted of two lead sheets, separated by strips of flannel, rolled together and immersed in dilute sulphuric acid. Planté discovered that, by passing an electric current through the plates for a considerable period, he was able to convert the surface of one plate to lead dioxide (positive) and the surface of the other plate to spongy lead (negative). This combination produced an electric current when the two plates were connected to an external circuit, and by alternate discharge and charge, Planté was able to increase the storage capacity of the cell. The only source of charging available to Planté was by primary battery, and his early cells took as long as a year to charge. It was not surprising, therefore, that for the first ten years following the invention, Planté cells, or accumulators as they were often called, were used only in laboratories where they were capable of supplying current in excess of that available from primary cells.

FAURE (PASTED) PLATES

In 1881, Faure, a Frenchman, and an American named Brush took out, independently, patents for pasting the surface of lead plates with coatings of lead oxides which could be readily formed, by the passage of current through the plates, into the active materials lead dioxide and spongy lead. The adherence of the active materials to the solid lead plates was poor, and the paste was easily shed from the plate surfaces.

An improved plate containing numerous holes filled with a paste of lead oxide and sulphuric acid was patented by Volckmar, also in 1881. The idea was developed by Swan and Sellon, who produced a grid for holding the paste.

In 1882 Sellon patented a modified grid using an alloy of lead and antimony, the grid mesh being designed to key the active material in the grid. This grid was to be the basic design for pasted plates used in most portable lead-acid batteries.

ALKALINE STORAGE BATTERIES

Planté and other scientists had experimented with various combinations of metal electrodes and electrolytes in their search for the

perfect reversible cell. Most combinations or couples had no practical value and were merely laboratory curiosities.

After much experimental work the only other type of cell which was comparable in commercial value with the lead-acid cell was invented by Edison of America and Jungner of Sweden. In 1900 Jungner patented the nickel-cadmium-alkaline cell, and a year or so later Edison patented the nickel-iron-alkaline cell. Both types used an alkaline electrolyte of dilute potassium hydrate, and were the prototypes of present-day nickel-cadmium and nickel-iron batteries.

Definition and Chemistry of the Storage Battery

A storage battery is a chemical device reversible in its action, which stores energy at one time for use at another. The energy stored is chemical, not electrical. Electrical energy in the form of direct-current electricity is applied to the battery during the operation termed *charging*. The electric current produces chemical changes in the battery, and the chemical energy stored in the plates is reconverted to electrical energy when the cell is *discharging*.

Types of storage battery which have most practical and commercial value are lead-acid batteries and alkaline batteries, the latter including nickel-iron and nickel-cadmium assemblies.

LEAD-ACID STORAGE CELLS

The fundamental parts of a lead-acid storage cell are two dissimilar plates, or electrodes, immersed in an electrolyte in a suitable container, namely

Positive active material . . .	Lead dioxide (PbO_2)
Negative active material . . .	Spongy lead (Pb)
Electrolyte	Dilute solution of sulphuric acid (H_2SO_4) in water

In a fully charged healthy cell the positive active material is dark chocolate colour, and the negative active material slate-grey colour.

Lead plates *similar* in chemical composition and immersed in dilute sulphuric acid produce *no* chemical reactions or electric current when connected to an external circuit.

The most elementary form of commercial lead-acid cell, consisting of a single pair of plates in a plastic (polystyrene) box, is shown in Fig. 1.1. This type is designed to supply small discharge currents, and is used mainly for bell circuits, alarms and laboratory work.

Although the lead-acid battery suffers the handicap of utilizing one of the heaviest of metals—lead—it is still the most widely used

of the storage battery devices. Some of the characteristics which have contributed to its success are worth noting—

(a) The lead-acid battery has the lowest initial and operating costs of the various types of storage battery. These include alkaline batteries, (nickel-cadmium and nickel-iron) and silver-oxide-zinc.

(b) Its voltage on discharge is the highest of all the reversible combinations used.

(c) It uses comparatively cheap and plentiful materials.

(d) The completely reversible chemical reactions produce little physical change in the plates.

(e) It can operate satisfactorily over a wide range of temperature from approximately 0° to 110° F (-18° to 43° C).

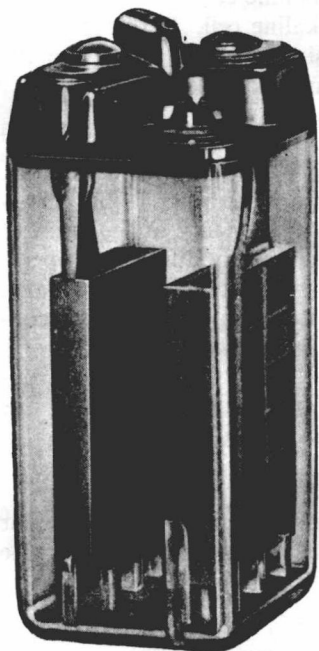


FIG. 1.1. LEAD-ACID CELL OF SIMPLE CONSTRUCTION OF ONE POSITIVE AND ONE NEGATIVE PLATE IN A POLYSTYRENE CONTAINER

(Chloride Batteries Ltd.)

CHEMICAL REACTIONS OF LEAD-ACID BATTERIES

In general, a storage battery must be given a charge before it can function, and this is carried out by connecting a suitable low-voltage d.c. supply across its terminals for a certain number of hours. There are, however, some batteries which can be activated merely by adding acid. These batteries, usually of the automotive type, are fitted with plates which have been specially processed or “dry charged” (see Chapter 6).

When a battery is fully charged the chemical changes taking place within the cell are complete. The positive active material has been converted to lead dioxide (PbO_2), and the negative to spongy lead (Pb), in contact with the electrolyte of dilute sulphuric acid (H_2SO_4).

DISCHARGING

When the battery is discharged by connecting a conductor across its terminals, a current will flow in the external circuit from the

positive to the negative terminal. Current also flows inside the battery between plates of opposite polarity by way of the conducting sulphuric acid solution.

It is in the dilute sulphuric acid (the electrolyte) that very important chemical changes take place when a current passes between the battery plates. This is very different from the flow of current (electrons) in the conductor across the terminals of the battery, which leaves the conductor completely unchanged.

Electrolytes are substances which, in the liquid state or in solution, are largely dissociated into positive and negative ions, or charged particles. Thus in solution a molecule of sulphuric acid (H_2SO_4), which is electrically neutral, is dissociated into one sulphate ion (SO_4^{--}), carrying two electronic charges, and two hydrogen ions (H^+), each carrying a positive charge which is numerically equal to the charge of an electron (1.602×10^{-19} coulomb).*

It is the migration of these ions to the electrodes (plates) immersed in the sulphuric acid which causes electricity to flow within the cell. Most of the chemical changes take place at the surface of the plates in contact with the electrolyte, for it is here that the ions produce chemical changes within the active material.

CELL ON OPEN-CIRCUIT

With no external circuit connected to the terminals of the cell, the two sets of ions within the electrolyte are in equilibrium and prevented from moving to the respective plates.

CELL ON DISCHARGE

When an external circuit is connected across the cell terminals the sulphate ions move to the negative plate and part with their negative charge. This produces an excess of negative charge on the plate, which is relieved by a flow of electrons into the conductor from the negative terminal to the positive terminal, that is, from a point of low potential to one of higher potential. (This is opposite to the conventional direction of electric current, which is that in which positive charges would move—if they could—in the external circuit.) The passage of surplus electrons from the negative plate to the conductor allows more sulphate ions from the electrolyte to combine with the lead to form lead sulphate (PbSO_4).

At the positive plate, the highly oxidized lead dioxide (PbO_2) is short of negative charge, so that it readily accepts the electrons arriving from the conductor. Hydrogen ions now move in to the positive plate from the electrolyte and combine with oxygen to

* 1 coulomb = 1 ampere-second; 60×60 coulombs = 1 ampere-hour.

form water (H_2O). This leaves some lead free to combine with the sulphuric acid to form lead sulphate and more water.

As the discharge proceeds and current continues to flow, more lead sulphate is formed, in both plates, by combination of the acid from the electrolyte. Water also is manufactured, which helps to dilute the electrolyte, and it is this progressive weakening of the electrolyte by formation of water which provides a convenient way of measuring the amount of discharge taking place. The cell is discharged when its voltage falls rapidly, and at this stage most of the active material has been converted to lead sulphate and the plates are almost identical in chemical composition.

CELL ON CHARGE

To reverse the chemical changes taking place in the cell during discharge, it is necessary to pass a current into the cell in the opposite direction to that of discharge.

The charging source must therefore have a voltage greater than that of the cell or battery to be charged. The charging source connected across the cell supplies an excess of negatively charged electrons to the negative plate and creates a shortage at the positive plate. The result is that hydrogen ions (positively charged) are attracted to the negative plate, where the hydrogen combines with the lead sulphate to form lead (Pb) and acid (H_2SO_4).

The shortage of charge produced at the positive plate results in sulphate ions being attracted, and combining with hydrogen of the water to form sulphuric acid. Some of the oxygen of the water combines with the lead of the positive plate to form lead oxide. At the negative plate the process of recombination of the hydrogen and sulphate continues as long as there is sulphate present. When the process of conversion of lead sulphate to lead is almost complete, hydrogen bubbles form at the negative plate and rise through the electrolyte.

Similarly sulphate ions react with water at the positive plate, forming sulphuric acid and leaving oxygen to react with lead to form lead dioxide. When most of the lead is converted, the oxygen appears as gas at the positive plate. The formation of hydrogen and oxygen gas at the plates is a sign that the cell is reaching the fully charged condition.

As the charge proceeds, acid which is released from the plates passes into the electrolyte and the specific gravity slowly increases. Measurement of the specific gravity of the electrolyte during the course of a charge does not give a true indication of the charged condition of the cell or battery. It is not until *gassing* commences