NICKEL-CADMIUM

Vented pocket-plate

STORAGE BATTERIES

W.S Thomson

Limited Impression 1980

MADE and PRINTED

in

GREAT BRITAIN

by

RATCLIFFE'S

of

ROTHERHAM

W.S. Thomson – 1980

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Anthony Green. www.alcadhistory.org.uk

Forward

Redditch was unique in having two alkaline battery manufacturers within its area.

The first to arrive was Batteries Limited which was established in 1918 by the Swedish company Nife in a factory in premises at Hunt End which had previously been occupied by the Enfield Cycle Co. They were set up to manufacture nickel-cadmium pocket plate cells, portable lamps and cap lamps for the UK market and British overseas markets.

Nife were the original manufacturer of the nickel-cadmium pocket plate battery invented by Waldemar Jungner in Sweden in 1899 and were world leaders in the technology.

The second was Britannia Batteries which was set up by the German company, Varta, in 1928-29 in a factory previously occupied by the Eadie Manufacturing Co. in Union Street, Redditch. Initially, they manufactured lead acid, alkaline (Edison tubular and a fiat plate type) and dry batteries (Pertrix).

In 1923, the Chloride Group bought some shares in Batteries Ltd. In 1926/28 Lucas took an interest and in 1933 Chloride finally acquired a controlling interest with Lucas retaining a shareholding.

Subsequently Lucas was bought out in 1968/69.Some 40 years before then, in Following negotiations between 1931 and 1936, Chloride purchased all Varta interests in the UK.

For a time, Chloride continued with the manufacture in Redditch of lead acid and dry batteries, in addition to the two alkaline types, but the lead-acid activities were gradually absorbed by other companies in the Group.

Chloride disposed of the Pertrix dry battery section, helped perhaps by a disastrous fire which occurred during the Second World War and destroyed the main Pertrix building.

In about 1933 Batteries Ltd. was renamed Nife Batteries Ltd. and in 1947 the company moved from Hunt End to Union Street to be merged with the alkaline section of Britannia Batteries, forming a new unit named Alkaline Batteries Ltd.

The names of Nife Batteries and Britannia were retained for commercial use.

This continued until 1970, when, the Chloride Group interest having become predominant, the name of the company was changed to Chloride Alcad Limited.

Developments and new products continued at the Redditch plant. These included new cap lamp batteries, plastic cased cells, sealed pocket plate products and sintered products.

In 1966 Alkaline Batteries Ltd. began using the Alcad brand name and the Company was now employing over 1,000 people with factories in Redditch, Southampton (Bardic) and Ponthenry (S. Wales), and with local assembly in Australia and South Africa. It had sales offices and distributors in almost every country in the World.

Chloride Alcad was now the second largest manufacturer of nickel-cadmium pocket plate industrial batteries in the world, only being exceeded by its original parent, the Swedish company Nife-Jungner,

However, things were about to change as, due to financial difficulties in the Chloride group, Chloride Alcad was sold in 1982 to the Marathon Manufacturing Inc of Waco, Texas, USA and the company was then renamed Marathon Alcad.

Marathon retained ownership for 5 years and continued investment in new plant and products.

However, again due to the financial difficulties of the new parent company, Marathon Engineering, resulting from the oil crisis of that time, they were forced to sell a number of their acquisitions, including Alcad.

In 1987 it was acquired by the French specialist battery company Saft, who embarked on a major transfer of all their pocket plate manufacture from their site in Bordeaux to Redditch.

This was of great benefit to the Redditch site and new products continued to be introduced and the production volume was increased,

However, in 1991 Saft acquired the Swedish company NIFE AB, the descendant if the original Nife Company, who were in financial difficulty due to a large manufacturing investment.

After some deliberation, Saft decided that they could not support two sites manufacturing the same technology and in 1993 the Redditch plant was closed and the production of the Alcad products moved to the Swedish factory based in Oskarshamn.

The Alcad brand name was retained and still continues to made and sold.

Sidney Thomson joined Nife Batteries at the Hunt End works, Redditch, In 1938 as an Application Engineer. Over the following years he was engaged continuously in the Technical and Commercial Application of the Nickel-Cadmium Electric Storage batteries produced by the company, initially at Hund End and later, when the two sites were amalgamated, at the Union Street site. He retired in 1972 and during his retirement wrote this account of 'Nickel Cadmium Vented Pocket-file Storage Batteries'.

He worked in the Nickel-Cadmium battery industry in Redditch during a crucial time in its history and, during which time, they had numerous world firsts to their credit.

Consequently, this account of this unique battery technology gives an important insight into all aspects of the product and is still relevant today.

Anthony Green

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Biography

Sidney Thomson was born in Inverness in 1908, the eldest of three sons of James Thomson, a photographer. He was educated at the Royal Academy there, and it is said that he assembled the first crystal set in Inverness.

In 1925 the family emigrated to Christchurch, New Zealand where he took up an apprenticeship with Watkinson’s, a local electrical engineering firm, at the same time attending Christchurch Technical College on an engineering course. He qualified and registered as an Electrical Wireman and was also registered for High Live Wiring work before, in 1929, enrolling at Canterbury College, Christchurch. After graduating with honours in Electrical and Mechanical Engineering, he joined the Hydro-Electric branch of the New Zealand Public works Dept. However, he was successfully nominated by the Faculty of Engineering for a placement as a Research Assistant at G.E.C. Witton and shortly afterwards left New Zealand for the U.K. in 1933.

While working for G.E.C., he was a freelance contributor to several publications including The British Technical Press, the Electrical Times and The Electrical Review, the latter printing an article on ‘Engineering Students in New Zealand.’ In 1936 he was awarded a Students’ Premium by the Institute of Electrical Engineering for a paper on ‘Insulator Testing and Maintenance on Live H.T. Lines,’ read before the South Midlands Section of the IEE at Birmingham.

In 1938 he joined Nife Batteries at the Hunt End works, Redditch, as an Application Engineer, and the following year was appointed Assistant Design and Technical Sales Engineer. In 1943 he was named in a number of British Patents involved in ‘Improvements relating to Plates for Nickel-Cadmium Storage Batteries.’ A surviving letter dated 6th Nov. 1945, from the Ministry of Supply, reveals something of his work during the war years. It thanks him for his ‘efforts in supplying batteries for the (V2) rocket experiments made in Germany. The batteries arrived on time, gave the desired performance and created a very favourable impression amongst the German Staff’. Enclosed as a ‘small memento of your co-operation’ is a photograph of the launch of a V2 rocket.

Post-war he was, in his words, ‘engaged continuously in the Technical and Commercial Application of Nickel-Cadmium Electric Storage batteries to the requirements of Industry generally, and to Railways as a speciality, in the UK and Overseas, with periodic visits mainly to Canada, U.S.A, Australia, New Zealand, South Africa, Sudan and Pakistan.'

On a first trip to Canada in 1954 he carried out a coast-to-survey, industry by industry. Special literature was prepared to cater for the different technical specifications of the Canadian market and many tests were carried out to determine battery characteristics at extremely low temperatures. Enquiries were received from electricity supply, railway, mining and industrial concerns and a number of trial orders was executed. One important enquiry was received from the Canadian Government for the supply of nickel-cadmium batteries which could withstand severe transport conditions to isolated sites, resist very low temperatures and operate vital equipment without fail after prolonged periods without skilled maintenance or attention. This was for the 'Distant Early Warning' (DEW) Line, some 63 radar stations strung along the north coast of Canada and Alaska, to detect potential attacks on the US and Canada during the Cold War. Since a proportion of these stations were unmanned, reliability was vital.

The trip resulted in initial orders of over half a million pounds from Canadian customers for nickel-cadmium batteries.

He travelled extensively between 1954 and 1971, a period in which foreign travel lacked some of today's refinements. In a log he records details of some of the more memorable journeys. Perth, 1968, and the captain is filling in the time afforded by a delayed flight to Johannesburg with a lengthy description of the ditching procedure, followed by a short lecture explaining that after the only stop to refuel, in Mauritius, there follows the longest flight in the world over water (3700 miles) without places for dry emergency landings or for refuelling. For good measure he adds that the distance and flight time are very nearly the limit of the fuel capacity of the Boeing 707 aircraft.

Lyallpur, 1969, and thirty or so passengers and crew are standing on the runway beside the crash-landed Fokker Friendship 48-seater out of which they have been ordered to 'Jump and Run.' They wait, in the sun. Then down the runway comes an old and battered jeep equipped with 'a couple of hand-held fire extinguishers.'

In Sept. 1970 an unforgettable journey in Australia, by 'road.': Port Hedland to Mount Goldsworthy, 80 miles, temperature 100 degrees F, driver and car hired from Avis. 'The car is crunching and thumping along a two-lane dirt track through the desert which is N.W. Australia and all around is brick-red sand and dust mixed up with boulders, stones, gravel and grit….The wheels are all the time dipping into pot-holes and climbing over heaps of stones so that there is unceasing rattle of doors and fittings.’ They arrive desperate for a beer. They will return to Port Hedland the following day.

Altogether in the years between 1954 and 1971 he made 37 trips to 13 countries.

Following his retirement in 1972, Sidney Thomson wrote an account of ‘Nickel Cadmium Vented Pocket-file Storage Batteries.’ Copies are held by Alcad, and by the Institute of Engineering Technology.

He moved to Rotherham, where he died in 1982.

W.S. Thomson Overseas Business Trips

Country	Year
Canada	1954, 1956, 1958, 1964,1966,1967, 1968, 1969, 1970, 1971
USA	1956, 1966, 1967, 1968, 1969, 1970, 1971
Australia	1967, 1968,1969,1970
New Zealand	1967,1968, 1969, 1970
Pakistan	1968, 1969
Portugal	1968
Thailand	1970
Belgium	1969
Chile	1967
Italy	1968
Malaya	1970
Sudan	1968
South Africa	1967, 1968, 1969

Jean Asher,

Daughter of Sidney Thomson

Preface

'Nickel-Cadmium Storage Battery' is a generic description which does not refer to any one particular design, but to the various forms in which the same basic materials - nickel and cadmium - are adapted to the different purposes for which Industry needs rechargeable storage batteries.

Every Nickel-Cadmium Storage Battery consists of a number of separate similar cells which are connected electrically in series. The cells follow orthodox storage battery practice in that each is made up of two groups of flat rectangular plates which are interleaved and immersed vertically in a solution in a rectangular container of sheet-steel or moulded-plastic.

The overall cell design, however, takes various forms, apart from the simple considerations of physical size, Small, Medium and Large.

One fundamental distinction in form is between cells which have Sintered-Plates and cells which have Pocket-Plates.

Another is between cells which have Vented Containers and cells which have Sealed Containers.

Cells may have Sintered-Plates in Containers which are Vented or Sealed; similarly, cells may have Pocket-Plates in Containers which are Vented or Sealed.

Vented cells have either Steel or Plastic Containers, but Sealed cells have Steel Containers only.

Each combination suits a particular field of Storage Battery Application, but this book concerns itself specifically with the Nickel- Cadmium Storage Battery in which the cells are of Vented Pocket-Plate design; and this qualification, for that reason, is incorporated in the title.

Contents

INTRODUCTION

Nickel-Cadmium Vented Pocket-Plate Storage Batteries are particularly appropriate where the environmental conditions welcome simplicity of installation, operation and maintenance, with in-built strength and durability.

Typically, they provide the energy by which Internal-Combustion Engines are electrically started, by which Switch-Gear is opened and closed to control the nationwide Distribution of Electric-Power, and they provide reservoirs of DC Energy which maintain Lighting and other Electrical Services during periods of temporary failure of the normal Sources of Supply to these.

For the purposes of detailed consideration and study, these industrial functions are conveniently separated into two groups, STATIONARY and MOBILE, since each group operates in an entirely different environment.

In the STATIONARY group, Electricity Generating Stations and Distribution Substations are provided with storage batteries for the opening and closing of Switchgear; common Equipment Nameplate DC Voltages are 220, 110, 32 and 24.

Storage batteries at voltages ranging from 6 to 220 provide Standby DC for lighting, telecommunications, inverters and for driving auxiliary machines during periods when the regular Sources of DC Supply to these have been temporarily interrupted.

12, 24- and 32-volt batteries provide for the DC electric-starting of Stationary Internal-Combustion Engines and Gas-Turbines.

In Signalling Systems on Railroads, batteries include 1.25 volt for section-control, 24, 32 and 110 volts for operating DC Rail-Point Switching machines, and 12 and 24 volt batteries provide operating and standby DC for audible and visible Warning Systems in situations where Rail-Roads and Motor-Roads cross on the same level.

In the MOBILE group, 24, 32, 64- and 110-volt batteries provide for the DC electric-starting of the engines of Diesel Locomotives and Rail Cars.

Locomotives and Rapid-Transit Railcars which are propelled by electric power from the rails or from an overhead conductor wire carry 32, 64- or 110-volt batteries as Standby DC for control and lighting when the regular DC Supply to these is temporarily not available.

In all these situations, both STATIONARY and MOBILE, the battery is one part of a Three-Part SYSTEM; the other parts are the DC Equipment to be provided with energy by the battery, and the DC Source for charging the battery.

Accordingly, the DC Electrical Characteristics of all Three Parts need to be compatible for the SYSTEM to operate successfully, and it is the responsibility of Application Engineering to ensure this.

Application Engineering takes in the overall concept of the SYSTEM, from the initial Electrical Specification to the final Maintenance, by way of choosing the battery size, its physical layout, the charging arrangements, the installing, commissioning, operating and servicing procedures. It considers each of these aspects in relation to all the others and has as its basis the interpretation and application of the comprehensive Data which is issued by manufacturers of Nickel-Cadmium Vented Pocket-Plate Storage Batteries.

In particular, it ensures that battery-charging arrangements are adequate in relation to the SYSTEM requirements, and that installation arrangements are appropriate to the environment. These are the prerequisites for overall operational success, which is that the battery is consistently available to perform the function for which it has been installed.

To appreciate and apply the features and characteristics of the Nickel -Cadmium Vented Pocket-Plate Storage Battery, a deep theoretical knowledge of electro-chemistry is unnecessary; an understanding of the basic principles is sufficient. It is desirable, however, to have some detailed knowledge of the principles of working of the Equipment with which the battery is to operate, so that the relevant battery and DC Source for charging can be correctly matched to the requirements of the Equipment and to the SYSTEM as a whole.

Chapter 1. outlines the Electro-Chemical Principles in sufficient detail for the purpose of Application Engineering.

Chapters 2, 3, 4 and 5 describe the Mechanical Design and the Electrical Performance.

Chapter 6. gives guidance in the choice of battery sizes and charging arrangements in relation to SYSTEM requirements. This is the important part of Application Engineering, and the principles are applied to typical SYSTEMS.

Chapters 7 and 8. recommend Installing and Maintaining procedures.

Chapter 9- consists of Appendices which relate to specific aspects of Nickel-Cadmium Vented Pocket-Plate Storage Battery technology which are not included in any detail in the text of the other Chapters; moreover it is convenient for the subject matter of each to be available separately, for ease of reference. They discuss Internal Resistance and Impedance, Ventilation and Approved Water; and the Nomenclature tabulates the Abbreviations and Symbols which are used throughout the text.

1 Electro-Chemical Principles

The Nickel-Cadmium Electric Storage Cell derives its description from its basic constituents which are compounds of Nickel and Cadmium.

When arranged in suitable physical relationship with each other and immersed in a solution of Potassium-Hydroxide, they form an electro- -chemical system which will store and release electrical energy.

In storage battery technology these compounds of Nickel and Cadmium are referred to as ’Active-Materials’; the solution is referred to as the ‘Electrolyte’.

As with other systems of electro-chemical storage, the cell has one group of flat plates supporting the +ve active-material which are interleaved with, but separated and electrically insulated from another group of flat plates supporting the -ve active-material; both groups being immersed vertically in electrolyte in a suitable containing vessel.

+ve and -ve terminals are brought out above the surface of the solution as a means of connecting the +ve and -ve plate groups to an external electrical circuit.

This arrangement results in an electric storage cell which has an open-circuit PC voltage of 1.28 between its +ve and -ve terminals.

ACTIVE-MATERIALS

In the Pocket-Plate cell, the Active-Materials are in powder form.

The +ve plate active-material is Nickel-Hydroxide, which is compressed in order to create electrical conductivity in the masse by pressing the particles together.

But Nickel-Hydroxide particles, even under pressure, are poor electrical conductors one to the other, and so as to increase the inter- -particle conductivity to a more satisfactory level, finely divided graphite, which is a good conductor, is mixed intimately with the Nickel- -Hydroxide powder, prior to its being compressed.

The graphite takes no part in the electro-chemical functioning of the cell, nor does it prevent the electrolyte from reaching the particles of Nickel-Hydroxide; it acts as a physical conductor of current.

The -ve plate active-material is an intimate mixture of Cadmium- Oxide and Iron-Oxide, the former predominating; it is compressed in order to create electrical conductivity in the masse by pressing the particles together.

By itself, Cadmium-Oxide in compressed form lacks the porosity which will allow the electrolyte to effectively reach all particles in the masse of the -ve plate active-material, so that each can make its contribution to the electro-chemical reactions within the cell.

The role of the Iron-Oxide is to create and maintain a mechanical separation of the Cadmium-Oxide particles and being a good conductor, it improves the electrical conductivity of the masse of the -ve plate active-material.

But Iron-Oxide itself has electro-chemical storage properties in relation to Nickel-Hydroxide - the +ve plate active-material - when both are immersed in the same electrolyte; so that in addition to acting as a conducting separator for the Cadmium-Oxide particles, the Iron- Oxide also takes part in the electro-chemical reactions within the cell.

The Electrolyte is Potassium-Hydroxide dissolved in water, and the solution is mixed to a Specific Gravity of 1.20 at Normal Temper- mature which is 20°C/68°F.

CHARGING and DISCHARGING

Electrical energy is stored by the process of Charging, that is by connecting the cell terminals electrically to a Source of DC Power, +ve cell terminal to +ve Source terminal, and -ve cell terminal to -ve Source terminal, and forcing a Charge current through the cell for an appropriate number of hours. It is not possible for the process to be completed within the context of seconds or minutes.

The DC energy provided by the Charging process is stored by electro -chemical conversion of the active-materials of the +ve and -ve plates by oxidation and reduction respectively. That is to say, the active materials change their chemical form.

Oxygen is passed from the active-material of the -ve plates to that of the +ve plates by ion transfer through the electrolyte, when the Charge current is passing. The Cadmium-Oxide and Iron-Oxide are reduced to Cadmium and Iron respectively, and the Nickel-Hydroxide of the +ve plates is raised to a corresponding higher degree of oxidation.

When the -ve plate active-material has been completely reduced to Cadmium and Iron, the maximum possible amount of electrical energy has been stored by the cell.

The energy thus stored is released to do useful work by reconversion of the active materials to their previous form by Discharging, that is by connecting the© cell terminals electrically to an external circuit, so that a Discharge current passes through it from the cell, and in the reverse direction to the Charge current.

In the Discharging process, oxygen-ion transfer takes place in the reverse direction to the Charging process; the -ve plate active- -material reverts to Cadmium-Oxide and Iron-Oxide, and the Nickel- Hydroxide of the +ve plate active-material is reduced to a corresponding lower degree of oxidation.

The Electrolyte functions as a carrier of the Change and Discharge currents, by ionic transfer of oxygen between the +ve and -ve plate active-materials. It does not enter into any chemical association with the active materials at any time; nor does its density alter during the processes of Charge and Discharge.

CAPACITY

In storage battery technology the unit of electrical energy is the ‘Ampere hour’, which is current in ’amperes’ multiplied by time in hours.

The capability of a cell for electrical storage is measured numerically in ‘Ampere hours’, which in turn are in proportion to the quantity of active-material contained in its +ve and -ve plates; this is referred to as its ‘Ampere hours-Capacity’, or simply as its ‘Capacity’.

The electrical energy required for Charging is also measured numerically in Ampere hours and is applied in terms of an appropriate number of amperes for a specified number of hours; and in extra quantity to compensate for the inefficiency of the conversion process.

A battery consists of a number of cells of equal •Ampere hours- Capacity* in which the -ve terminal of each cell is connected electric- -ally to the +ve terminal of its neighbour; except for the +ve and -ve terminals respectively of the two cells at the extreme ends of the row which form the main +ve and -ve terminals of the battery; as shown diagrammatically in Fig. 1.1.

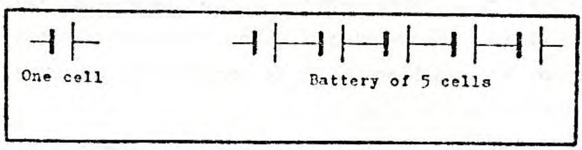


Fig. 1.1

The battery voltage is the sum of the individual cell voltages; the ampere hours-capacity of the battery is that of each cell.

2 Mechanical Design

The Nickel-Cadmium Vented Pocket-Plate cell follows orthodox storage battery practice in that a group df +ve plates are interleaved with, but insulated from, a corresponding group of -ve plates, and both are immersed in an electrolyte solution in a suitable enclosure. The plates are flat and rectangular in form; they support the electro-chemically active-materials and are in upright position.

PLATE DESIGN

The basis of the Plate Design is a tube of rectangular section. It is fabricated from two ribbons of annealed low-carbon steel about 0.10 mm thick, each rolled into a shallow channel section, then crimped together at their longitudinal edges to form a flat tube. Each ribbon is perforated, except at its edges, by holes, usually round and approximately 0.25 mm in diameter. There are 400 holes or thereabouts, equally spaced, to each square centimetre of perforated ribbon surface.

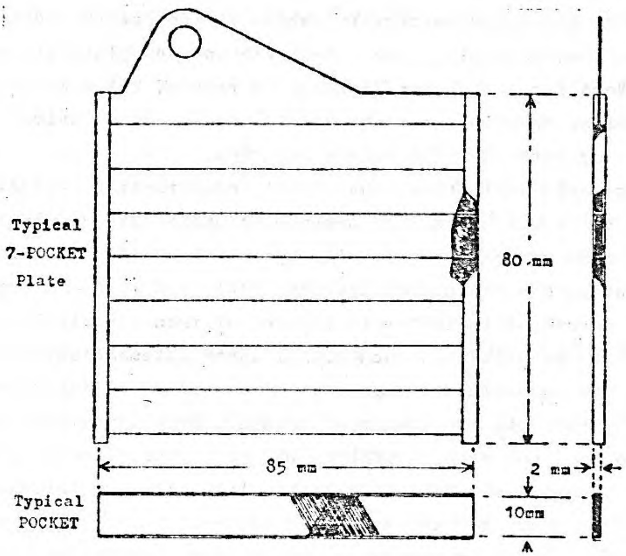


Fig. 2.1

The tube is packed with electro-chemically active-material, and in completed form in described as a POCKET. Fig. 2.1 illustrates the principle of its construction.

POCKETS are, in general, from 10.0 mm wide and 1.0 mm thick to 15.0 mm wide and 3*0 mm thick; and from 50«0 to 200.0 mm in length.

A plate is built up from a number of similar POCKETS placed one above the other, lengths horizontal, interlocked at their longitudinal edges, and mounted in a steel frame, in accordance with Fig. 2.1.

The frame consists of two U shaped strips of steel, 1.0 mm thick or thereabouts, which are spot-welded to a sheet steel crosspiece of similar thickness. These 13 strips seal the ends of the POCKETS against loss of active-material and constrain the FOCKETS into a rigid plate.

+ve and -ve plates are to exactly the same design, except that the +ve POCKETS contain the Nickel-Hydroxide / Graphite mixture, and the -ve POCKETS the Cadmium-Oxide / Iron-Oxide mixture, introduced in each case in dry powder form, and consolidated by pressure applied uniformly to the completely assembled plate. This also provides a firmly maintained contact between the steel ribbon and the active material inside the POCKETS.

The thickness of a plate is the thickness of the POCKETS from which the plate is built up.

The holes which perforate the steel ribbon give the electrolyte solution access to the active materials, which is necessary for the cell to function electro-chemically. The steel ribbon and plate frame act as metallic conductors for the charge/discharge currents, but take no part in the electro-chemical reactions, or enter into any chemical union with the active-materials or with the electrolyte solution.

It is coincidental that the steel construction results in a storage battery plate which has the maximum possible mechanical strength; steel is possible by virtue of potassium-hydroxide being the constituent electrolyte solution of the nickel-cadmium cell, and potassium-hydroxide is in itself, a corrosion inhibitor in respect of iron and steel.

When a plate is built up, each POCKET contributes an equal quantity of ampere hours. The ampere hour-capacity of the plate is the capacity of each POCKET multiplied by the number of POCKETS. By varying the length of the POCKET and the number of POCKETS, plates of different shape and ampere hours-capacity are obtained. Similarly, the ampere hours-capacity of a cell is varied by adjusting the number of plates.

This illustrates the versatile nature of the construction, and the ease with which the shape of Nickel-Cadmium Pocket-Plate cells may be adjusted to suit situations where specific battery dimensions are desirable.

In any cell the total ampere hours-capacity of the +ve platen needs to balance the total ampere hours-capacity of the -ve plates; but since the capacity obtainable from unit weight of -ve active-material is greater than the capacity obtainable from unit weight of +ve active-material, there is always one more in number of +ve plates. Accordingly, when +ve and -ve plates are interleaved to form a complete cell assembly, the outside plater, are +ve.

THIN, MEDIUM and THICK PLATES

It is not possible, economically, to cater for the entire Spectrum of Nickel-Cadmium Vented Pocket-Plate Storage Battery Applications with one single standard thickness and width for the POCKET, however desirable this might be from the point of view of manufacturing convenience and lowest production cost.

At one end of the Spectrum, the requirement is for currents up to about 2500 amperes for a fraction of a second, or for several seconds at the most. This is described as an AMPERE SECONDS Duty.

At the opposite end, the requirement is for currents of the order of several amperes and for a time duration reckoned in hours. This is described as an AMPERE HOURS Duty.

In between, there are requirements for currents of Intermediate value and time duration.

In order to cater economically for these diverse requirements, Nickel-Cadmium Pocket-Plate Cells are produced with Three alternative plate thicknesses, described as THIN-PLATE, MEDIUM-PLATE and THICK-PLATE respectively. The first mentioned is aligned basically with the AMPERE-SECONDS end of the Spectrum, and the last with the AMPERE HOURS end.

In explanation, the width and thickness of a POCKET determines how the contained active-material v/ill function in terms of electrical performance•

The distance between any particle of active-material and the nearest steel ribbon determines the extent by which that particle contributes to the total energy output of the POCKET. Particles close to the ribbon contribute more than those which are at the centre core of the POCKET, and the shorter the distance between core and ribbon, the lower is the electrical resistance of the inter-particle path from core to ribbon.

In electrical terms, a Thin and Narrow POCKET - for example 1.0 mm in thickness and 10.0 mm in width - has lowest internal-resistance, which means that a cell built with Thin Narrow POCKETS has a lower internal -

resistance than a cell built with Thick and Broad POCKETS - for example 3.0 mm in thickness and 15.0 mm in width, the comparison being between THIN-PLATE and THICK-PLATE cells which accommodate the same total quantity of active-material.

Moreover, the active-material in the THIN-PLATE cell is contained in a greater number of +ve and -ve POCKETS; so that there is a wider exposure of the +ve active-material to the -ve active-material, and this makes a further substantial contribution to the lower internal-resistance of the THIN-PLATE cell.

Consequently, the THIN-PLATE cell, by virtue of its lower internal resistance, is capable of delivering currents of much higher relative value than its THICK-PLATE counterpart of equal ampere hours-capacity.

In the context of ability to provide these high value currents, a THIN-PLATE cell will need a lesser quantity of active-material, and be smaller in dimensions and lover in weight than a THICK-PLATE cell which can provide currents of the same value; this rakes the THIN-PLATE design the most economical for the AKPERE SECONDS end of the Application Spectrum.

At the opposite end of the Spectrum, the requirement is for AHPERE HOURS. Low internal-resistance is not relevant where low current values are concerned, in which case the requirement is met most economically by a THICK-PLATE cell with its fewer in number +ve and -ve POCKETS than a THIN-PLATE cell containing the same quantity of active-material. The THICK-PLATE cell will be smaller in dimensions and lower in weight.

Some typical Comparative Characteristics of THIN-PLATE and THICK-FLATE cells are -

A cell of 2500 cu.cm. in volume has

With THIN plates, an ampere hours-capacity of		100.
"	THICK " " " "	135.

A cell of 100 ampere hours-capacity has

With	THIN plates, a volume of	2500 cu.cm, and a weight of			7.25Kg.
"	THICK """ "	1900 • "	”	"	5.00Kg.

A cell of 100 ampere hours-capacity will deliver

With	THIN plates, a high value current of	67O amperes.
"	THICK """ "	320"

These comparative figures demonstrate the economy of the THIN-PLATE design for the AMPERE SECONDS end of the Application Spectrum, and of the THICK-PLATE design for the AMPERE HOURS end.

But between the extreme ends of the Application Spectrum there are requirements for currents of Intermediate value and Time duration; moreover an AMPERE SECONDS Duty and an AMPERE HOURS Duty may be required from the same battery, and which may not be catered for economically by either the THIN-PLATE design or the THICK-PLATE design. In these circumstances the economical solution is provided by cells which have plates of MEDIUM thickness, and whose Comparative Characteristics are Intermediate to those of THIN-PLATE and THICK-PLATE cells.

CELL DESIGN

Fig. 2.2 is a part horizontal section through a typical Nickel-Cadmium cell of POCKET-PLATE design.

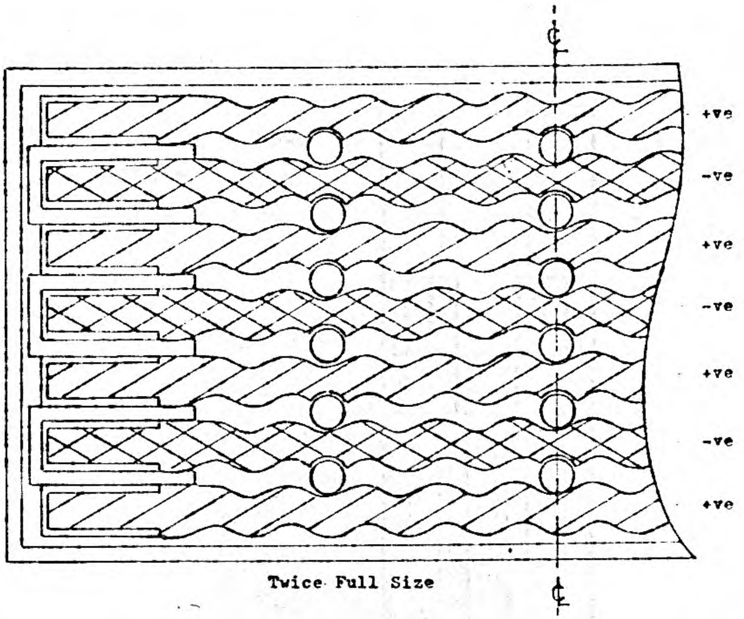


Fig. 2.2

The +ve and -ve plates are kept apart by round rods of insulating material; these have diameters comparable with the thickness of the plates which they separate, and they extend from top to bottom of the height of the plates.

The rods are pitched 20 to 25 mm apart and are located in shallow grooves which are indented vertically from top to bottom of both sides of each plate, during the plate-pressing operation.

U shaped insulating strips about 10 mm deep are slipped on to the vertical edges of the -ve plates, to their full height, to insulate the edges of the -ve plates from the adjacent +ve plates.

The feature of the vertical rod style of separation and insulation is that the electrolyte solution can circulate freely between the surfaces of the plates. It allows the gases produced during charging to be released quickly upwards, and this has a cleansing effect on the plate surfaces.

Moreover, the +ve and -ve plate surfaces are exposed to each other to the maximum extent, which ensures best possible utilisation of the active-materials and lowest electrolyte electrical resistance.

Fig. 2.3 is a part vertical section of the typical cell referred to in Fig. 2.2 and in which for example a group of 4 + ve plates has been interleaved with a group of 3 -ve plates and insulated from each other by rod separators and U strips on the edges of the -ve plates.

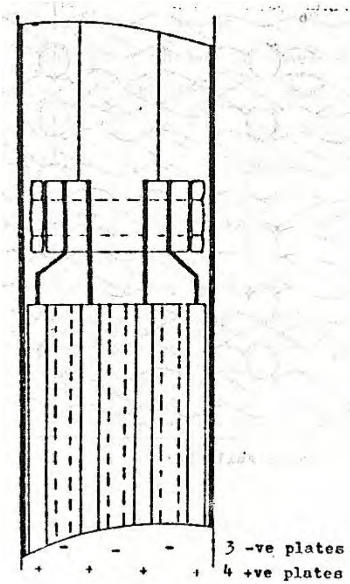


Fig. 2.3

The 3 -ve plates are coupled together mechanically and therefore electrically by a machined steel bolt - with nuts at each end – which passes through the holes in the top cross-pieces of the plate framer, shown in Fig. 2.1.

Machined Steel washers of appropriate thickness are also threaded on to the holt between the plate frames to maintain correct Reparation of these. One separating washer in formed at the lower end of the round machined steel pillar set vertically as the -ve terminal of the cell.

The 4 +ve plates are coupled together in similar fashion, and a steel pillar provided to form the +ve terminal of the cell.

The plate assembly complete with insulating rods and edge strips is immersed upright in electrolyte contained in a suitable enclosure; the +ve and -ve terminal pillars protrude above the surface of the solution, then pass vertically through insulating liquid-tight glands to the outside of the cell.

The plate assembly may be contained in an enclosure fabricated from Sheet steel, alternatively moulded in a plastic material. The former is then described as a Steel-Cased Nickel-Cadmium Cell, and the latter as a Plastic-Cased Nickel-Cadmium Cell.

STEEL-CASED CELLS

Fig. 2.4 shows the arrangement of a typical Nickel-Cadmium

Vented Pocket-Plate Cell, with two sides of the case cut away to give an interior view. The electrolyte solution is not shown.

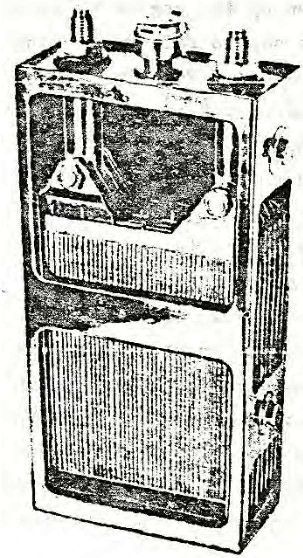


Fig. 2.4

The cell in Fig. 2.4 has an ampere hours-capacity of 80, with dimensions 60 mm long by 160 mm wide by 500 mm high for the steel case.

The rectangular case is fabricated from sheet steel around 1.0 mm in thickness, and made leak-tight at all seams, including those of the lid, by gas-welding. It is deliberately made a firm fit around the plate assembly; this exerts pressure which retains the vertical separator rods in place, and through the rods this pressure maintains firm electrical contact between the steel ribbon of the pockets and the active material inside•

The case is of such height as allows the top edges of the plates to be immersed to a depth of 50 mm below the surface of the electrolyte solution; plus, an air-space of similar height between the surface of the solution and the lid of the case. The height also allows for clearance between the lower edges of the plates and the bottom of the case.

Between the terminals is a round opening through which the electrolyte solution can be introduced into the cell; it takes the form of a steel cup welded into the lid.

The opening is smaller than the diameter of the cup, and a thin steel disc rests loosely on the rim formed between the two diameters. This disc is a poppet-valve, releasing gas pressure from within the cell, at other times preventing the ingress of air, which if it contains impurities, may contaminate the electrolyte.

The disc - which has a centre hole - is loosely captive on a steel peg fastened to the underside of the hinged cap which closes the open end of the cup, and is withdrawn by the peg so as to give clear access to the inside of the cell when the cap is raised to the open position, in which it stands upright on its hinge. The hinge is spring-loaded so that the cap is kept firmly closed on to the rim of the steel cup, but it is an imperfect fit with the rim so as to allow the free escape of gas.

All the external steel parts of the cell receive a rust-resistant finish of nickel-plating over a base of cadmium-plating. Since the number of +ve plates is one more than the number of -ve plates, the two outside plates of the assembly are of +ve polarity and are in firm contact with the inside walls of the steel case. The case is therefore at the same voltage as the +ve terminal of the cell.

In these circumstances, individual cells which are connected in series to form a battery need to be arranged so that their cases do not touch each other. Otherwise, a metallic contact between adjacent cells will create a short-circuit condition and the resulting current develop an electric arc sufficiently intense to burn and damage their metal parts.

The cells are accordingly constrained at a suitable distance apart, at least 10 mm, by an arrangement which virtually air-insulates them from each other and from ground, by a suspension system in an open hardwood frame to the general design shown in Fig.2.5.

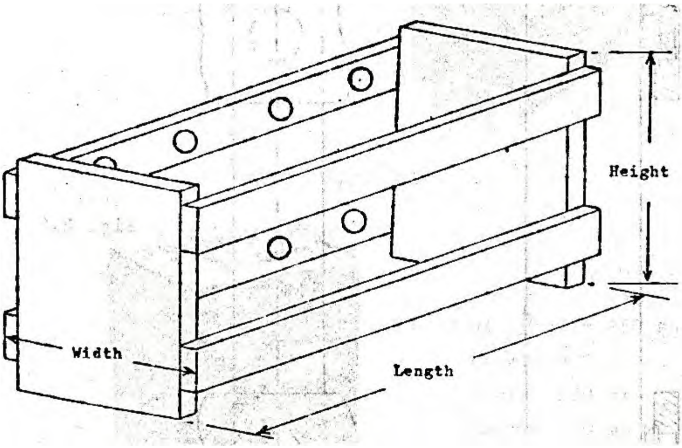


Fig. 2.5

The suspension system is by round pressed-steel protrusions on each side of the cell towards top and bottom, locating in insulated recesses in the side rails of the frame. The protrusions are on the opposite sides of the cell case which are adjacent to the edges of the +ve and -ve plates inside; two on each side are sufficient for small cells, but for larger cells four or six are necessary in order to adequately support the greater weight.

They are seen in Fig. 2.4 and the principle of the suspension system is shown in Fig. 2.6. Each protrusion locates in a socket of electrically insulating material, hard rubber or nylon, which in turn is recessed into the side rail of the hardwood frame Fig. 2.5.

The frames which support the cells are known variously as TRAYS or CRATES and they are made from straight-grained hardwood which is machined all over and impregnated with a preservative, or painted with a flame- retardant solution, whichever finish is best suited to the environmental conditions in which the battery is to be installed. They are an essential feature, and steel-cased cells are not operated unless supported in TRAYS/ CRATES to the design of Fig. 2.5.

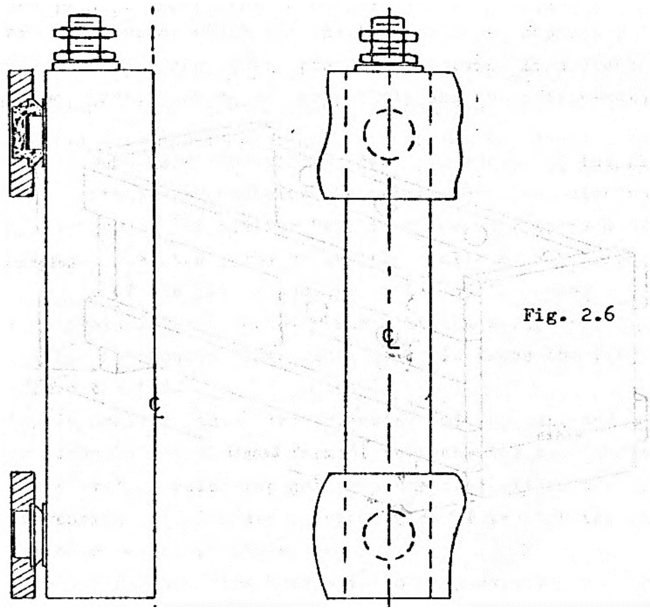


Fig. 2.6

The four side-rails which support the cells are fastened to the TRAY/CRATE ends by recessed-head wood screws; the TRAY/CRATE is thus of a demountable design which facilitates assembly as well as removal of cells when this is necessary.

TRAYS may contain only one cell or a number of cells. In the latter circumstances the choice is relevant to convenient handling weights and dimensions, and to the shape of the space available for accommodation of the battery. Typical TRAYS containing Three cells and Four cells are shown in Fig. 2.7.

Where TRAYS need to be moved for servicing, the two bottom strips of the hardwood frame are protected from mechanical damage by steel strips which run the length of the frame and are fastened by recessed- head wood screws.

It also makes for convenience in moving heavy TRAYS to provide lifting-handles; these are fastened to the ends of the frame.

Tray of 4 cells 250 ah.
Length 500 mm
Width 230 mm
Height 460 mm

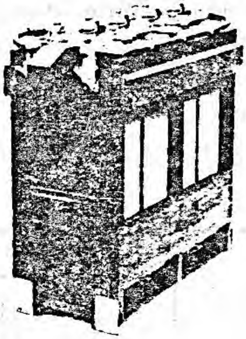
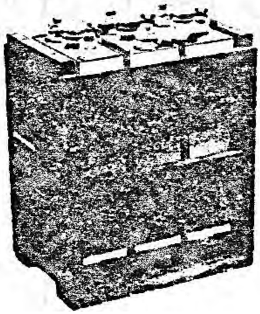


Fig. 2.7



Tray of 3 cells 250 ah.
Length 430 mm
Width 200 mm
Height 460 mm

Cells in TRAYS are connected electrically in series by flat copper busbars, of appropriate length and current carrying ability, which bridge the terminal pillars of adjacent cells, -ve terminal to +ve terminal. They are pierced at each end by a hole which is a close fit to the pillar and are tightly secured by steel nuts on the pillars which are suitably threaded to receive them.

They are nickel-plated all over as a protection against corrosion, and the general arrangement is seen in Fig. 2.7.

Cable connections from the open +ve and -ve terminals of a TRAY may be taken directly from the end-cells themselves, and this is described as Top-Terminal Take-Off.

In another arrangement, also shown in Fig. 2.7 connections may be taken from a pair of terminals, one +ve and one -ve, mounted on one of the vertical ends of the frame, and which terminals are already connected by permanent cables to the two cells at opposite ends of the frame; this is described as End-Terminal Take-Off.

Manufacturers of Nickel-Cadmium Vented Pocket-Plate Storage batteries issue Tabulated Information giving dimensions of their STANDARD ranges, of Steel-Cased Cells, and Fig. 2.8 is typical. Since, however, these cells are not connected together or to a circuit unless mounted in hardwood frames, the dimensions quoted are those of TRAYS which contain different numbers of cells.

Cell			TRAY Dimensions mm				
					Length mm		
mark	ah	weight	width	height	2 cell	3 cell	4 cell
AB065S	65	4kg	140	360	150	210	270
80S	80	5	140	400	150	210	270
95S	95	6	140	400	170	240	300
115S	115	8	190	350	170	240	300
135S	135	9	190	350	180	260	330
155S	155	10	190	400	200	280	380
175S	175	11	190	400	180	260	330
200S	200	12	190	400	200	280	380
220S	220	13	190	400	220	310	410
245S	245	14	190	400	240	340	450
270S	270	15	190	400	250	370	480
295S	295	16	190	400	270	400	520
AB320S	320	17kg	190	400	290	430	560

Fig. 2.8

There rare separate Tabulations for cells with THIN, MEDIUM and THICK-PLATES. In addition, each cell-case needs to be indelibly marked in order to reveal the plate design and ampere hours-capacity and corresponding with the identification mark which it has been given in the appropriate Tabulation.

It is customary for the numerical figure for its ampere hours capacity to be prefixed by letters to indicate plate thickness, and a suffix to indicate the case material.

Typically, TN35S is a THIN-PLATE cell of 35 ampere hour-capacity in a steel case; ME25S is a MEDIUM-PLATE cell of 25 ampere hours-capacity in a steel case; and TK65P is a THICK-PLATE cell of 65 ampere hours capacity in a plastic case.

A battery of steel-Cased Cells consists of a number of Trays of similar size placed side-by-side and connected electrically in series.

The number of Trays is the number of cells in the battery divided by the number of cells chosen for each Tray, and which is selected to suit the shape of the space available for accommodating the battery.

The length of the battery is then the width of one Tray multiplied by the number of Trays; the width of the battery is the length of each Tray.

The length of the accommodation space may be a limiting dimension for the battery, so that the number of Trays, and cells in each Tray, need adjustment to suit; similarly if the width of the accommodation space is restricted, the adjustment may need to suit this. The dimensions of Trays containing different numbers of cells are set out typically for example in Fig. 2.3.

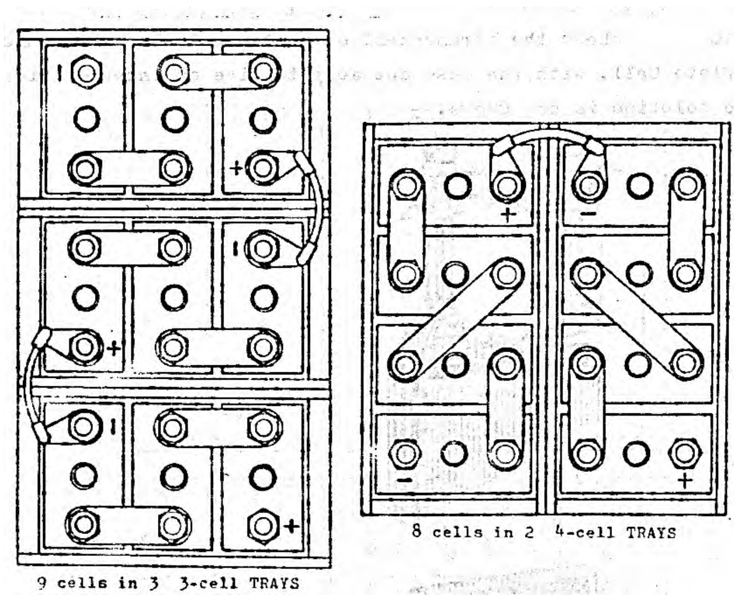


Fig. 2.9

An odd number of cells for each Tray is preferable, since the +ve and -ve terminals of adjacent Trays are close together, which facilitates the fitting of inter-tray connectors, and these ore kept short. This can, however, be arranged for in Trays having an even number of cells by providing a cross-over connector between two cells in the Tray. These alternatives are shown in plan view in Fig. 2.9.

The electrical connections between Trays standing side-by-side are made by insulated flexible copper conductors of suitable current carrying ability. They consist of an appropriate length of cable to each end of which is soldered a nickel-plated brass lug. The open + ve terminal of the end cell of each Tray is connected to the open -ve terminal of its neighbour, and the lugs at each end of the coble are bolted to the cells by the terminal nuts, as illustrated in Fig.2.9

The open +ve and -ve terminals of the battery are fitted with similar lugs into which the main outgoing cables from the battery are soldered.

PLASTIC-CASED CELLS

Fig. 2.10 shows the arrangement of a typical Nickel-Cadmium Vented Pocket-Plate Cell, with the case cut away to give an interior view. The electrolyte solution is not shown.

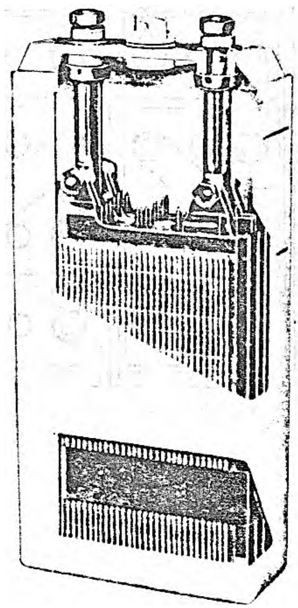


Fig. 2.10

The cell in Fig. 2.10 has an ampere hour capacity of 80, with dimensions of 70 mm long by 170 mm wide by 35c mm high for the plastic case.

The case is in two parts; one is the moulded lid, which is sealed in position after the plate assembly has been inserted into the other part, the container itself.

Since the sides of the plastic case have insufficient rigidity to exert the pressure necessary to retain the vertical plate separator rods in position, a firmly fitting rectangular sheet steel sleeve is wrapped around the plate assembly; this is equivalent to the steel case of the Steel-Cased Cell design.

The surface level of the electrolyte solution within the cell is discernible through the sides of the plastic case.

Between the terminals is an opening through which the electrolyte is introduced into the cell; it is a round hole with a screw-thread moulded into the lid and kept closed by a correspondingly threaded plug also of moulded plastic. The plug is hollow, with small holes top and bottom through which gas can escape from within the cell* But for larger cells, a cup with hinged cap and gas release valve, to the same design as for steel-cased cells, but moulded in plastic, takes the place of the threaded plug.

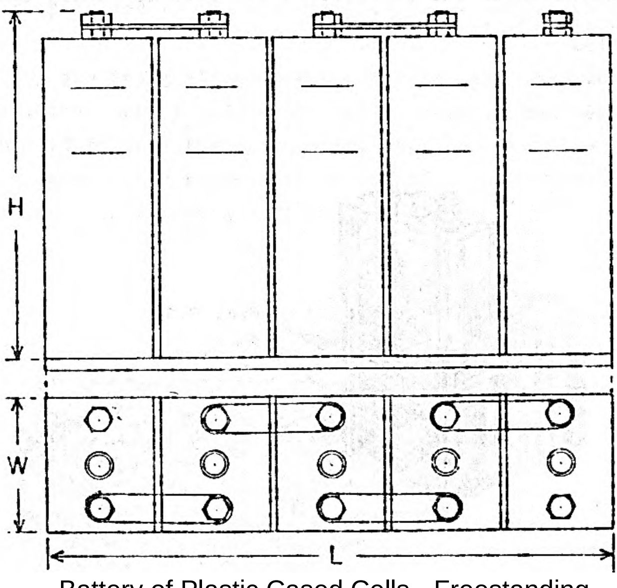


Fig. 2.11

Battery of Plastic Cased Cells - Freestanding

Since the plastic material chosen for the case is also an electrical insulator - so long as it is clean and dry - cells making up a battery may be stood close together, and Free-Standing on an insulating base is a usual arrangement for plastic-cased cells in the larger sizes, as in Fig. 2.11 for example.

But for ease of handling, the smaller sizes are generally arranged in groups of several cells which are accommodated in steel or wooden Trays in the basic style of Fig. 2.12.

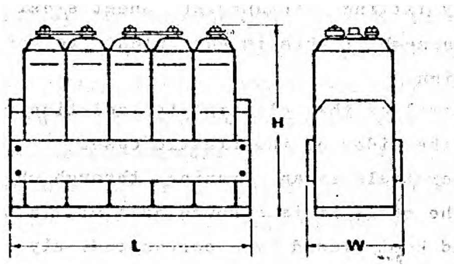


Fig. 2.12

Battery of Plastic Cased Cells in Wooden Tray

Fig. 2.13 shows the arrangement of a typical Nickel-Cadmium Vented Pocket-Plate Cell in which the case is moulded in a transparent plastic material through which the interior of the cell is easily seen.

Fig. 2.13

The cell in Fig. 2.13 has an ampere hours-capacity of 80, with dimensions of 80 mm long by 160 mm wide by 290 mm high for the plastic case.

The plastic material has high impact resistance to mechanical shock and vibration. It provides the case with rigid sides and corners, so that it is a firm fit round the plate assembly, and is able to exert the pressure which retains the vertical plate separator rods in place, in the same way as for steel-cased cells.

The surface level of the electrolyte solution within the cell is clearly seen through the transparent sides of the plastic case.

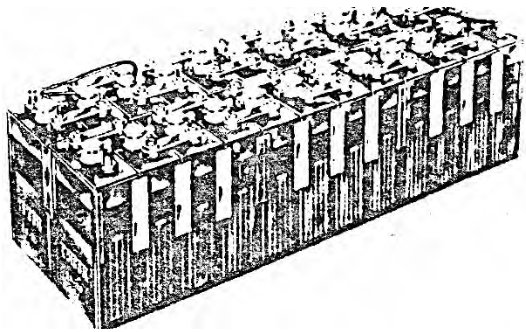
Between the terminals is an opening through which the electrolyte is introduced into the cell; it is a round hole with a screw-thread mould- -ed into the lid, and which can be closed by a correspondingly threaded plug, also of moulded plastic. The plug is hollow, with small holes top and bottom through which gas can escape from the cell.

Alternatively, a cup with hinged cap and gas-release valve, to the same design as for steel-cased cells, but moulded in a plastic material, can be fitted instead of the threaded plug.

Since the plastic material chosen for the case is also an electric- -al insulator - so long as it is clean and dry - cells making up a battery may be stood close together, and in the design of Fig. 2.13 means are provided for firmly attaching each cell case to its neighbour.

At the corners of the short sides of each cell case there are projecting and integrally moulded vertical ribs, and when cells are stood together, the ribs of adjacent cells form a channel over which a metal clip is slid to hold them firmly together.

A compact and rigid battery assembly is obtained by this means, and the principle is illustrated in Fig. 2.14.



36 cell battery
80 ah.

Length	960 mm
Width	320 mm
Height	290 mm

Fig. 2.14

Plastic-Cased Cells are connected electrically in series by flat copper busbars, of appropriate length and current carrying ability, which bridge the terminals of adjacent cells - +ve terminal to -ve terminal. Busbars are pierced at each end by holes which are a close fit to the terminal pillars and are tightly secured by steel nuts on the pillars which are threaded to receive them. They are nickel-plated all over as a protection against corrosion, and the general arrangements for busbars are seen in Fig. 2.11, Fig. 2.12 and Fig. 2.14.

The open +ve and -ve terminals of a battery are fitted with lugs into which the main outgoing cables are soldered.

Manufacturers of Nickel-Cadmium Vented Pocket-Plate Storage Batteries Issue Tabulated information giving dimensions and weights of their STANDARD ranges of Plastic-Cased Cells, and Fig. 2.15 is typical.

ah	Width mm	Height mm	Length mm	Weight kg	Mark	cc over plates
10	110	180	40	1.30	AB010P	110
15	110	180	55	1.70	015P	170
20	110	200	55	2.00	020P	170
30	110	230	65	2.60	030P	190
40	110	230	75	3.30	040P	220
55	170	260	75	5.70	055P	470
65	170	260	95	6.80	065P	600
85	170	330	95	8.20	085P	600
100	170	330	95	8.80	100P	600
120	170	330	95	9.40	120P	600
135	170	320	125	12.20	135P	800
150	170	320	125	12.70	150P	800
170	170	320	125	13.30	AB170P	800

Fig. 2.15

There are separate Tabulations for cells with THIN, MEDIUM and THICK Plates; in addition, each cell case needs to be indelibly marked in order to reveal its plate design and ampere hours-capacity, corresponding with the identification mark which it has been given in the appropriate Tabulation.

It is customary for the numerical figure for ampere hours-capacity to be prefixed by letters to indicate plate thickness, and a suffix to indicate the case material.

Typically, TN35P if a THIN-Plate Cell of 35 ampere hours-capacity in a plastic case; ME253 is a MEDIUM-Plate Cell of 25 ampere hours-capacity in a steel case and TK65P is a THICK-Plate Cell of 65 ampere hours-capacity in a plastic case.

THE ELECTROLYTE

The electrolyte is chemically pure potassium-hydroxide - which is a solid material in flake form - dissolved in sufficient purified water to give the resulting solution a Specific Gravity (SG) of 1.20 at 20°C/ 68°F. The solution is clear, as water, and has the same fluidity.

The Specific Gravity (SG) of the solution in the cell does not change due to the processes of Charging and Discharging, but it varies for another reason.

During the Charging process the water-content of the electrolyte is electrolysed into oxygen and hydrogen which escape from the cell as gases, and through the Vent provided for this purpose.

Continuous Charging steadily reduces the volume of water, but the amount of potassium-hydroxide remains the same. In these circumstances, a lessening volume of water is associating with an unchanging amount of potassium-hydroxide; in consequence, the Specific Gravity (SG) of the remaining electrolyte rises.

In practical terms, the level of the solution within the cell gradually falls, and so that a reasonable time can elapse before the +ve and -ve plates become uncovered, room for a reserve of solution is provided above their top edges, as in Fig. 2.13 for example.

When the level is restored to its original height by replenishment with water equal in volume to that lost by the electrolysis, the Specific Gravity (SG) returns to its original value. This is the procedure known in Storage Battery Technology as Topping-Up or Watering.

LOW-MAINTENANCE CELLS

Since, and unlike other types of storage battery, the electrolyte in the Nickel-Cadmium Vented Pocket-Plate Cell takes no part in the electro-chemical reactions during Charge and Discharge, there is no fixed relationship between ampere hours-capacity and volume of electrolyte.

Accordingly, this type of cell can be provided with a much greater volume of electrolyte than is needed simply to immerse the +ve and -ve plates; and clearly the larger the volume above the tops of the plates, the longer is the period of time which can elapse before replenishment with water is needed, which is a saving in maintenance time and cost.

The +ve and -ve plate assembly of Fig. 2.4 can therefore be placed in a larger steel case which will allow a greater volume of electrolyte, either at the same height or at other heights if more appropriate; for the same volume above the plates can be accommodated at different heights by adjusting the length and width of the steel case.

The most common heights are 50 mm as Fig. 2.4, and 100 mm.

The working limits of the Specific Gravity (SG) are 1.15 to 1.25

and within these the electrolyte has maximum conductivity, otherwise described as minimum electrical resistance. The volume above the plates is therefore regulated to ensure that at maximum level the SG of the electrolyte is not below 1.15» and when the level has fallen - by electrolysis - to the top edges of the plates, the SG is not above 1.25*

Commencing with SG 1.15 at maximum level, 35% of the total volume in the cell needs to be above the top edges of the plates so that when the level has fallen to that point by electrolysis, the SG does not exceed 1.25. The remaining 65% of the total volume needs to be between and below the plates.

When the calculated volume for above the plates cannot be accommodated within the prescribed standard height of 50 or 100 mm, room for the additional solution is provided at both sides of the +ve and -ve plate assembly, by fitting shallow U shaped sheet steel spacing pieces, which extend over- the entire area of the two outside +ve plates. These also maintain the pressure formerly exerted by the steel case which holds the vertical rod separators in place between the plates. The arrangement is shown in Fig. 2.16.

Varying the depth of these U pieces in conjunction with the space between the lower edges of the plates and the bottom of the steel case, is the means for adjusting the shape of the volume of electrolyte above

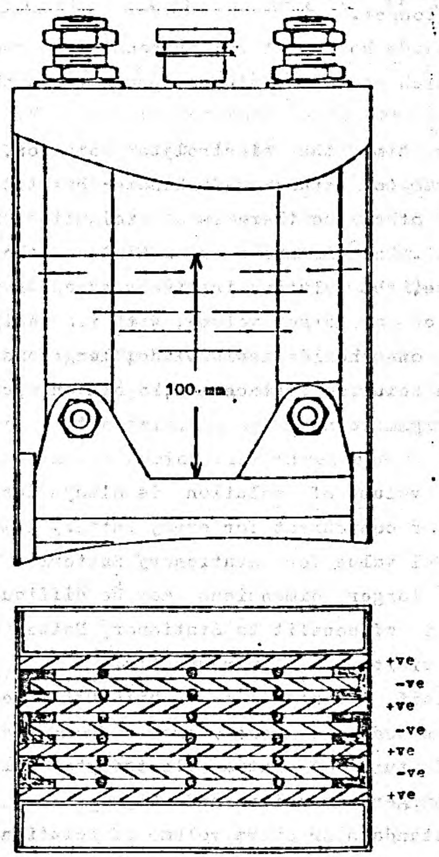


Fig. 2.16

the top edges of the plates, and in the correct proportion with the volume of solution in the cell, whilst retaining one or other alternative heights of SO mm and 100 mm.

The basis of the design calculations which are necessary, definition of Specific Gravity (SG), which is

Weight of unit volume of potassium-hydroxide solution

/Weight of an equal volume of water

The other feature of a large volume is that the lifetime of the solution is very much longer.

Potassium-hydroxide has a natural propensity to absorb carbon-monoxide and dioxide, which gases are always present in the atmosphere, in high or low degree.

In the course of time, the electrolyte solution, by this absorption, gradually converts to Potassium-Carbonate; but the process is not allowed to go too far, otherwise there is a diminution in the electrical performance of the cell. This is known as AGEING of the electrolyte, and at the appropriate time, the solution is discarded and replaced with new.

The provision of a large volume, with its ability to absorb a larger amount of carbon-monoxide and dioxide, lengthens considerably the period of time between solution replacement; again, an operational advantage of considerable significance.

While the extra volume of solution is always desirable, it is not necessarily justified or convenient for every battery installation.

It is of doubtful value for Stationary Batteries to which access is easy; moreover, the larger dimensions may be difficult to accommodate. On the other hand, it is of benefit to Stationary Batteries which are in remote locations and visited only infrequently.

It is of distinct advantage to Mobile Batteries which are not regularly accessible, since they are remote from their base for long periods of time; the feature of extra electrolyte volume may overrule the disadvantages of larger dimensions and weight.

The choice of standard or extra volume of solution is a compromise requiring individual consideration of each battery installation, and the decision can be important to the operator.

3 Electrical Performance

Electrical Performance is defined as the variation in the terminal-voltage of a cell whilst it is being Charged and Discharged.

The basic reference is the Open-Circuit-Voltage; it is also described as the Zero-Current-Voltage and the Reversible-Voltage. It is the voltage recorded at the terminals of the cell by an electrostatic meter, which means that zero current is passing through the cell at the time of measurement. In general, its highest value is 1.32 immediately after termination of the Charging Process; but it falls to 1.28 after the cell has stood idle for a period of time, weeks and months.

During Charging the terminal-voltage is higher than the Open- Circuit-Voltage, and lower during Discharge, due to internal resistance losses.

PERFORMANCE DATA

It is the purpose of Electrical Performance Data to indicate the precise extent of these voltage changes. The highest Charge-voltage is

1.70; the lowest Discharge-voltage of practical significance is O.65* and the operational range is in diagrammatic form in Fig. These

voltages are measured at the terminals of the cell.

	charge		open-circuit					discharge		
1.70	1.60	1.50	1.40	1.30	1.20	1.10	1.00	0.90	0.80	0.70
				Terminal Voltage						

Fig. 3.1

Performance is concerned with current with voltage deviation and is presented in for ease of explanation and interconnection.

Performance Data is produced in reference to the behaviour of single cells; in thin way it is conveniently applied to batteries which contain different numbers of similar cells in series connection. The voltage of one cell, when multiplied by the number of cells in the battery gives the total battery voltage.

Current value and time are common factors regardless of the number of cells in the battery.

The arrangements for obtaining Performance Data are shown diagrammatically in Fig. 3.2.

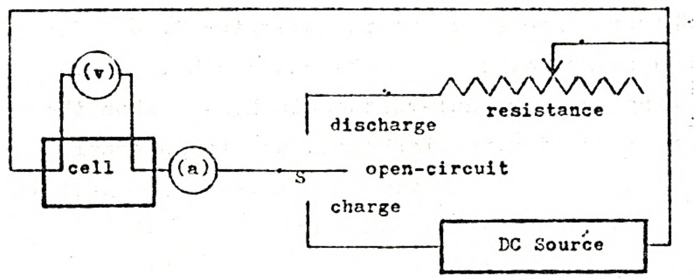


Fig. 3.2

The cell can be connected to a DC Source for Charging, or to an adjustable resistance for Discharging, or be on Open-Circuit, by manipulating the changeover-switch S. A DC ammeter indicates the Charge current or the Discharge current as may be appropriate to the position of the switch. A DC voltmeter indicates the voltage at the terminals of the cell.

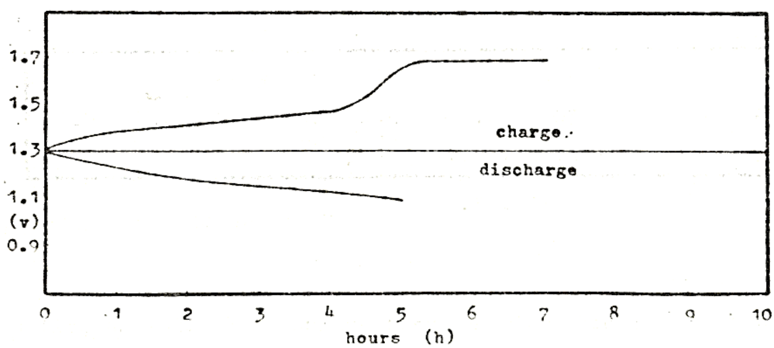


Fig. 3.3

Fig. 3.3 is a. typical presentation of the Performance of a Nickel-Cadmium Vented Pocket-Plate cell obtained from the arrangements in Fig. 3.2.

The curves connect terminal-voltage (v) with time. At pre-zero hours the cell is neither delivering a Discharge current nor accepting a Charge current. It is on Open-Circuit at 1.28 / 1.32 volts.

The curve below 1.32 volts connects voltage on the ordinate with time on the baseline, commencing at zero hours with a single cell which is already Charged. In Fig. 3*2 the switch is placed in the Discharge position, and the resistance adjusted so that the current stays at its pre-selected Constant value. The curve indicates how the terminal-voltage changes as the cell Discharges, and the endpoint of the curve signifies when the cell has completely Discharged its Ampere hours-capacity, in this case after 5 hours. This curve relationship is referred to in storage battery technology as a Discharge Characteristic.

The curve above 1.32 volts connects voltage on the ordinate with time on the baseline, commencing at zero hours with a single cell which is already Discharged. In Fig. 3*2 the switch is placed in the Charge position, and the DC Source is adjusted so that the current stays at the same Constant value as was pre-selected for Discharge. The curve indicates the rising voltage which needs to be applied to the terminals of the cell, by adjusting the DC Source, in order to keep the current Constant as the Charge proceeds, and the end-point of the curve signifies when the cell has received sufficient Ampere hours to complete the Charge, in this case after 7 hours. This curve relationship is referred to in storage battery technology as a Charge Characteristic.

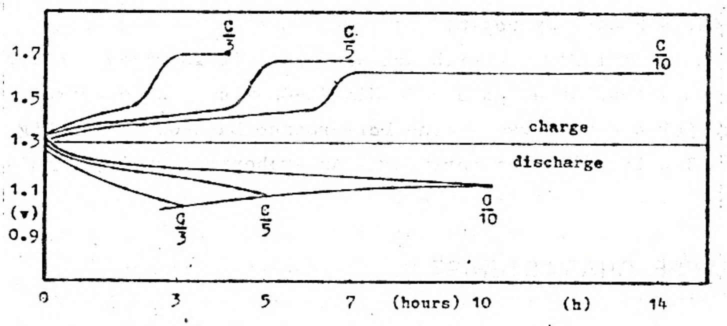


Fig. 3.4

But the same cell can Discharge its Ampere hours-capacity in shorter or longer periods of time, by adjusting the amperes value of the Discharge current to suit the time in hours, or vice-versa. Similarly, the cell can be Charged in shorter or longer periods of time, by adjusting the amperes value of the Charge current. In these circumstances, the same cell has a comprehensive number of Discharge and Charge Characteristics, and for the purposes of illustration and explanation, Fig. 3***is Fig. 3*3

to which two further examples have been added, with one Discharge Characteristic terminating after 3 hours, and the other after 10 hours; the corresponding Charge Characteristics also being included.

For the sake of clarity in presenting Performance Data, it is customary to select hours in whole numbers, and to adjust the ampere values to suit.

Ideally, the cell should maintain the same terminal-voltage for all values of the Discharge current, but this is not achieved in practice; its internal resistance - in the widest sense - ^creates voltage loss, in consequence of which the terminal-voltage falls away as the Discharge proceeds, and higher current values increase the rate of fall. Similarly, higher voltages are needed for higher values of the Charge current.

In these circumstances, each curve of Charge and Discharge in Fig. 3-^ is separated quite distinctly from its neighbours.

THE SYMBOL C

So that Fig. 3.4 may be applicable to a cell of any selected

numerical value for Ampere hours-capacity, the curve relationships are expressed in terms of the Symbol C.

C is a Symbol for Ampere hours, and when it is given a numerical value within the available range of Nickel-Cadmium Vented Pocket-Plate Cells - 5 to 300 ampere hours - The Performance Data of Fig. 4 refers to a cell which has that particular Ampere hours capacity.

DISCHARGE CHARACTERISTICS

The Discharge Characteristics of Fig.3.4 express the time in hours (h) which correspond with the Discharge amperes (a) in terms of the Symbol C.

C, (a) and (h) have these relationships

C = (a) x (h) ampere hours
(h) = C/(a) hours
(a) = C/(h) amperes
When C is given a numerical value, (a) and (h) may each be varied numerically, within limits which are discussed later, so long a6 the product of (a) and (h) is still equal to the numerical value assigned to C.

When (h) is given a numerical value in the relationship

(h) = C/(a) hours

C/(a) becomes a ratio in which for any change in the value of C there is an equivalent change in the value of (a). For example, if the numerical value of the Ampere hours assigned to C is doubled, then the numerical value of the amperes (a) is also doubled; (h) remaining the same.

In Fig. 3.4 the three Discharge Characteristics are the graphical expression of

(a) = c/(h) amperes

and in which (h) has been assigned numerical values of 3, 5 and 10 hours respectively, and C has the same numerical value of Ampere hours.

Accordingly (a) = C/3 amperes when (h) = 3 hours

(a) = C/5 amperes when (h) = 5 hours

(a) = C/10 amperes when (h) = 10 hours

Each Discharge Characteristic Curve is marked appropriately indicates the behaviour of the terminal-voltage (v) during the corresponding period of hours (h). The endpoint of the curve signifies that the cell has completely Discharged its Ampere hours-capacity C at that particular value of (a)^amperes. It also indicates the terminal-voltage at the end of the period, and just before the Discharge circuit is opened.

The three endpoints themselves connect into a smooth curve, and by including intermediate values for (a) amperes and (h) hours, a family of Characteristic Curves become available with their endpoints on the same curve.

The noteworthy significance of the end-points curve is that as the numerical value of (a) amperes is increased from C/10 to C/3, so the terminal-voltage needs to fall to a lower value if the cell is to completely Discharge its Ampere hours-capacity C. While Fig. 3.4 shows Discharge Characteristics within the range of C/3 to C/10 amperes, the end-points curve can be extended in both directions to include for Discharge Characteristics at higher currents with shorter times, and at lower currents with longer times. These are the Ampere seconds and the Ampere hours ends respectively of the Application Spectrum, Chapter 2. and dealt with comprehensively in Chapter 4.

CHARGE CHARACTERISTICS

The Three Charge Characteristics of Fig. 3.4 indicate the terminal-voltages (v) and the hours (h) which correspond with the Charge amperes C/3, C/5 and C/10, and they make allowance for the Efficiency of the Charge - Discharge Process.

The Efficiency requirement is that the Ampere hours of Charge need to be 40% greater than the Ampere hours of Discharge. Accordingly, the Ampere hours for Charge are 1.4 x C.

C, (a) and (h) have this relationship with Efficiency –

$$1.4 \times C = 1.4 \times (a) \times (h)$$

To implement the Efficiency -

The amperes (a) are increased by 40% with the hours (h) unchanged, or -

The hours (h) are increased by 40%, with the amperes (a) unchanged.

In Fig. 3.4 it is chosen that the amperes (a) remain unchanged, in which case

(h) = 1.4 x 3 = 4.2 hours when (a) = C/ 3 amperes

(h) = 1.4 x 5 = 7.0 hours when (a) = C/ 3 amperes

(h) = 1.4 x 10 = 14.0 hours when (a) = C/ 3 amperes

The Three Charge Characteristics are accordingly marked respectively with the.-. same values for amperes as for the corresponding Three Discharge Characteristics.

The endpoint of each Charge curve signifies when the cell is completely Charged, and the three endpoints themselves connect into a smooth curve. By including other Charge currents having intermediate values, a family of Characteristic Curves become available with their endpoints on the same curve.

While Fig. 3.4 shows Charge Characteristics within the range C/3 to C/10 - amperes, the end-points curve can be extended in both directions to include for Charge Characteristics at higher currents with shorter times and at lower currents with longer tines, and these are dealt with comprehensively in Chapter 5. Charging.

Fig. 3.4 presents Charge and Discharge Characteristics on

the basis of pre-selected Constant Currents and Varying Voltages, but this does not imply operating conditions. It is more usual for Nickel- Cadmium Vented Pocket-Plate batteries to be Charged by an arrangement in which the Voltage is maintained at a pre-selected Constant Value, and the Charge Current allowed to vary.

Similarly, batteries Discharge at Currents which vary widely in value and are not necessarily Constant.

It is customary therefore, for the purposes of Application Engineering, to separate entirely, Performance Data in respect of Discharging from Performance Data in respect of Charging.

Chapter 4 discusses the former, and Chapter 5. the latter.

TEMPERATURE EFFECT

Fig. 3.4 is based upon the cell being at the same temperature

as the air in its immediate vicinity, in this case 20°C/68°F. which in Storage Battery technology is defined as NORMAL, and at this temperature the Nameplate Ampere hours-capacity of the cell is declared.

Temperatures above NORMAL are defined as HIGH and below NORMAL

as LOW.

At temperatures above NORMAL there is a slight increase in the levels of the voltage curves during Discharge, with a small increase in Ampere hours-capacity over the Nameplate figure. During Charge there is a slight decrease in the levels of the voltage curves.

At temperatures below NORMAL there is a decrease in the levels of the voltage curves during Discharge, with a reduction in Ampere hours- capacity from the Nameplate figure. During Charge there is an increase in the levels of the voltage curves.

These deviations in Voltage and Ampere hours-capacity are attributed to change in Internal Resistance, as this is defined in the broadest sense. There is changing response to temperature in electro-chemical reactions; rising temperatures accelerate activity, falling temperatures retard it and there is change in the electrical resistance of the electrolyte solution.

The cumulative effect is to reduce the Internal Resistance of the cell as temperatures rise, and to increase its Internal Resistance as temperatures fall.

The overall quantitative effect is revealed by Graphs in the style of Fig. but where the Charge and Discharge Characteristics are taken with the cell at selected temperatures other than NORMAL.

4 Discharging

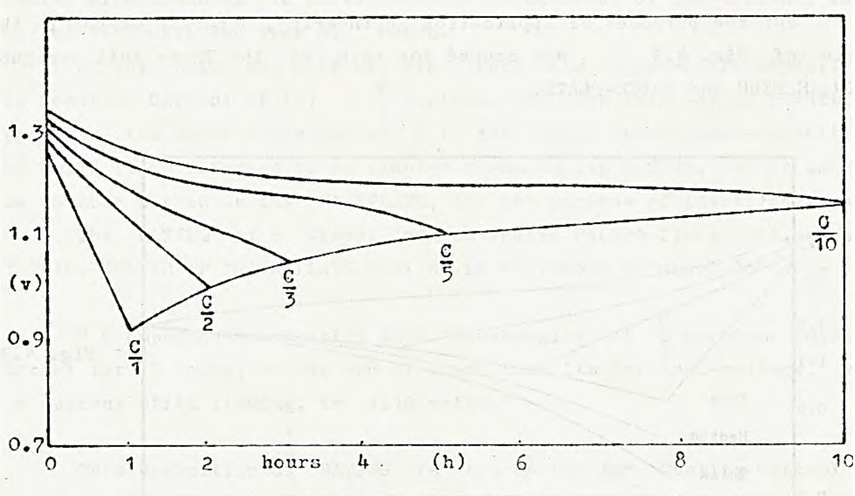


Fig. 4.1

Fig. 4.1 is a typical presentation of Data which

expresses the Discharge Performance of a Hickel-Cadmium Vented Pocket-Plate cell, of C ampere hours-capacity.

The curves connect terminal-voltage (v) with tine in hours (h), and each commences at zero hours with a cell which is Charged.

Each curve is obtained by connecting the cell to a resistance of ohmic value appropriate to the current in amperes; the resistance is adjustable so that the current is kept Constant by manual control as the voltage falls during the period of the Discharge, and the terminal-voltage (v) is recorded at regular intervals of time.

The circuit arrangement is shown in Fig. 4.2.

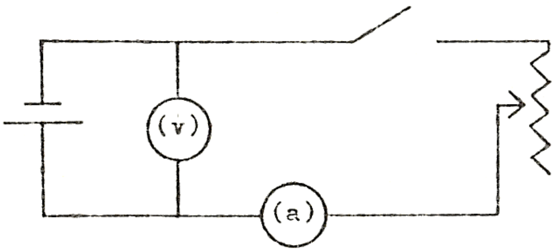


Fig. 4.2

Each curve indicates the behaviour of the terminal-voltage (v) during the chosen time period in which the cell is Discharging, and the endpoint of the curve signifies when the cell has completely discharged its ampere hours-capacity C at that particular Constant-Current.

For the purposes of Application Engineering, separate Graphs in the style of Fig. 4.1 are needed for each of the Three cell designs, THIN, MEDIUM and THICK-PLATE.

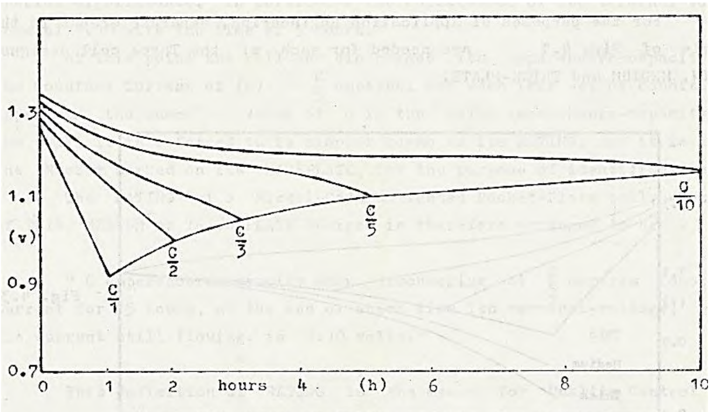


Fig. 4.1

Fig. 4.3 compares the Discharge Performance ofTHIN, MEDIUM and THICK-PLATE cells when the relationship

(a) = C/(h) amperes

has been given values for (h) from 1 hour to 5 hours; C having the same numerical value in each case.

Each cell design is seen to have its own distinctive end-points curve, and which illustrates the effect of its internal resistance on its Discharge Characteristics in relation to that of the other two designs.

The lowest internal resistance of the THIN-PLATE design provides relatively superior voltages when currents are HIGH, for example at (h) = 1' hour; but the superiority decreases as currents fall in value with the hours becoming longer, since when approaching (h) = 5 hours it steadily reduces, and beyond S hours the three end-points curves merge into one single curve which is then applicable to all Three cell designs, THIN, MEDIUM and TIIICK-PLATE. At the lower currents beyond 5 hours the voltage differences due to the different internal resistances of the Three designs are negligible.

RATED AMPEREHOURS CAPACITY

The curve for (a) = C/5 amperes in Fig. $.1 and Fig. 4.3 has special significance, in particular the coincidence of the terminal volt- -age of 1.10 with the time of 5 hours.

At this point the cell has discharged its ampere hours-capacity at the Constant Current of (a) = C/5 amperes, and when this set of conditions appertain, the numerical value of C is the RATED ampere hours-capacity of the cell. It is referred to in simpler terms as its RATING, and it is also the Number marked on its NAMEPLATE, for the purpose of identification.

The RATING of a Nickel-Cadmium Vented Pocket-Plate cell, whether of THIN, MEDIUM or THICK-PLATE design, is therefore arranged to be

“C ampere hours-capacity when discharging at C/5 amperes Constant Current for 5 hours, at the end of which time its terminal-voltage, with the current still flowing, is 1.10 volts.”

This definition of RATING is the means for Quality Control and Acceptance Testing and is always declared at NORMAL temperature,20°C/68°F. It also refers to the numerical values for ampere hours-capacity quoted in the Tabulations of Standard Cell Sizes, Fig. 2.8 and Fig. 2.15 in Chapter 2. Mechanical Design.

RATING refers only' to the capacity of a cell for electrical storage; it makes no reference to dimensions, weight or Plate design. Moreover, cells in THIN, MEDIUM and THICK-PLATE design which are of the same physical size, have different RATINGS.

DISCHARGE CHARACTERISTICS

The Discharge Characteristics at lower currents than (a) = C/5 amperes, with the corresponding longer hours, are shown by the curves in Fig. 4.4.

They extend to (a) = C/50 amperes, and their endpoints connect into a smooth curve which is a continuation of the end-points curve of Fig. 4.3. Moreover, they apply to all three designs, THIN, MEDIUM and THICK-PLATE; C having the name numerical value in each case.

Accordingly, this section of the AIIPEREHOURS end of the Application Spectrum, as discussed in Chapter 2. Mechanical Design, and Chapter 3 Electrical Performance, can be served by either of the Three designs; but the economical choice will be the THICK-PLATE cell.

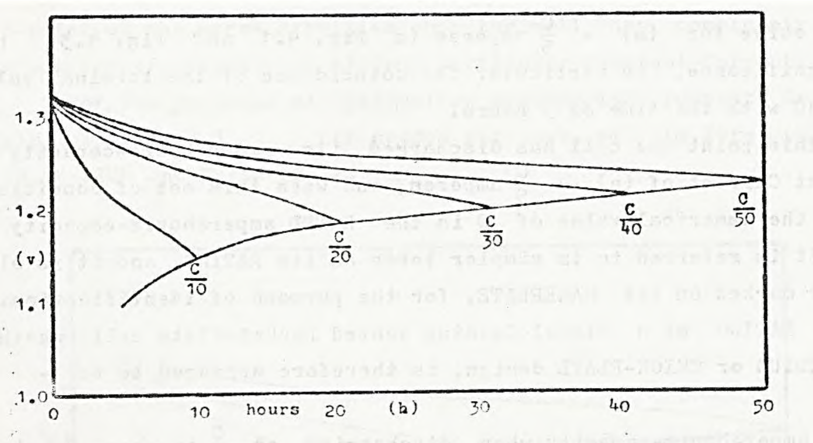


Fig. 4.4

In Fig. 4.5 the first 30 minutes of the baseline of Fig. *f.1 has been expanded so that the Discharge Characteristics of higher currents than (a) = ~ amperes, with corresponding shorter times, are accurately indicated. The ordinate is still volts-per-cell (v).

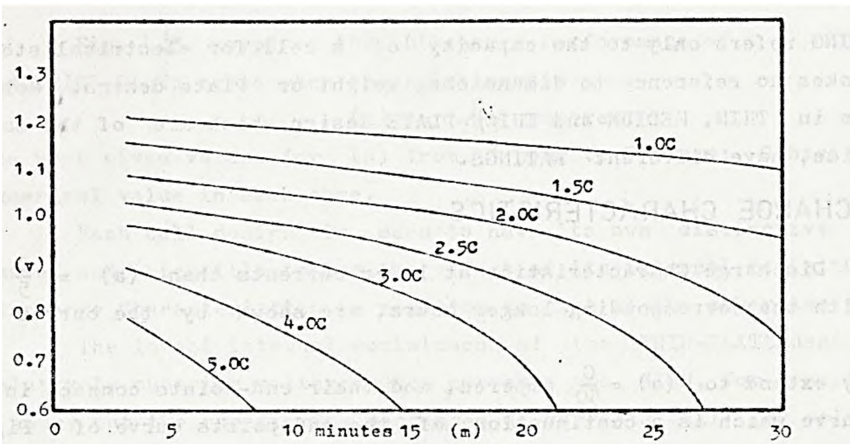


Fig. 4.5

Moreover, the representative values chosen for the currents are in whole-number multiples of C, rather than fractions of C as in Fig. 4.1, Fig. 4.3 and Fig.4.4

In which circumstances, in Fig. 4.5

(a) = XC amperes and as examples,

X has been given values 1.0, 1.5, 2.0, 2.5, 3.0, 4.O and 5.0.

In this area of time, the relationship

C ampere hours = (a) amperes x (h) hours

becomes invalid, since as currents become higher than C/1, the rate of fall of voltage becomes faster, and the minimum useful voltage - 0.65 volts - is reached long before the cell has discharged its RATED ampere hour- capacity C. But the cell is still identified by the numerical value of its RATED ampere hours-capacity, as marked on its NAMEPLATE.

For the purposes of Application Engineering, separate Graphs in the style of Fig. 4.5 are provided for each of the Three cell designs.

The Graph for THIN-PLATE cells will show voltages markedly superior to those in the Graphs for MEDIUM and THICK-FLATS cells, as a consequence of having the lowest internal resistance.

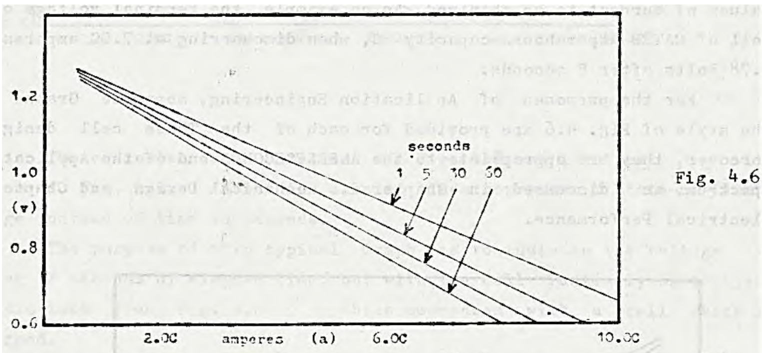


Fig. 4.6

In Fig. 4.6 - the first 60 seconds of the baseline of Fig. 4.5 is expanded in order to indicate the Discharge Characteristics in this short period of time with greater accuracy and convenience.

The form of presentation has also been changed; current replaces time on the baseline, which is scaled in multiples of C, and to a maximum multiple of 10.0, since the highest current which a Nickel-Cadmium Vented Pocket-Plate cell is capable of delivering at a useful voltage-per-cell, corresponds to around 10 times the numerical value of its RATED ampere.

hours-capacity, that is 10. OC amperes. But the ordinate to the Graph is still volts-per-cell (v).

The Constant-Current, multiples of C in Fig. are now represented by vertical lines erected at their corresponding values on the baseline of Fig. ^.6.

A Charged cell is Discharged at selected Constant-Currents - the circuit arrangement of Fig. U.2 is relevant - and the terminal voltage (v) is read and recorded after 1 second, 5 seconds, J>0 seconds and 60 seconds of elapsed time; and these voltages are plotted on the appropriate vertical line which represents the current value.

Voltages associated with 1 second of time for each current are linked together and provide a line relationship between terminal voltage (v) on the ordinate, and current on the baseline. Similarly, there are line relationships for 30 and 60 seconds, a total of k sloping lines to express the Discharge Characteristics, within this short period, of C ampere hours at current values which are whole-number multiples of C.

Fig. h.6 also enables the voltages (v) for intermediate values of current to be obtained. As an example, the terminal voltage of a cell of RATED ampere hours-capacity C, when discharging at 7-OC amperes is 0.78 volts after 5 seconds.

For the purposes of Application Engineering, separate Graphs in the style of Fig. **.6 are provided for each of the Three cell designs. Moreover, they are appropriate to the AMPERESECOHDS end of the Application Spectrum, as discussed in Chapter 2. Mechanical Design and Chapter 3 Electrical Performance.

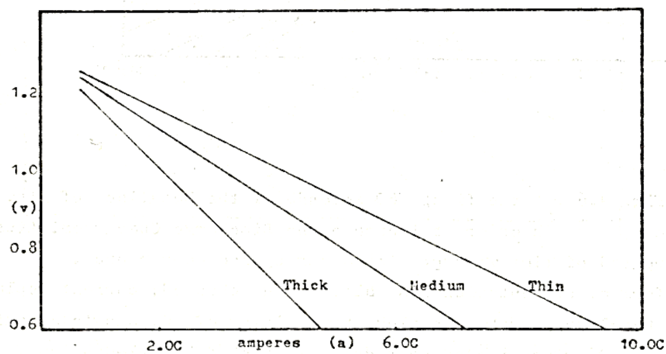


Fig. 4.7

The Graph for THIN-PLATE cells v/ill show voltages superior to those in the Graphs for MEDIUM and THICK-PLATE cells, as a consequence of having the lowest internal resistance.

Fig. 4.7 shows typically, the relative Discharge Performances of the Three Designs after, for example, an elapsed time of 5 seconds, C having the same numerical value of ampere hours in each case.

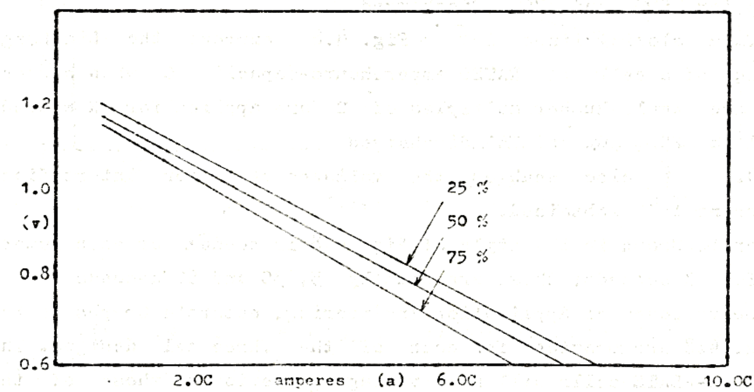


Fig. 4.8

The ordinates and baseline of Fig. 4.8 are identical with those of Fig. 4.6, but the sloping lines represent % State-of-Discharge instead of time in seconds.

The purpose of this typical Graph is to indicate the voltage (v) after X seconds of elapsed time, but with the cell Partially Discharged, as distinct from Fig. 4.6which commences with a cell which is Charged.

A Charged cell of RATED ampere hours-capacity C is discharged the circuit arrangement of Fig. 4.2 is relevant - at a Constant Current, for example C/4 amperes, for a total period of 5 hours, but at the end of each hour the- .discharge is interrupted, and the cell discharged by a separate circuit for X seconds at a selected current which is a V/hole- number multiple of C.

At the end of the X seconds the terminal voltage (v), with the current still flowing, is read and recorded. After 1 hour, 2 hours and 3 hours the cell is 25 %% 50 % and 75 % discharged respectively.

The Three voltage readings so obtained are plotted on Fig. 4.8

on the appropriate vertical line which represents the value of the current.

selected as the Whole-Number multiple of C.

The same procedure is repeated for other selected current values which are Whole-Number multiples of C, all other parameters remaining the same. Voltages associated with 25% discharged for each current when linked together provide a line relationship between terminal-voltage (v) on the ordinate, and current on the baseline. Similarly, there are line relationships for 50/® and 75% discharged.

The Three sloping lines in Fig. 4.8 express the Discharge Characteristics of a cell of RATED ampere hours-capacity C when current values which are Whole-Number multiples of C are applied for X seconds when the cell is 25%, 50% and 75% discharged.

Fig.4.8 also enables the voltages (v) for intermediate values of current to be obtained. A separate Graph in the style of Fig. ^.8 is needed for each numerical value for X seconds; these are usually 5* 50 and 60 seconds. For the purposes of Application Engineering, separate Graphs in the style of Fig. 4.8 are provided for each of the Three cell designs. The Graph for TIIIN-PLATE cells will show voltages superior to those of the Graphs for MEDIUM and THICK-PLATE cells, as a consequence of having the lowest internal resistance.

DERIVED PERFORMANCE DATA

While Fig. 4.1 to Fig. 4.8 are the basic Discharge Characteristics issued typically by battery manufacturers, other forms of presentation are needed for the purposes of Application Engineering, and these are derived as required, and conveniently by graphical reconstruction, from Fig. 4.1 to Fig. 4.3.

For example, a Graph can be derived which relates (v) and time for any chosen current in Fig. 4.6 over a period of 60 seconds. A vertical line from the baseline of Fig. 4.6 is erected to represent the current, and (v) for each point of its intersection with the lines marked 1, 5» 30 and 60 seconds is read off the ordinate.

The derived Graph will have (v) as ordinate and time - 0 to 60 seconds - for its baseline. This enables a curve to be drawn which will show, second by second, the change in terminal-voltage while the cell is discharging continuously at the chosen current for 60 seconds. Curves for other current values can similarly be produced on the same Graph, by derivation from Fig. 4.6.

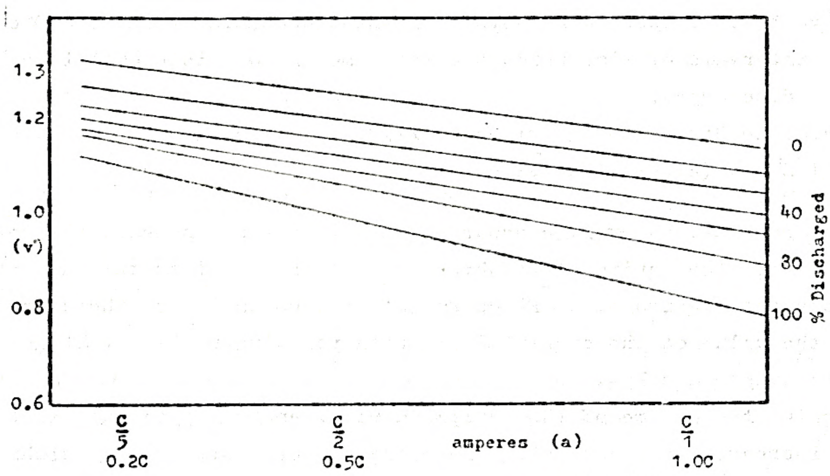


Fig. 4.9

Fig, 4.9 is a typical presentation of Data which has been derived from Fig. 4.1.

The time-base length of each of the Constant-Current Discharge curves in Fig. 4.1 is divided into 10 equal parts; each part then represents 10 % of C ampere hours, with the whole time-base length corresponding to C.

The points which separate the parts are projected vertically upwards to meet the curve, and each intersection reads a voltage (v) on the ordinate of Fig. 4.1. proceeding from zero time therefore, each succeeding part increases the State-of-Discharge by 10 %, and in 10 % of the total discharge time appropriate to the current.

The baseline of Fig. 4.9 is scaled in amperes, and vertical lines are erected at, for example, C/5, C/2 and C/1 amperes.

Along these vertical lines, the voltages corresponding to each of these currents which have been read off the ordinate of Fig. 4.1 are plotted.

The sloping lines marked % State-of-Discharge in Fig. 4.9 are the result of linking the voltages which correspond with the same c/o State-of-Discharge of the Three selected currents C/5, C/2 and C/1 amperes.

A vertical line from any position on the baseline of Fig. 4.9 therefore represents a Constant-Current in terms of C. Accordingly while a cell is discharging at that value, the intersection points of the vertical line with the eloping lines indicate, on the ordinate of the Graph, its terminal voltage at succeeding States-of-Discharge, in steps of 10 or 20 /j, and at intervals of time which are the same % of the total time from 0% to 100% discharged.

Separate Graphs in the style of Fig. 4.9 need to be provided for THIN, MEDIUM end THICK-PLATE cells.

In practice, however, discharge currents are not necessarily constant in value; the equipment to which the battery supplies current often has the characteristics of a Fixed-Resistance, so that as the discharge proceeds the value of the current falls with reducing battery voltage, in accordance with Ohm's Law.

Again, the nature of the equipment requirement may be such that it draws an increasing current with reducing battery voltage, in which case it is described as having a Constant-Power characteristic.

Fixed Resistance

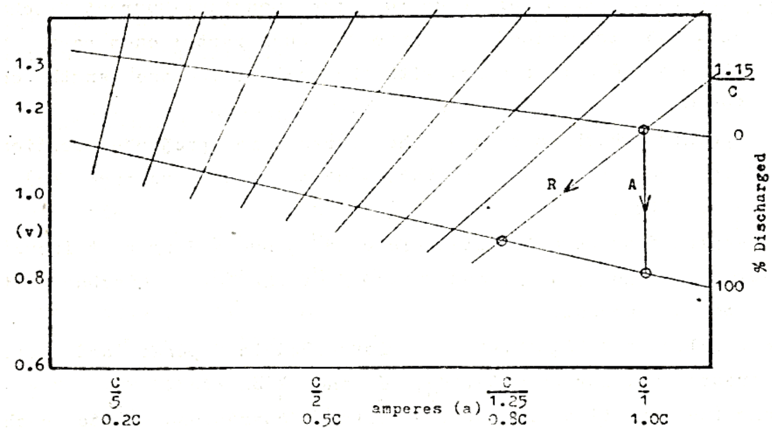


Fig. 4.10

Fig. 4.10 is Fig. 4.9 upon which several Fixed-Resistance characteristics have been superimposed.

Each Fixed-Resistance is represented by a sloping line which has its origin at zero-volte and zero-amperes. At any point on the line the ratio of (v) on the ordinate to (a) on the baseline is constant and equal to the Fixed-Resistance in ohms. The slope 5s therefore in accordance with Ohm's Law, which is

Voltage/ Current = Resistance

The intersections of the Resistance Lines and the % State-of-Discharge Lines, when projected horizontally and vertically, each indicate a voltage (v) on the ordinate and a corresponding current (a) on the base- -line of Fig.4.10.

Accordingly, when a Fixed-Resistance is connected to a Charged cell of RATED ampere hour-capacity C, the change in voltage and current at each stage of the discharge is indicated by the projections of the intersecting points, and particularly the voltage (v) and current (a) at the commencement and when 100 % State-of-Discharge has been reached.

The time duration of the discharge in hours is

C ampere hours/average amperes, in terms of C, from 0% to 100%discharged

The average amperes are the arithmetical mean of the highest and lowest currents read off the baseline*

Line R represents a Fixed-Resistance, and Line A, a Constant-Current; at the moment of 'switching-on* both currents are equal at C/1 amperes, and the Performance of both types of discharge are compared.

Voltage	at Start	(v) for Line R is 1.15 and for Line A is 1.15
	At End	(v) for Line R is 0.89 and for Line A is 0.82
Current	at Start	(a) for Line R is 1.00C and for Line A is 1.00C
	At End	(a) for Line R is 0.78 and for Line A is 1.00C
Time of Discharge		for Line R is C/0.89C = 1.12 hours
		For Line A is C/1.0C = 1.00 hours

One noteworthy result of this comparison is the longer period of time from 0 % to 100 % Discharged, given by Line R. Another is the higher voltage at 100 % Discharged. Both are advantages of significant importance although they diminish as current values approach £ amperes and smaller.

Moreover, for the same Resistance, the absolute values of time periods and voltages will be different for each design of cell, THIN, MEDIUM and THICK-PLATE, C having the same numerical value in each case, since each design has its own Characteristics in the style of Fig.4.9.

In Fig. 4.10 the ohmic values of the Fixed-Resistance Lines are in reference to a single cell. For a battery, these ohmic values need to be multiplied by the number of cells, in order to establish the resistance applicable to the v/hole battery.

Constant Power

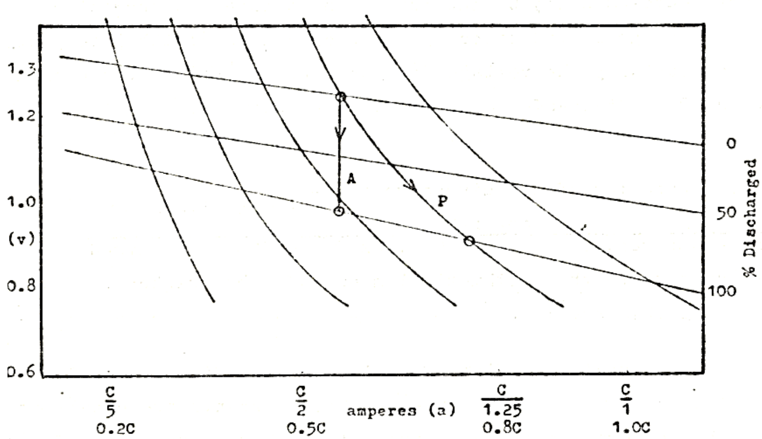


Fig. 4.11

Fig. 4.11 is Fig. 4.9 upon which several Constant-Power characteristics have been superimposed.

Each is represented by a curved Line having its own numerical value, which is a constant for every point on the Line, being the product of volts (v) on the ordinate and amperes (a) on the baseline, and the Power is expressed in watts.

The intersections of the Constant-Power Lines and the % State-of- discharge lines, when projected horizontally and vertically, each indicate a voltage (v) on the ordinate and a corresponding current (a) on the base- -line of Fig. 4.11.

Accordingly, when an equipment with a Constant-Power characteristic is connected to a Charged cell of Rated ampere hours-capacity C, the change in voltage-per-cell and current at each stage of the Discharge is indicated by the projections of the intersecting points, and particularly the voltage (v) and current (a) at the commencement and when 100 % State-of-Discharge has been reached.

The time duration of the Discharge in hours is

C- in Ah/amperes, in terms of C, from 0% o to 100% discharged

The average amperes are the arithmetical mean of the highest and lowest currents read off the baseline.

Line P represents a Constant-Power characteristic, and Line A, a Constant-Current; at the moment of * switching-on* both currents are equal at -C/1.82 amperes, and the Performance of both types of discharge are compared.

Voltage:	At Start (v) for Line P is	1.25 and for Line A is 1.25
	At End (v) for Line P is	0.91 and for Line A is 0.98
Current:	At Start (a) for Line P is	0.55C and for Line A is 0,55C
	At End (a) for Line P is	0.75C and for Line A is 0.55C
Time of Discharge:	For Line P is	C/0.65C = 1.54 hours
	For Line A is	C/0.55C = 1.82 hours

From this comparison it is noted that Line P takes a shorter period of time to reach 100 % Discharged, moreover it shows a lower voltage at 100 % Discharged. Line P has an inferior Performance in relation to Line A, although the disadvantage diminishes as current values approach C/5 amperes and lower.

Also, for the same Constant-Power characteristic, the absolute values of time-periods and voltages will be different for each design of cell, THIII, MEDIUM and T1IICK-PLATE, with C having the same numerica.1 value in each case, since each has its own characteristic in the style of Fig. 4.9.

In Fig. 4.11 the watts values of the Constant-Power Lines are in reference to a single cell. For a battery, these watts values are to be multiplied by the number of cells, in order to establish the watts applicable to the whole battery.

Fig. 4.12 gives the Constant-Power Lines of Fig. 4.11 a relationship with time, which is the form in which it is required by Application Engineering.

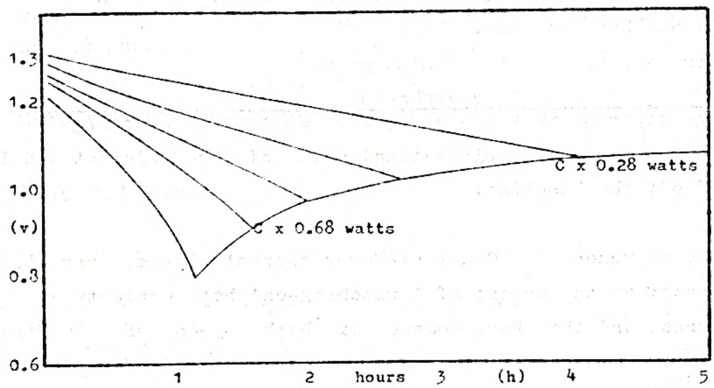


Fig. 4.12

The volts-per-cell (v) and amperes (a) which define the points of intersection of the Constant-Power Lines with the % State-of-Discharge lines are transferred to Fig, 4.12 which has volts-per-cell (v) on the ordinate and time in hours (h) on the baseline.

Taking Line (C x 0.68) watts for example on Fig. 4.11.

Voltage	at Start (v) is 1.25
	At End (v) is 1.25
Current	at Start (a) is 0.55C
	At End (a) is 0.75C

Average Current = (0.55+0.75)/2 = 0.65C

Time of Discharge = C/ 0.65C = 1.54 hours

Accordingly, 1.25 volts at zero time, with a cell which is Charged, and 0.91 volts after 1.54 hours are the extreme points on a curve which represents a Constant-Power discharge of (C x 0.68) watts on Fig-4.12 and at the end of 1.5*f hours the cell has completely discharged its RATED ampere hours-capacity C.

The position of intermediate points on this curve are calculated as follows, taking 50 % Discharged on Fig 4.11 as example.

Voltage At 0 % Discharged is 1.25

At 50 % Discharged is 1.05

Current At 0 % Discharged is 0.55C

At 50 % Discharged is 0.65C

Average Current = (0.55+0.65)/2 = 0.60C amperes

Time of Discharge = C/(2*0.60C) = C/1.20C = 0.835 hours

Accordingly, 1.05 volts and 0.835 hours gives an intermediate point on the Constant-Power discharge of (C x 0.68) watts on Fig. 4.12. Similarly, other points are calculated and plotted on Fig. 4.12 upon which they connect into a smooth curve, which is suitably marked.

In the same way, other Constant-Power Lines on Fig. 4.11 are expressed in terms of volts and time and added to Fig. 4.12.

Moreover, the endpoints of the Constant-Power curves in Fig. 4.12 connect into a smooth curve, upon which any Constant-Power curve will terminate, since it 'indicates when the cell has completely discharged its RATED ampere hours-capacity C.

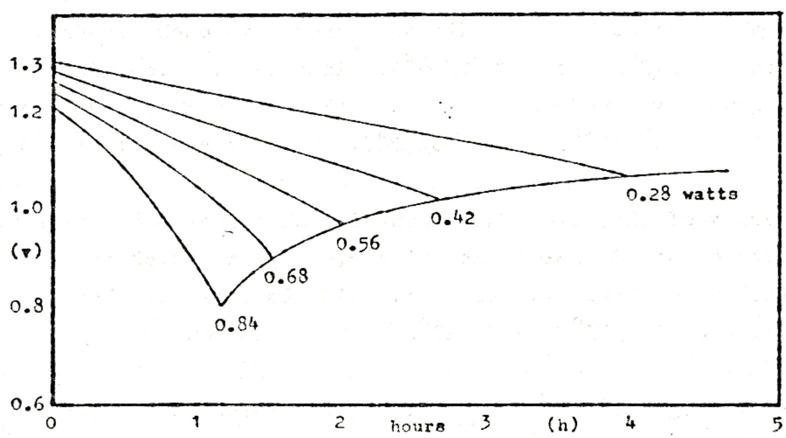


Fig. 4.13

But to suit the purposes of Application Engineering, the Symbol C in Fig. 4.12 is given a numerical value of 1, in which case each Constant-Power curve is marked in terms of watts only, as in Fig 4.13 which is Fig. 4.12 in which C = 1.

The Constant-Power curves of Fig 4.13 therefore represent the Discharge Performance of a single cell of 1.0 ampere hours-capacity.

Separate Graphs in the style of Fig. 4.13 need to be provided for the Three cell designs, THIN, MEDIUM and THICK-PLATE.

TEMPERATURE EFFECT

Fig. 4.1 to Fig. 4.13 are based upon cells being at the same temperature as the air in the immediate vicinity, in this case 20°C/68°F, which in Storage Battery technology is defined as NORMAL; and at this temperature the RATINGS of cells, in ampere hours, are declared.

At temperatures above NORMAL - which are defined as HIGH - there are small-percentage increases in voltage levels during Discharge, due to small increases in ampere hours-capacity beyond the Rated.

These increases are insufficient to justify the preparation of Performance Data with special reference to this temperature range, and it is customary therefore to regard Performance Data at 20°C/68°F as being applicable to HIGH temperatures as well.

At temperatures below NORMAL - which are defined as LOW with a minimum of around -20°C/--4°F - there is significant decrease in voltage levels during Discharge, due to a considerable decrease in ampere hours- -capacity from the Rated. But the rate of decrease is much slower to 0°C /32°F than from 0°C/32°F to -20°C/-4°F. In view of this 0°C/32°F is regarded as a boundary line which divides the LOW temperature area into two parts, one from 20°C/68°F to 0°C/32°F, and the other from 0°C/32°F to -20°C/-4°F.

The majority of Nickel-Cadmium Vented Pocket-Plate batteries operate in temperatures of 0°C/32°F and higher in which case Performance Data similar to Fig.4.1 to Fig.4.13 is made available at temperatures between 0°C/32°F and 20°C/6S°F.

Typically, Fig. 4.1*+ is Fig. 4.6 to which has been added the Discharge Performance at 0°C/32°F. It shows the relative performance at 20°C/68°F and 0°C/32°F of cells of similar design and Rated ampere-

-hours-capacity• For example, a cell of RATED ampere hours-capacity C when discharged at 4.0C amperes for 5 seconds will show a terminal voltage of 1.0 when the temperature is 20°C/68°F, but only 0.9 volts when the cell temperature is 0°C/32°F. Again, for a terminal voltage of 1.0 the same cell discharges 4.0C amperes at 20°C/68°F, but only 3.0C amperes at 0°C/32°F.

0°C/32°F is appropriate for the lower limit; it is the freezing point of water and the lowest for human comfort without special protection. Moreover, standard electrical equipment is normally able to operate satisfactorily down to temperatures of 0°C/32°F.

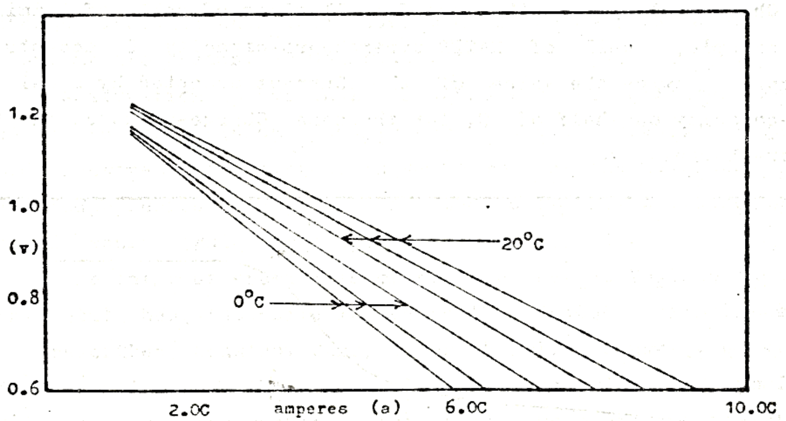


Fig. 4.14

Nickel-Cadmium Vented Pocket-Plate batteries operating in temperatures below 0°C/32°F are in the minority, and to provide comprehensive Performance Data in this temperature area, and in the style of Fig. 4.1 to Fig.4.13 is hardly justified. Such batteries are regarded as special cases, and it is customary to make laboratory tests appropriate to the purposes for which they are to be installed, and to the particular LOW temperature of their environment, in order to choose a suitable design and RATED ampere hours-capacity.

It is fortuitous as well that these batteries are uncommon, since there are inherent difficulties in servicing them. For example, water which is added "ill freeze into a block of ice above the +ve and -ve plates within the cells; gas between the plates is sealed off and develops internal pressure which may expand and burst the cell containers.

5 Charging

The Nickel-Cadmium Vented Pocket-Plate cell is Charged by forcing a Direct-Current through it in the reverse direction to Discharge, and this requires a Charge-voltage which is higher than the Open-Circuit- Voltage of the cell, as discussed in Chapter 3 Electrical Performance.

There is a well-defined relationship between the Current and the Voltage; moreover, there is a Time-Element, in terms of hours, in the Charging Process, since it is not inherently possible for the cell to be Charged in the context of instantaneous time.

The Charge-voltage is the same for all sizes of cell of similar design. For example, a cell of RATED ampere hours-capacity C accepts a Current which is twice the value of the Current accepted by a cell of ampere hours-capacity one-half of C, for the same Charge-voltage, and the same Time-for-Charge.

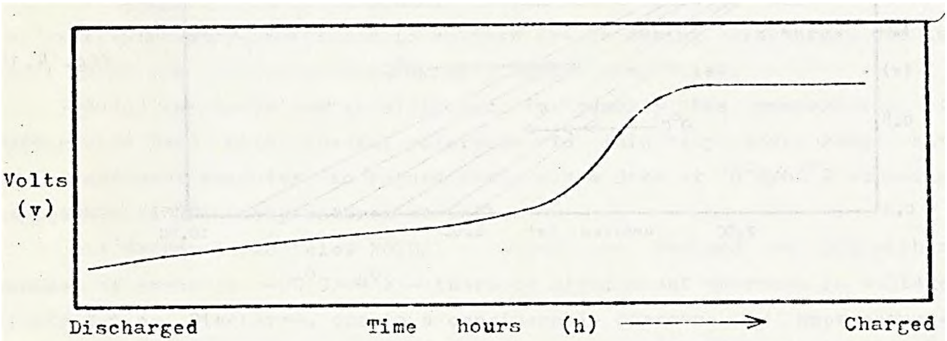


Fig. 5.1

A typical relationship between Charge-voltage and Time, as issued by a battery manufacturer, is shown in Fig. 5.1.

This curve is obtained by forcing a- Direct-Current of controlled Constant value into a Discharged cell, and recording continuously, the Voltage necessary to maintain the Current at its prescribed Constant value until such time as the cell is Charged. The circuit arrangement is shown in Fig. 5*2.

In explanation of the shape of the curve, the starting point is at zero hours when the cell is first connected to the DC Source of voltage and current - +ve terminal to +ve terminal and -ve terminal to -ve

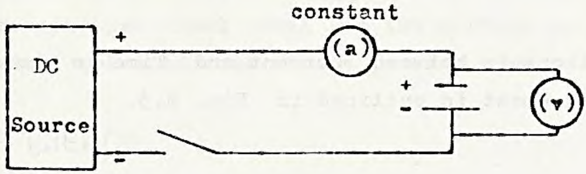


Fig. 5.2

terminal - and when the cell, being completely Discharged, is in its most receptive condition to accept electrical energy and at a low value for the Charge-Voltage.

As time passes and energy is absorbed, the Voltage needs to be adjusted upwards, in this case under manual control, in order to keep the Current at its prescribed Constant value.

A situation is eventually reached when the Voltage takes a pronounced upward turn, rising steadily over a short period of time; thereafter the Current remains Constant in value without the need for adjustment to the Voltage, which condition, if the cell is not disconnected when Charged, would persist indefinitely.

The point of special interest is where the Voltage takes its upward turn. Until then, the curve indicates the Voltage which is needed to pass the prescribed Constant-Current, which will convert, electrically, the Cadmium portion of the -ve plate active-material from cadmium-oxide to cadmium and its corresponding portion of +ve plate active-material from a lower to a higher nickel-hydroxide; the subsequent higher steady Voltage is needed to pass the same Current in order to convert the Iron portion of the -ve plate active-material from iron-oxide to iron, and its corresponding portion of +ve plate active-material from a lower to a higher nickel- -hydroxide.

the position where the voltage takes its upward turn reveals the relative proportions of Cadmium and Iron in the -ve plate active-material; these are 75/80 for the Cadmium and 25/20 for the Iron.

The charging process in Fig. 5.1 is referred to as the Constant-Current method, but in the circumstances in which most Nickel-Cadmium Vented Pocket-Plate batteries operate, this style of charging is unsuitable since it does not lend itself to automatic control, by which is inferred unattended operation.

In these circumstances the Constant-Voltage method is employed. The Charge-Voltage is held at a prescribed Constant value, and the Charge-

Current allowed to change; the cell absorbs a relatively high value current when it is Discharged, and a relatively small value current when Charged.

A typical relationship between Current and Time is shown in Fig. 5.4. The circuit arrangement is outlined in Fig. 5.3.

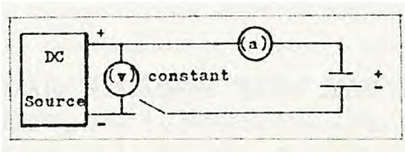


Fig. 5.3

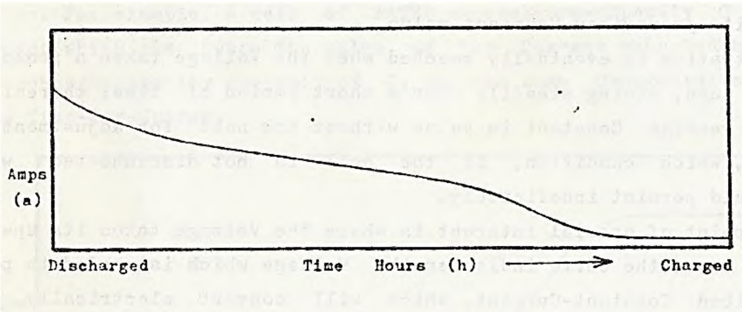


Fig. 5.4

Fig. 5.4 is obtained by applying a prescribed Constant-Voltage to a Discharged cell and recording the changing value of the resulting current. The DC Source has adequate output so that the cell obtains the full amount of current which it can naturally absorb and is not inhibited by any current limitation in the DC Source.

The curve begins at zero time when the cell is in its most receptive condition to absorb energy, but the initial current value cannot be sustained since, as intended, no upward adjustment of the voltage is made. Therefore, the value of the current falls, and as time elapses and energy is absorbed, it assumes lower values, and eventually reaches a relatively low steady figure which will persist so long as the cell is connected to the DC Source.

The point at which the current assumes its final steady value has the same significance as where, in Constant-Current Charging - Fig. 5.1 - the voltage turns to assume its steady value. It is a state of equilibrium where voltages and currents have settled at their respective steady values; and it is evident that when the final steady voltage of the Constant-Current method is equal to the voltage of the Constant-Voltage method, the same numerical value for the current is present, C having the same numerical value of ampere hours in each case.

EFFICIENCY

The cell is Charged when the active-materials of the -ve and -ve plates have been completely converted, and if the cell is disconnected from the DC Source after (1.4 x C) ampere hours of energy have been absorbed, then C ampere hours of stored energy are available for Discharge.

In terms of effectiveness of the electro-chemical conversion process, this is an Efficiency of 7l.5%. But it is an overall Efficiency only, and from completely Charged to completely Discharged; for when the Charge/Discharge process is considered step-by-step, the Efficiency is not constant; it is higher in the early part, and lower in the later stages.

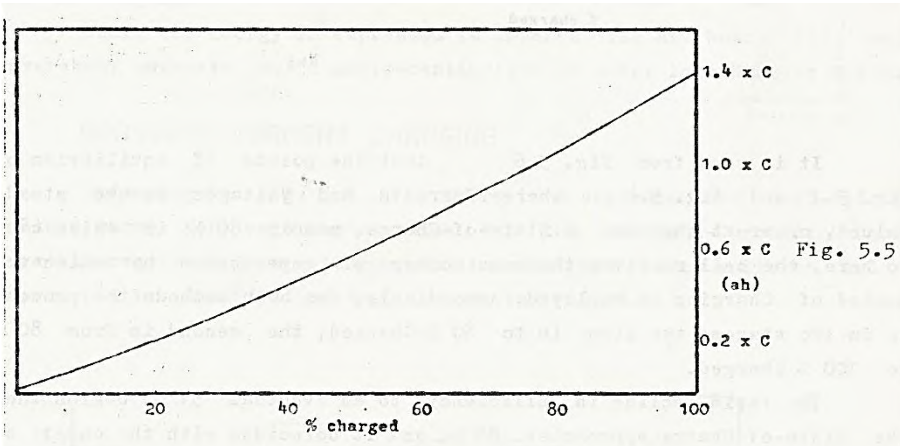


Fig. 5.5

The changing Efficiency is indicated in Fig.5.5. The % Charged is defined as the proportion of C which is stored and is available for Discharge and is scaled along the baseline. The ordinate indicates the corresponding ampere hours of Charge which are required in order to reach that % State-of-Charge. For example, for 50 % of C to be available for Discharge, the ampere hours of Charge need to be 0.6 x C.

The significance of the chancing Efficiency is demonstrated by superimposing the Charge-Voltage curve of Fig. 5.1 and the Charge- Current curve of Fig.5.4 on to the Efficiency curve of Fig. 5.5 and creating Fig. 5.6 with all three curves to the common baseline of % Charged.

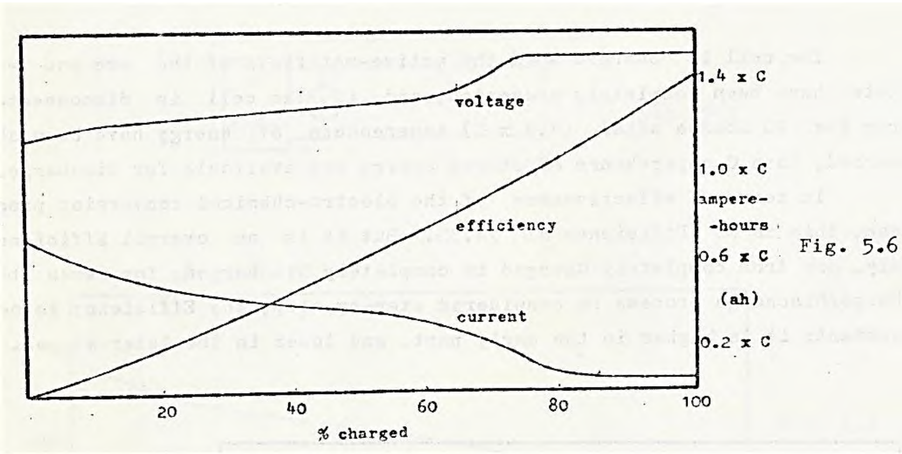


Fig. 5.6

It is seen from Fig. 5.6 that the points of equilibrium of Fig. 5.1 and Fig. 5.4 where Currents and Voltages assume steady values, occur at the same % State-of-Charge, namely 80 %; in which case to here, the cell receives the same number of ampere hours by whichever method of Charging is employed. Accordingly, for both methods the process is in two stages; the first is to 80 % Charged, the second is from 80 % to 100 % Charged.

The rapid decline in Efficiency, to an eventual 51%, begins when the % State-of-Charge approaches 80 %, and it coincides with the onset of appreciable gassing from electrolysis of the water content of the electrolyte solution. The oxygen and hydrogen which is produced is released through the vent in the lid of the cell.

The reduced Efficiency is a consequence of gassing. Up to 80 % Charged the amount of gassing is relatively small; the current is almost wholly absorbed in converting those portions of the +ve and -ve active- materials which function on the Nickel-Cadmium principle, which is the first stage in the charging process. In these circumstances the Efficiency is high.

But the higher voltages which are needed to charge the portions of the +ve and -ve active-materials which function on the Nickel-Iron principle increase the amount of water which is electrolysed into gas from the electrolyte; in which case only a portion of the charge current is available for electro-chemical conversion. Accordingly, there is a marked reduction in the Efficiency during the second stage of the Charging process.

If the cell is not disconnected when 100 % Charged has been reached in both the Constant-Current and Constant-Voltage methods of Charging, the continuing current is wholly dissipated in electrolysing the water content of the electrolyte into oxygen and hydrogen gases, which escape through the vent in the cell lid. This is referred to in storage Battery Technology as a state of Overcharge.

The rate of gas evolution is proportional to the value of the Overcharge current in amperes, and there is a fixed electro-chemical relationship between the quantity of water and the electrical energy expended in Overcharging.

Where the energy is expressed in amperes (a) and hours (h), each ampere hour converts 0.336 cubic centimetres of water into Gas, at N.T.P.

CONSTANT CURRENT CHARGING

Referring to Fig. 5.1 there is a separate and well-defined Voltage curve for each chosen value for the Constant-Current; higher currents require higher voltages; smaller currents lower voltages and a representative family of curves is shown in Fig. 5.7.

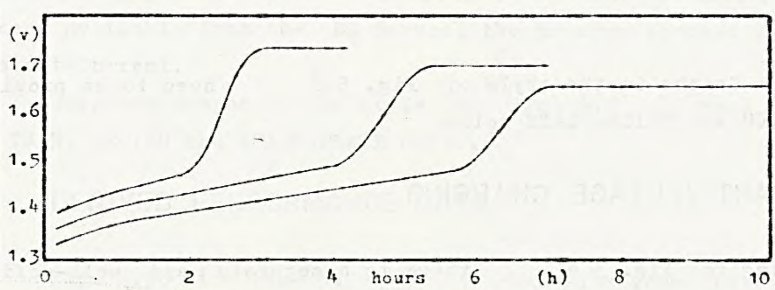


Fig. 5.7

All three curves in Fig. 5.7 have a common factor in that the ampere hours for 100% Charged is the same for each, namely (1.4 x C) where the Rated ampere hours-capacity of the cell is C.

The Time-for-Charge shortens as currents become higher, and there is a minimum feasible period, of the order of 2/3 hours, with the corresponding maximum current of (1.4 x C)/2/3 hours amperes; the voltages required are higher.

Similarly, the Time-for-Charge lengthens with lower currents, and the longest feasible period for effective charging is of the order of 150 hours, with the corresponding minimum current of (1.4 x C)/150 hours amperes; and the voltages required are lower.

The maximum Voltages for each value of the Constant-Current connect into a smooth curve, and with time in hours on the baseline, this is Fig. 5.8.

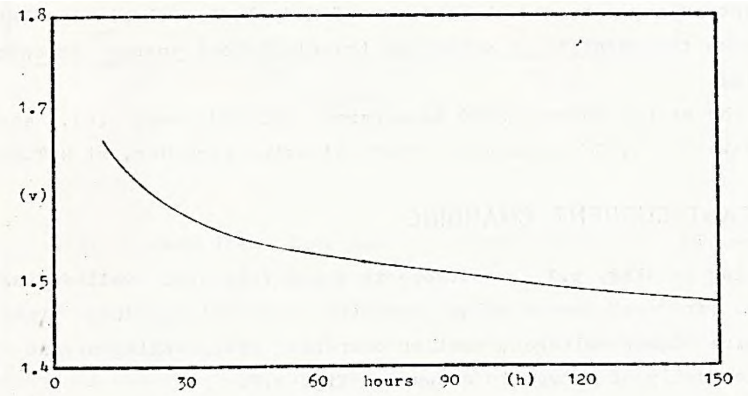


Fig. 5.8

Separate Graphs in the style of Fig. 5.8 need to be provided for THIN, MEDIUM and THICK-PLATE cells.

CONSTANT VOLTAGE CHARGING

Referring to Fig. 5.4 there is a separate and well-defined Current curve for each chosen value for the Constant-Voltage; higher voltages produce higher currents, lower voltages lower currents, and two representative curves are shown in Fig. 5.9.

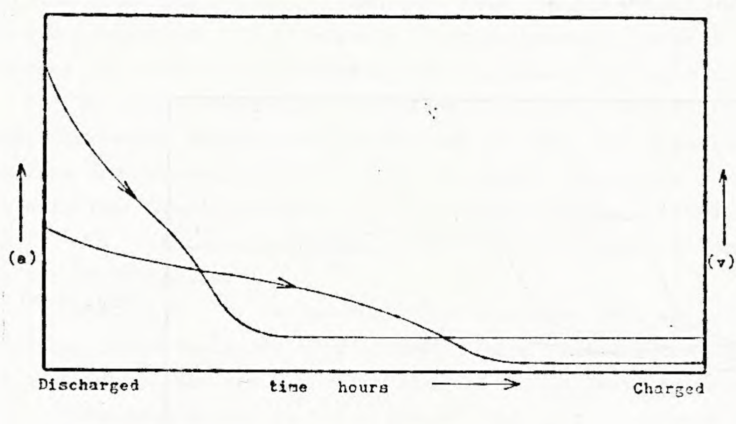


Fig. 5.9

Both curves in Fig. 5.9 have a common factor in that the ampere hours for 100% Charged is the same for each, namely (1.4 x C) where the Rated ampere hours-capacity of the cell is C.

The Time-for-Charge shortens as Voltages and Currents become higher; similarly, it lengthens as Voltages and Currents become lower.

But these typical curves relate to a DC Source which has unlimited current availability, as explained in the text with Fig. 5.4. This, however, is unrealistic and uneconomical for Storage Battery installations in industry, and while Constant-Voltage Charging is an established principle, the DC Source is deliberately designed so that its maximum current is limited to an appropriate predetermined value.

The purpose of the Derived Performance Data which follows is to illustrate the effect on the Charging Process of limiting the maximum current available from the DC Source; the process becomes in fact, partly Constant-Current.

Separate Graphs in the style of Fig. 5.9 need to be provided for THIN, MEDIUM and THICK-PLATE cells.

DERIVED PERFORMANCE DATA

Fig. 5.10 is Fig. 5.7 but with each curve pinpointed at 20%, 40% 60%, 80% and 100% Charged.

Each point is a Time measurement from zero on the baseline, obtained by dividing the ampere hours needed to reach that % State-of-Charge

- reference Fig. 5.5 by the value of the Constant-Current applicable to the curve.

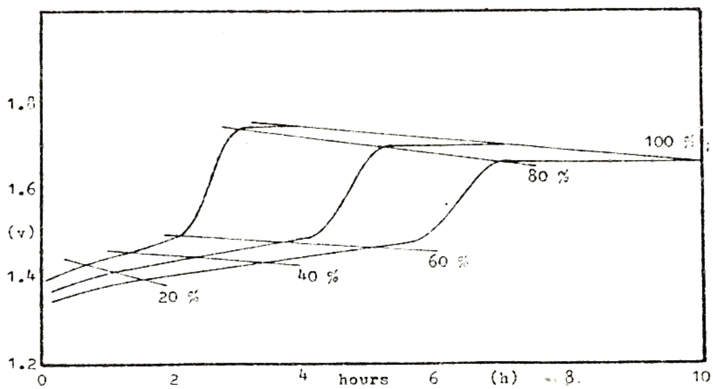


Fig. 5.10

The voltage (v) corresponding to each point is read off the ordinate of Fig.5.10 and together with its associated Constant-Current, is plotted on Fig. 5.11 in which the ordinate is scaled in volts-per- cell (v), and the baseline in amperes in terms of C

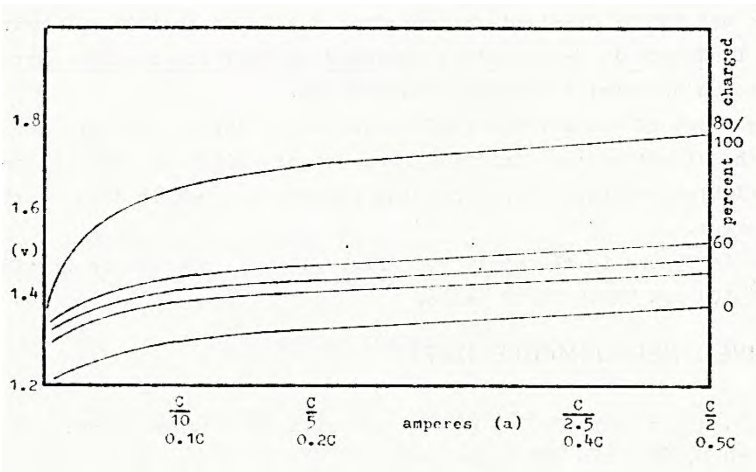


Fig. 5.11

In Fig. 5.11 points of equal % State-of-Charge which have been plotted from Fig. 5.10 connect into smooth curves, and these are marked accordingly. They indicate the relationship between voltage (v), current (a) and % State-of-Charge at any moment during a Charging Period.

The relationship is a transient one until 80 % Charged is reached; thereafter begins the second stage of the Charging Process in which voltage and current stabilise each at their respective Constant values, in both the Constant-Current and Constant-Voltage methods of charging, as in Fig. 5.6. Accordingly, the same curve serves for 100 % Charged as for 80 % Charged.

Fig. 5.11 is the DERIVED Performance Data which represents the Charging Characteristics of a Nickel-Cadmium Vented Pocket-Plate cell; and it is basic to the study and devising of SYSTEM Charging arrangements.

Separate Graphs in the style of Fig. 5.11 need to be provided for THIN, MEDIUM and THICK-PLATE cells.

A vertical line from any point on the baseline of Fig. 5.11 for example at 0.2C amperes, will intercept the State-of-Charge curves, and in particular those marked 0 % and 100 % Charged. Between these two endpoints, that portion of the vertical line represents the Constant Current of 0.2C amperes.

The voltage at each endpoint is read off the ordinate to the Graph and they are the lowest and highest voltage required from the DC Source to maintain the chosen current at its Constant value, whilst the cell is passing from Discharged to Charged.

The Time-to-Charge a cell of RATED ampere hours capacity C is

(1.4 x C) ampere hours/amperes in terms of C = hours

NORMAL-CHARGE is, an expression used in Storage Battery Technology, and it refers to Charging by the Constant-Current method.

Normal-Charge specifies a standard Period for the Time-to-Charge, which by traditional acceptance is 7 hours, and the value for the Constant -Current is adjusted to correspond with this Period.

To conform with the Efficiency requirement of (1.4 x C) ampere hours for a cell of RATED Ampere hours-capacity C, the current is 0.2C amperes, and this is defined as the NORMAL-CURRENT.

The voltage and time remain the same whatever numerical value may be assigned to C.

Higher values of current than 0.2C amperes may be used, which will shorten the times-for-charge; similarly, lower values will lengthen the times-for-charge.

Typically, at 0.4C amperes the time is 3½ hours, and at 0.1C amperes the time is hours; and these are the shortest and longest periods regarded as acceptable under the working conditions of industry.

The lowest and highest voltages differ for each current value and are read from Fig. 5.11.

The lowest and highest voltage corresponding to the chosen Constant Current value, in terms of C, specify completely the electrical characteristics for the DC Source to be used for charging.

That is to say, for a Normal Charge, the DC Source needs to be able to provide a Constant-Current of 0.2C amperes over a voltage range continuously adjustable - of (1.32 x N) to (1.70 x N), N being the number of cells in the battery which is to be charged.

The Charge Characteristics of Fig. 5.11 are repeated in Fig. 5.12 for ease of explanation and discussion, and the baseline of Fig. 5.12 has been adjusted to include for current values of higher multiples of C than 0.5.

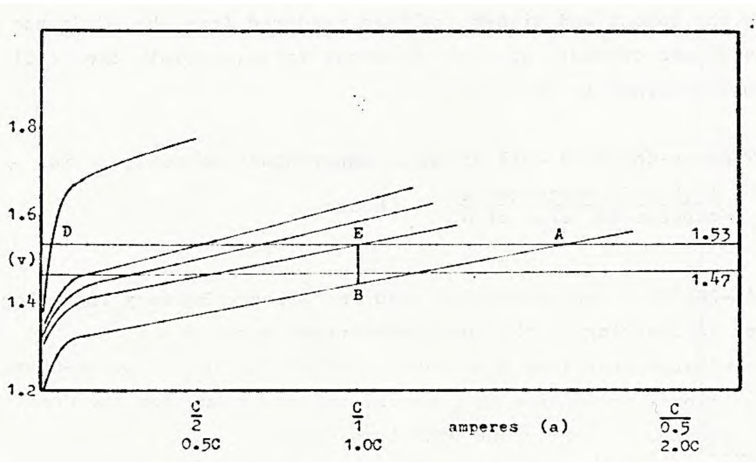


Fig. 5.12

In Fig.5.12 a horizontal line originating at any chosen voltage above 1.40 represents a Constant-Voltage as provided by a DC Source. The length of the line is a measure of the current - in amperes on the baseline - available from the DC Source, which may be a DC Generator or a Rectified AC Supply, regulated so that its DC Voltage stays Constant from zero current to maximum current.

By superimposing the Constant-Voltage of the DC Source on to the Charge Characteristics of a cell, the behaviour of the Charging process can be studied and predicted.

Two such lines, at 1.47 and 1.53 volts for example, are superimposed in Fig.5.12 and the points of intersection between each horizontal line and the % State-of-Charge curves indicate the Charging Current into the cell at these moments, and read off the baseline by vertical projection downwards. The cell momentarily receives a high value current when in a Discharged condition, but as Charging proceeds, the value of the current is gradually falling, and when 80 % Charged is reached, it assumes a low steady value.

The length of each line, from zero amperes to where it intersects the Discharged curve, at Point A for example, is a measure of the maximum current which the cell can accept at that voltage, even though the DC Source can provide more current than this; in which case the DC Source need only be designed for the maximum current.

It is usually unnecessary, moreover uneconomic, even to design for this maximum current, in which case the line is shortened and the current reduced, for example as shown by reference to the line marked 1.53 volts in Fig. 5.12.

The line is terminated instead at intersection E, for example at which point the voltage of the DC Source is designed to fall sharply away and is represented by the vertical line which intersects the 0 % Charged curve at point B.

In Fig. 5.12 the DC Source is now providing a Constant Voltage from point E to point D, as Fig. 5.9; from point B to point E it provides a Constant Current as Fig. 5.11.

This style of DC Source is described as Constant-Voltage with Current-Limitation; and the sharp fall in voltage gives the DC Source self-protection against overload damage.

When this DC Source is connected to a Discharged cell of RATED Ampere hours-capacity C, the initial charging current at point B is 1.0C amperes at 1.45 volts. The current remains Constant until, at point E, the cell is in this case 20% Charged and the voltage has risen to 1.53 volts.

Thereafter the voltage remains Constant at 1.53 volts and the value of the current gradually falls to its lowest steady value when the cell is 80 % Charged at point D.

The relation between Voltage, Current and Time is shown graphically in Fig.5.13.

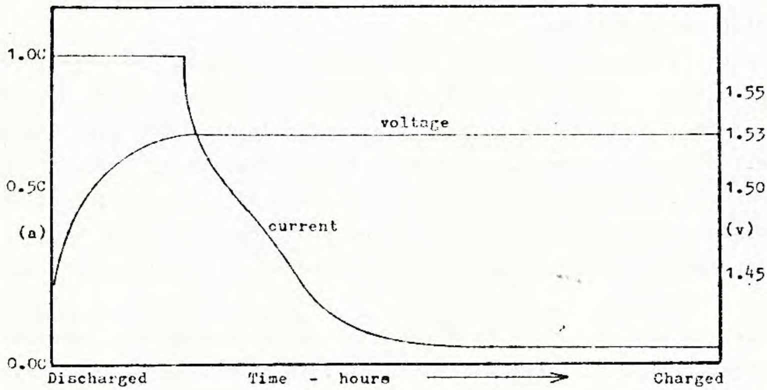


Fig. 5.13

It needs to be recognised that the Charge Characteristics of the cell itself are unalterable; on the other hand, the DC Source can be adjusted by suitable change in the design of its component parts. Also, by virtue of its lowest internal-resistance, the THIN-PLATE design accepts more current than the MEDIUM-PLATE design, which in turn accepts more current than the THICK-PLATE design.

In these circumstances, the DC Source is designed to suit the Charge Characteristics of the cell, of THIN, MEDIUM or THICK-PLATE design as the case may be.

Application Engineering needs to know the elapsed times to reach 80 % Charged and 100 % Charged, and the basis of the calculation is

(Ampere hours required – Fig. 5.5)/ (Average amperes – Fig. 5.12) = hours

There are three stages in the calculation, and as example, for a Limited-Current of 1.0C amperes and a Constant-Voltage of 1.53 -

0% to 20%	Charged =	(0.22 x C)/ 1.00C =	0.22 hours
20% to 80%	Charged =	(0.86 x C)/ 0.5C =	1.72 hours
80% to 100%	Charged =	(0.32 x C)/ 0.014C =	23 hours
0 % to 80%	Charged =	(0.22 + 1.72) =	1.94 hours
0 % to 100%	Charged =	(1.94 + 23.0) =	24.94 hours

These times are the same for any numerical value of ampere hours which may be assigned to C.

For the ready reference of Application Engineering, and in particular for choosing a DC Source, the elapsed times for a range of Limited Currents are arranged in tabulated form, and the example given below has reference to a Constant-Voltage of 1.53.

Limited Current amperes	hours to 80 % Charged	hours to 100 % Charged
0.1C	14.10	37.10
0.2C	7.05	30.05
0.5C	2.82	25.82
1.0C	1.94	24.94

Equivalent tabulations can be prepared for other Constant-Voltages for example, 1.47. and separate tabulations are needed for cells in THIN, MEDIUM and THICK-PLATE design.

The electrical characteristics of any chosen DC Source are specified by the Constant-Voltage and the amperes value of the Limited-Current.

TAPER VOLTAGE CHARGING

Fig. 5.14 is Fig. 5.11 upon which is superimposed an alternative DC Source to that shown on Fig. 512.

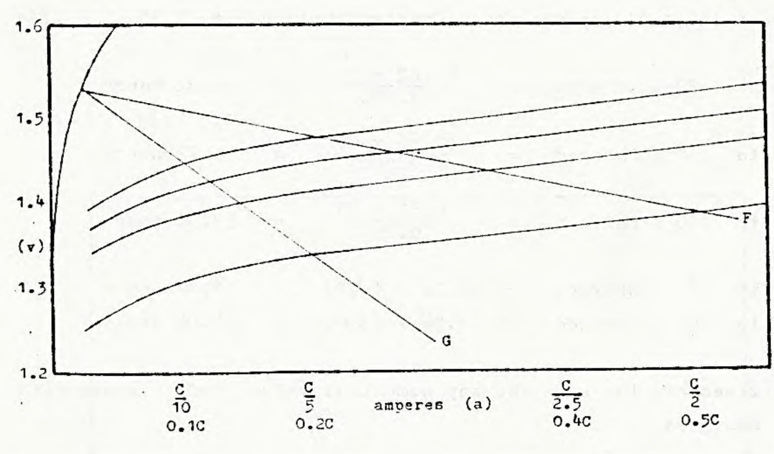


Fig. 5.14

Instead of a vertical Line to represent a Constant-Current, and a horizontal Line to represent a Constant-Voltage, a single sloping Line represents the DC Source.

Two typical Lines, each with a different slope, are marked G and F on Fig.5.14 and the points of intersection between these Lines and the % State-of-Charge curves indicate, for each Line, the current into the cell at these moments, and read off the baseline by vertical projection downwards. The cell momentarily receives a high value current when in a Discharged condition, but as charging proceeds, the value of the current falls, and when 80 % Charged is reached, it assumes a low steady value. Moreover, these two typical Lines pivot at the same point; in this case for example, at 1.53 volts on the curve marked 80 % to 100 % Charged. In these circumstances, the low value current is the same for both Lines; but the high value current for Line F is more than twice the high value current for Line G.

When the Line representing the DC Source slopes downwards as in Fig. 5.14 it is described as a Taper-Voltage charging arrangement; the slope of the Line is referred to as its Voltage-Regulation.

When the DC Source represented by Line G is connected to a discharged cell of RATED Ampere hours-capacity C, the current is momentarily 0.2C amperes and the voltage 1.34. The current then falls gradually to its low steady value of 0.025C amperes, with the voltage having risen to 1.53.

The corresponding figures for Line F are 0.5C amperes at 1.38 volts and 0.025C amperes at 1.53 volts.

The relation between Voltage, Current and Time-to-Charge is shown graphically in Fig. 5.15.

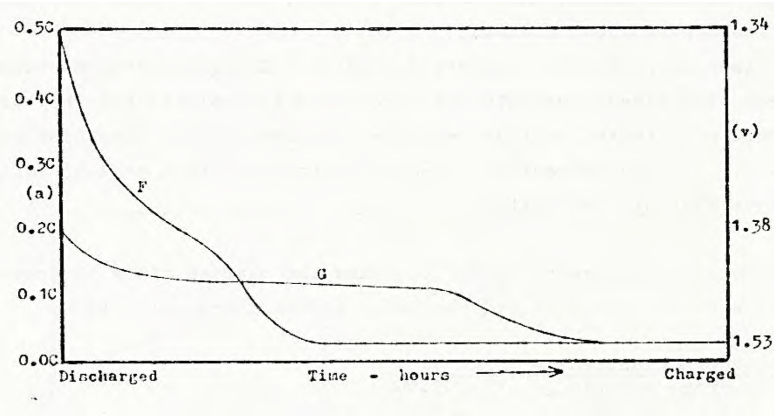


Fig. 5.15

It is seen that the low steady current at 80 % Charged is reached much sooner with Line F than with Line G, since its high value current is much greater; but the Time from 80 % to 100 % Charged is the same for both Lines.

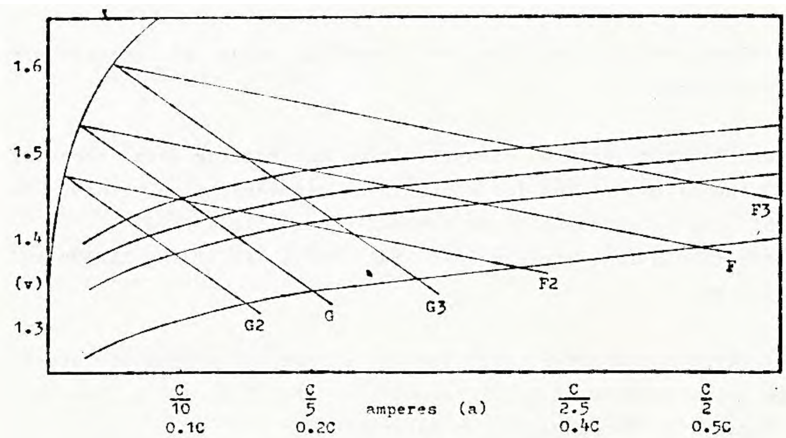


Fig. 5.16

Fig. 5.16 is Fig. 5.14 but with the Pivot-Point of Lines G and F moved to two other positions on the curve 80 % to 100 % Charged, and without change to their slopes.

As the Pivot-Point voltage is raised, the current values increase as well, and can be read off the baseline of Fig. 5.16; and the times to reach 80 % Charged are shortened.

The times to reach 100 % Charged from 80 % Charged are also reduced, since the low steady currents have increased in value; but they are not in proportion with the voltage increase, and reading off the baseline of Fig. 5.16, the current at 1.60 volts is twice that at 1.53 volts and four times that at 1.47 volts.

Application Engineering needs to know the elapsed times to reach 86 % Charged and 100 % Charged and the basis of the calculation is -

(Ampere hours required - Fig. 5.5)/ (Average amperes Fig. 5.16)

Taking Line G3 in Fig. 5.16 as an example, there are two stages in the calculation -

0 % to 80 %	Charged	(1.08 x C)/0.16C =	6.75 hours
80 % to 100 %	Charged	(0.32 x C)/0.05C =	6.40 hours
0 % to 100 %	Charged	6 .75 + 6.40 =	13.15 hours

These times are the same for any numerical value of ampere hours which may be assigned to C.

For the ready reference of Application Engineering when choosing a DC Source, the elapsed times for a number of representative lines, as in Fig. 5.16 can be calculated and set out in tabulated form.

Separate tabulations are needed for cells in THIN, MEDIUM and THICK-PLATE design.

The electrical characteristics for any chosen DC Source are specified by the volts/amperes at 0 % Charged and at 80 to 100 % Charged. Line G3 in Fig.5.16 for example, is described by -

0.28c amperes at 1.35 volts

and

0.05C amperes at 1.60 volts

SUMMARY OF CHARGING METHODS

Fig. 5.17 is Fig. 5.11 upon which the three typical DC Sources have been superimposed, representing Constant-Current, Constant- Voltage and Taper-Voltage methods of charging, as these have already been described separately in detail. It illustrates the basic differences between the three methods on a single Graph, for ease of reference and further explanation.

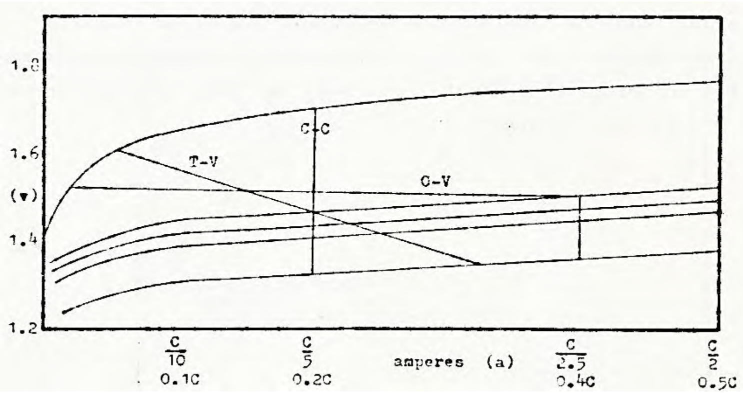


Fig. 5.17

Constant-Current

The Vertical Line representing a Constant-Current can be positioned to left or right in order to decrease or increase the Current value, and where it intersects the 0 % and 80 % to 100 % Charged curves, the voltages read off the ordinate enables the voltage range for the DC Source in terms of volts-per-cell, to be specified.

Constant-Voltage

The Horizontal Line representing a Constant-Voltage can be raised or lowered to increase or decrease the voltage, and the Vertical Line which represents a Limited-Current can be positioned to left or right in order to decrease or increase its value.

For whichever combination of Horizontal Line and Vertical Line are chosen, their intersections with the % State-of-Charge curves indicate on the baseline, the changing value of the current as the Charging process proceeds from 0 to 100 % Charged.

Taper Voltage

The doping Line representing a Taper-Voltage can be raised or lowered to increase or decrease the average current value between 0 % and 80 % Charged, and the steady current from 80 % to 100 % Charged, and the angle of the slope can be altered as well. For whichever position is chosen, its intersections with the % State-of-Charge curves indicate on the baseline the changing value of the current as the Charging process proceeds from 0 % to 100 % Charged.

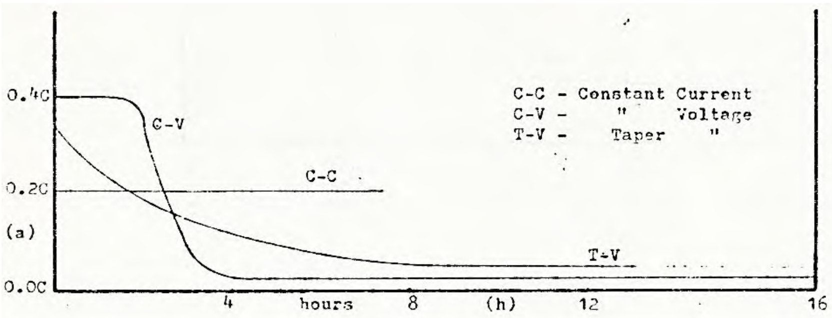


Fig. 5.18

Fig. 5•18 has hours on the baseline, amperes on the ordinate, and shows the relation between Current and Time-of-Charge for each of the three methods of Charging which are the subject of Fig. 5.17.

OVERCHARGE

If the cell is not disconnected from the DC Source when 100 % Charged is reached, the continuing Charge Current is wholly dissipated in electrolysing the water constituent of the electrolyte into oxygen and hydrogen gases, which escape through the vent in the cell lid. This is referred to in Storage Battery Technology as a condition of Overcharge.

There is a fixed electro-chemical relationship between the quantity of water converted to gas and the electrical energy expended in Overcharging.

Where the energy is expressed in amperes (a) and hours (h), each ampere hour converts O.336 cc of water into gas at Normal Temperature and Pressure, (NTP).

These ampere hours may be in terms of a small current for a long time or a larger current for a shorter time, and the value of the current is determined by the voltage at 80 % to 100 % Charged, as indicated for example by Fig. 5.11.

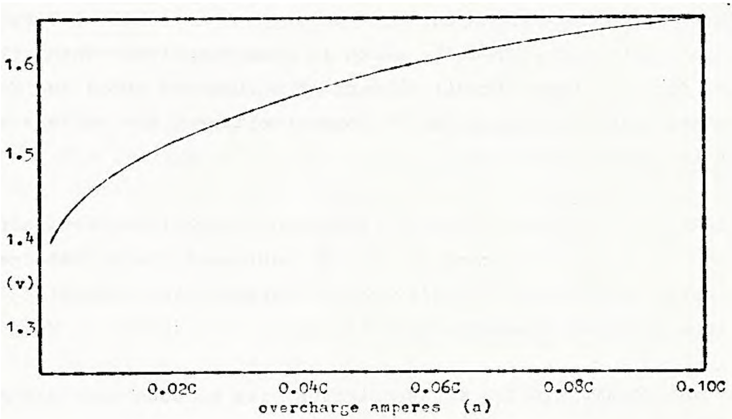


Fig. 5.19

The baseline of Fig. 5.19 is the baseline of Fig. 5.11 expanded so that low value currents are read off more accurately, and to a total baseline length of 0.10C amperes. The ordinate is still volts per cell.

The corresponding portion of the curve marked 80 % to 100 % Charged has also been transferred, and Fig. gives the relationship between the voltage (v) at 100% Charged and the Overcharge current (a) in amperes, within the baseline limit.

For each hour of Overcharge, the volume of water converted to gas is -

Amperes x 0.338 = cc

This refers to one cell; for a battery, the calculated quantity of cc. needs to be multiplied by the number of cells in the battery.

FLOATING and FLOAT CHARGING

The expressions FLOATING and FLOAT-CHARGING are in common use in Nickel-Cadmium Vented Pocket-Plate Storage Battery technology.

FLOATING is a situation where a cell is connected to a DC Source and where the voltage of the DC Source equals the Open-Circuit-Voltage of the cell; the cell FLOATS in that it cannot absorb an effective charge current because the voltage of the DC Source is too low; and is prevented from discharging because the voltage of the DC Source is too high.

Since however, it is not economically feasible to provide a DC Source which has zero tolerance on its voltage, the practical figure for FLOATING is 1.40 volts-per-cell, which is slightly higher than the figure of 1.32 for the Open-Circuit-Voltage of a Charged cell; and for a +/- 2.5% tolerance, which is common for DC Source, voltages, the voltage at the lower limit is still above 1.32.

FLOAT-CHARGING is an extension of FLOATING, in that voltages-per-cell higher than 1.40 are assigned to the DC Source. At these voltages the cell can absorb currents sufficiently high for effective recharging of the cell even from a deeply discharged condition.

FLOATING and FLOAT-CHARGING in association with a Constant-Voltage Limited-Current DC Source are basic to the Automatic Charging and Operation of Nickel-Cadmium Vented Pocket-Plate Storage Batteries, and their implications are discussed separately in detail. They are described in Battery Technology as Operational Modes, and each has its own special feature which is incorporated by itself or in association with the other, to suit the particular operating circumstances.

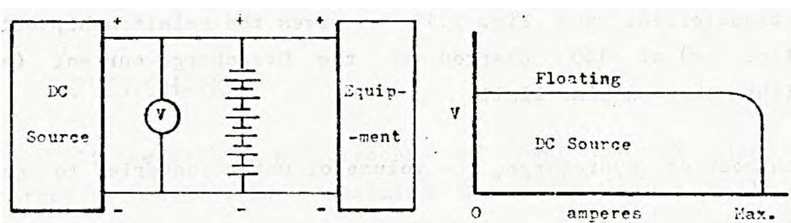


Fig. 5.20

Floating

In FLOATING installations, the DC Source, the Battery and the Equipment are in parallel connection, with a common voltage at their respective terminals. In Storage Battery Technology this arrangement is referred to as a SYSTEM, and the controlling voltage of the SYSTEM is that of the DC Source. It is illustrated diagrammatically in Fig. 5.20.

The current required by the Equipment is normally supplied by the DC Source, but when this is temporarily unavailable for any reason, the Battery discharges, but only to the limit of its capability, and sustains the Equipment in operation tor the time being.

Until this happens, the DC Source maintains the SYSTEM voltage at a constant value even though it may be supplying a varying or a zero current to the Equipment, in order that the battery does not discharge, which it would if the SYSTEM voltage were to fall; in which case the voltage of the DC Source is level at 1.40 volts-per-cell.

The feature of this SYSTEM is that the Equipment current transfers to the battery, not only without circuit interruption, but with minimum fall in voltage from the normal operating voltage of the SYSTEM, which is the FLOATING voltage.

While a disadvantage of the SYSTEM is that the FLOATING voltage is too low to restore the battery to high State-of-Charge after reinstatement of the DC Source, it has the operational advantage of minimum maintenance, in that the rate of Ioss of water from the electrolyte is so low that cells need replenishment only at very long intervals of time, possibly in the order of months even with the SYSTEM in continuous service.

Whenever a SYSTEM is in use based upon FLOATING at 1.40 volts-per-cell facilities are available to provide a higher voltage and adequate current for recharging the battery; this procedure is described as BOOST CHARGING.

There are Three possibilities

(1) If the Equipment can accept, without damage to itself, the higher voltage which is necessary, then the battery is recharged from the DC Source and with the Equipment still connected; the DC Source having built-in provision for its voltage to be raised temporarily, by manual or automatic switching, to a suitable level. The scheme is outlined in Fig. 5.21 and the DC Source needs to be able to provide sufficient amperes to charge the battery as well as supply, concurrently, the requirements of the Equipment.

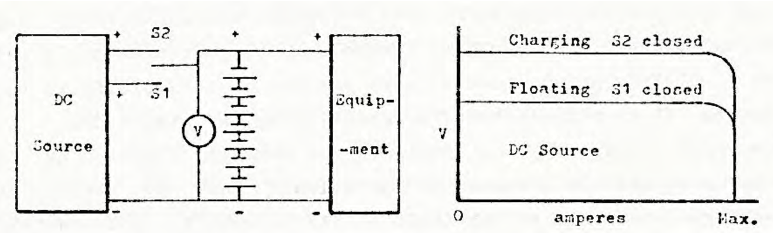


Fig. 5.21

(2) If the Equipment cannot accept, without damage to itself, the higher voltage which is necessary, the battery is disconnected from the SYSTEM and is recharged from a separate DC Source by the Constant-Current or Taper-Voltage method as may be most convenient. In the meantime, the Equipment is supplied with current from its regular DC Source at normal FLOATING voltage. On completion of the recharge, the battery is reconnected to the SYSTEM, and the scheme is outlined in Fig. 5.22.

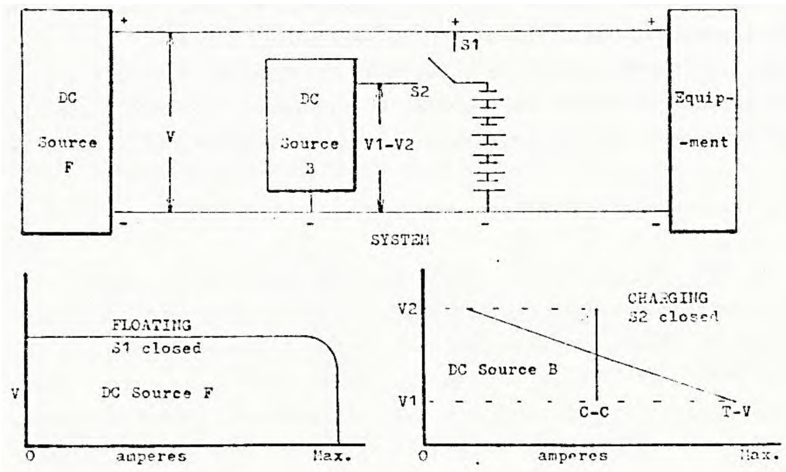


Fig. 5.22

(3) As an alternative to (2), a Counter-Voltage device can be inserted temporarily between the battery and the Equipment; this allows the voltage of the DC Source to be raised above the FLOATING value, without the higher voltage reaching the terminals of the Equipment. On completion of the charge, the Counter-Voltage device is eliminated, and the voltage of the DC Source readjusted to the FLOATING value. The scheme is outlined in Fig. 5.23 and the DC Source needs to be able to provide sufficient amperes to charge the battery as well as supply, concurrently, the requirements of the Equipment.

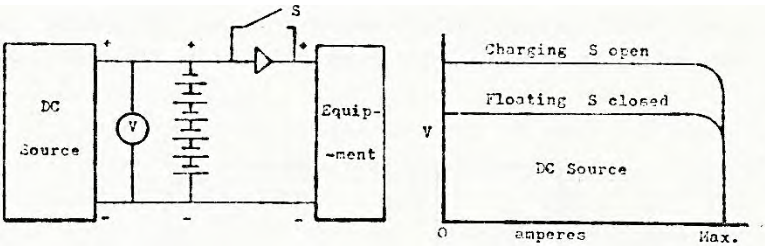


Fig. 5.23

But in reverting to 1.40 volts-per-cell, 100 % State-of-Charge is not retained. This is because nickel and iron in electro-chemical combination have an inherent propensity for self-discharge, in which case the portion of the ampere hours capacity of the cell which is attributable to the nickel-iron content of the active-materials is gradually dissipated, the stored energy being lost in gassing the water content of the electrolyte solution into oxygen and hydrogen.

The ampere hours capacity of the cell eventually stabilises, whilst FLOATING, at that of the nickel-cadmium content, which has no inclination to self-discharge, and is 80 % of the RATED Ampere hours capacity of the cell.

In these circumstances. Application Engineering depends upon only 80 % of the RATED Ampere hours capacity of the cell being available for useful discharge duty in FLOATING SYSTEMS.

To ensure continued perfect electro-chemical reversibility of the cadmium-oxide portion of the -ve plate active-material it is necessary that recharging is continued until 100 % State-of-Charge has been reached, before a battery is returned to the FLOATING Operational Mode.

1.40 volts-per-cell is the basic design voltage when FLOATING SYSTEMS are being devised, and it is applicable to THIN, MEDIUM and THICK - PLATE cells. This is because the currents at 80 % to 100 % Charged at this voltage are a small enough fraction of C as to be insignificantly affected by the difference in internal resistance of the Three designs.

Float-Charging

In FLOAT-CHARGE installations the DC Source, the Battery and the Equipment are in parallel connection, with a common voltage at their respective terminals. In Storage Battery Technology this arrangement is referred to as a SYSTEM, and the controlling voltage of the SYSTEM is that of the DC Source. It is illustrated diagrammatically in Fig. 5.24.

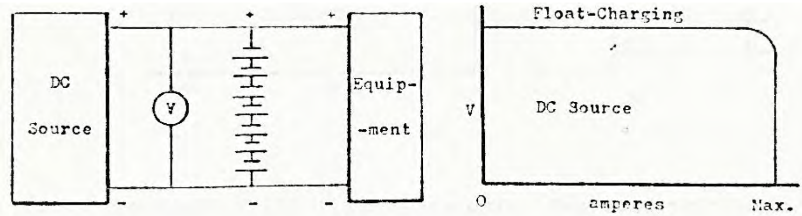


Fig. 5.24

The feature of FLOAT-CHARGING is that the DC Source recharges the battery, even from a deeply discharged condition, without manual intervention or circuit interruption. But to achieve this result it is necessary to apply SYSTEM voltages which are higher than the FLOATING voltage of 1.40. They will therefore be suitably selected points on the 80 % to 100 % Charged curve of Fig. 5.12.

The current required by the Equipment, whether constant or variable in value, is normally supplied by the DC Source, but when this is temporarily unavailable for any reason, the battery discharges, but only to the limit of its capability, and sustains the Equipment in operation for the time being.

Until this happens, the DC Source needs to maintain the SYSTEM voltage at a constant value even though it may be supplying a varying or perhaps zero current to the Equipment, in order that the battery does not discharge, which it would if the SYSTEM voltage were to fall; in which case the voltage of the DC Source is level, as for example at 1.53 volts-per-cell in Fig. 5.12.

Battery Charging is by the Constant-Voltage Limited-Current method, and the DC Source needs to be able to provide sufficient amperes to charge the battery, as well as to supply, concurrently, the requirements of the Equipment.

Recharging commences automatically as soon as the DC Source is reinstated following a temporary interruption of any kind which caused the battery to discharge, even its RATED Ampere hours-capacity. Moreover, 100 % State-of-Charge is reached and sustained, unlike with FLOATING, where only 80 % can be depended upon for discharge duty.

In addition, by appropriate choice of FLOAT-CHARGE voltage and current for the DC Source, the time for recharge can be rapid of slow to suit the SYSTEM needs. In particular, the choice can provide a rapid return to 80 % Charged, which is often of greater interest than the time to reach 100 % Charged.

But for the sake of securing these features, there is an operating disadvantage to be accepted; this is a greater rate of water loss from the electrolyte by gassing, particularly with SYSTEMS which are in continuous service. In these circumstances, cells need replenishment at more frequent intervals, because FLOAT-CHARGED batteries operate in a condition of Overcharge, as this has been defined; in which case Fig. 5.19 is relevant since it enables a numerical figure for rate of water loss for any chosen FLOAT-CHARGE voltage to be obtained, and a forecast made of the time interval between replenishment.

In the same way that the nameplate voltages of Electrical Equipment conform to certain standards, for example 12, 24, 32, 64 and 110 volts DC, so have the FLOAT-CHARGE voltages for Nickel-Cadmium Vented Pocket-Plate Batteries which are associated with these Equipments, reached a measure of standardisation.

Two specific voltages have become established as acceptable and effective; these are 1.53 and 1.47 volts-per-cell, and which have been referred to earlier in this Chapter.

A DC Source based upon 1.53 volts provides a shorter Time- to Charge than with 1.47 volts; in particular to 80 % Charged. 1.53 is desirable if discharges are deep and frequent and Time-for-Charge is short; but if discharges are shallow and rare and there are longer periods available for recharge, then 1.47 could be the appropriate choice. It is the responsibility of Application Engineering, Chapter 6, to decide which voltage is the most suitable for the SYSTEM under consideration, having regard to its particular circumstances.

1.53 and 1.47 volts-per-cell are basic design voltages where FLOAT-CHARGED SYSTEMS are being devised, and they are applicable to THIN, MEDIUM and THICK-PLATE cells; this is because the currents at 80% to 100% Charged are a small enough fraction of C as to be insignificantly affected by the difference in internal resistance between the Three designs.

But while 1.53 and 1.47 have been referred to as being precise voltages, it is not economically feasible to provide a DC Source with zero tolerance on its voltage.

+/- 1 % and +/- 2 % are the tolerances commonly encountered, and which show deviations as follows

1.53	+ 1 % =	1.5453	1.53	+ 2 % =	1.5606
	- 1 % =	1.5147		- 2 % =	1.4994
1.47	+ 1 % =	1.4847	1.47	+ 2 % =	1.4994
	- 1 % =	1.4553		- 2 % =	1.4406

+/- 1 % gives a distinct separation between the lower limits of 1.53 and the upper limits of 1.47, in this way preserving the identity of each Operational Mode.

+/- 2 % has a tendency for the lower limit of 1.53 to merge with the upper limit of 1.47.

The upper limits hasten the time to reach 80 % Charged and 100 % Charged, and the Overcharge current is increased in value.

The lower limits lengthen the times and reduce the value of the Overcharge current.

For the sake of the most precise control, 1 % is the preferred tolerance.

TEMPERATURE EFFECT

Fig. 5.1 to Fig. 5.19 are based upon cells being at the same temperature as the air in their immediate vicinity, in this case 20°C/68°F which in Storage Battery Technology is defined as NORMAL.

At cell temperatures above NORMAL - which are defined as HIGH - the same values of charging current are obtained with slightly lower voltages. Conversely, currents are slightly higher for voltages which are appropriate for 20°C/68°F.

These changes are insufficient to justify the preparation of Performance Data with specific reference to this temperature range, and it is customary therefore to regard Data at 20°C/68°F as being applicable to HIGH temperatures as well.

At cell temperatures below NORMAL - which are defined as LOW with a minimum of around -20°C/-4°F - significant increases in voltage are necessary to produce the same currents. Conversely, currents are lower at voltages appropriate to 20°C/68°F. But the rate of increase in voltage is much slower to 0°C/32°F than from 0°C/32°F to -20°C/-4°F; in view of this it is customary to regard 0°C/32°F as a boundary line dividing the LOW temperature area into two parts, one from 20°C/68°F to 0°C/32°F, the other from 0°C/32°F to -20°C/-4°F.

The majority of Nickel-Cadmium Vented Pocket-Plate Batteries operate in a temperature range of 0°C/32°F and upwards, in which case Performance Data is made available at 0°C/32°F and at a few selected temperatures between 0°C/32°F and 20°C/68°F and in similar style to Fig. 5.1 to Fig. 5.19 which are for 20°C/68°F.

Batteries which operate at temperatures below 0°C/32°F are in the minority and the provision of Data in similar style to Fig. 5.1 to Fig. 5.19 in this temperature area is not justified. Such batteries are regarded as special cases, and it is customary to make appropriate tests and to obtain relevant Data at the particular LOW temperature concerned.

FLOAT and FLOAT-CHARGE Voltages of 1.40 and 1.47/1.53 respectively are design voltages for calculating the number of cells for a battery, and for choosing the voltage to be provided by the DC Source at HIGH, NORMAL and LOW temperatures. The battery self-regulates the current which it accepts from the DC Source; above NORMAL temperatures the current increases in value, below NORMAL temperature it decreases.

The Charge Characteristics at 20°C/68°F for 80 % to 100 % Charged and for 0 % Charged are reproduced in Fig. 5.25 and the corresponding Characteristics for 0°C/32°F have been superimposed.

The change in current values between 20°C/63°F and 0°C/32°F during FLOAT-CHARGING are indicated by horizontal lines at 1.47 and 1.53 volts where they intersect the Charge Characteristics; and the corresponding currents are read off the baseline by vertical projection downwards.

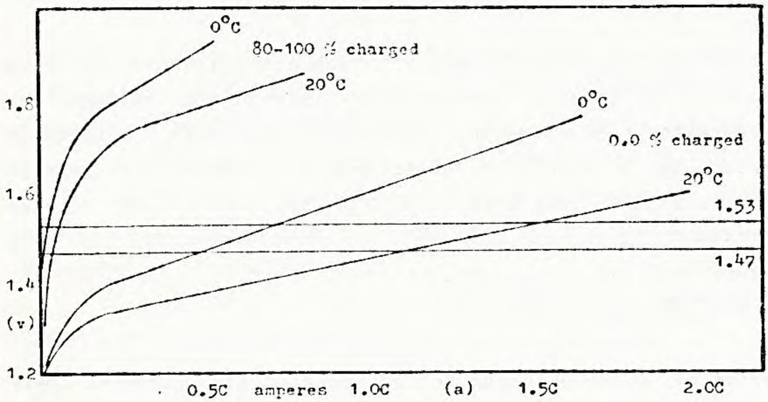


Fig. 5.25

As the temperature changes from 20°C/68°F to 0°C/32°F the current at 0 % Charged becomes considerably reduced, but at 80 % to 100 % Charged the current alters only slightly.

The lower currents below 20°C/68°F mean longer periods of time to reach 80 % Charged, and then 100 % Charged; and the rate of water loss during FLOAT-CHARGING is lower.

As temperatures rise above 20°C/68°F, the currents increase but not substantially, and the only effect is to increase, moderately, the rate of water loss during FLOAT-CHARGING.

During FLOATING at 1.40 volts, changes in current value due to temperature changes have negligible effect on the operation of the SYSTEM; the current at 20°C/68°F is small, moreover 1.40 volts has a HOLDING rather than a CHARGING function.

6 Application Engineering

The choice of Nickel-Cadmium Vented Pocket-Plate Electric Storage Battery - its design, ampere hours-capacity and number of cells for any given DC SYSTEM, as this has been defined - is the purpose of Application Engineering, and to fulfil this it interprets and applies the Data issued by manufacturers of storage batteries, and which has been explained in detail in Chapters 2, 3, 4 and 5.

The Battery which is technically correct in design and size to meet the SYSTEM DUTY will also be the most economical in terms of weight, bulk, maintenance and first cost; it will also ensure a long working life.

FUNCTIONS

The Nickel-Cadmium Vented Pocket-Plate Battery is a reservoir of DC Energy which performs various functions in association with electrically operated DC Equipment in the Engineering Industry.

The main functions are -

Initiating

and

Standby

Some batteries may perform only one of these functions, others may perform both.

In the Initiating function, the battery provides Energy to start and stop the operation of equipment and is only fractionally discharged.

In the Standby function, the battery provides DC Energy so that the operation of equipment can continue when the normal DC Supply to the equipment is temporarily interrupted for any reason, and it may become completely discharged.

In the context of the Application Spectrum, discussed in Chapters 2, 3 and 4, the Initiating function is an Ampere seconds Duty while the Standby function is an Ampere hours Duty.

Storage Batteries are also separable into two well-defined environmental groups, Stationary and Mobile.

STATIONARY BATTERIES

Batteries classified as STATIONARY are used -

- For the electric-starting of stationary internal-combustion engines and gas turbines. This is an Initiating function.
- For the opening and closing, by remote electrical control, of Switch-Gear which in turn controls the nationwide distribution of electricity from power-stations and sub-stations. This is an Initiating function.
- To provide an alternative source of DC for lighting, telecommunications, auxiliary machines and inverters, in power-stations and industry, when the normal DC Supply to these is temporarily interrupted for any reason. This is a Standby function.

Stationary batteries have the benefit of an easily controlled and supervised environment. Accommodation is clean, ventilation is consistent and positive. The batteries are free from the possibility of physical damage. Maintenance arrangements can be tired to suit operator convenience. Charging can be automated if desired, but it also amenable to manual control and supervision.

MOBILE BATTERIES

Mobile is the descriptive term for a Nickel-Cadmium Vented Pocket Plate Battery which is installed on a wheeled vehicle, and where the battery has an auxiliary purpose - control, engine-starting, standby lighting - as distinct from providing electrical energy for propulsion.

The Mobile battery operates in an environment which is the antithesis of that of the Stationary battery. There is continual motion, mechanical vibration and shock; the possibility of physical damage is always present. Accommodation space is usually restricted, and ventilation is a compromise between providing adequate air changes to remove gases produced during charging while at the same time restricting the ingress of damp and dirt. The battery spends long periods, perhaps weeks, remote from maintenance facilities, and servicing is at the convenience of associated operational schedules for the vehicle concerned. Charging arrangements need to be, of necessity, entirely automatic, the absence of the battery putting it beyond any form of manual control or supervision.

Batteries classified as MOBILE are used

- For the electric-starting of internal-combustion engines and turbines on wheeled vehicles. This is an Initiating function.
- To provide alternative sources of DC for lighting and control on wheeled vehicles, when the normal DC Supply is temporarily interrupted for any reason. This is a Standby function.

DUTY SPECIFICATION

A SYSTEM is illustrated diagrammatically in Fig. 6.1 and whether Stationary or Mobile it has its own distinctive features and needs a Duty Specification to explain its function or functions, and to provide the relevant details which enable the battery size and the Characteristics for the DC Source to be chosen, by the Process of Application Engineering.

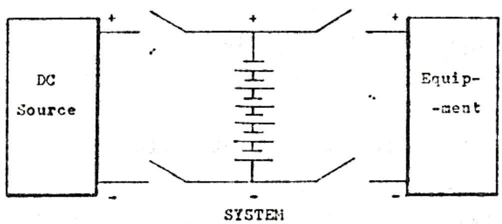


Fig. 6.1

The information provided by a Duty Specification is as follows –

A statement of the function or functions.

Equipment details.	Nameplate DC voltage	Ve
Highest permissible operating voltage	-	Vmax
Lowest effective operating voltage	-	Vmin
Operating current		Amperes

Time period to operate from the battery.

DC Source	Generator
	Alternator
	AC Mains-Rectifier

Time period preferred for recharging the battery.

The significance of Vmax (a + limit on Ve) is that a higher voltage applied to its terminals may damage the Equipment, whereas at a voltage lower than Vmin (a - limit on Ve) the Equipment may not work properly.
The tolerance on Ve is, however, crucial to the selection of the most economical Ampere hours-capacity and Number of Cells for the battery.

As explained in Chapter 3. a battery is not inherently able to sustain a fixed voltage at its terminals whilst delivering up its stored energy; nor can it receive energy for storage at a fixed voltage. It can operate only within its own voltage tolerance, and it is the purpose of Application Engineering to select a battery which has operating limits which are within and take advantage of, the Vmax and Vmin voltage limits of the Equipment. The wider the tolerance the smaller and therefore the more economical is the battery size, especially in terms of the minimum Ampere hours capacity.
In the selection of SYSTEM battery sizes, Vmax is the highest voltage permissible for charging, and Vmin is the lowest voltage permissible at the end of the period when the battery, by itself, is supplying the Equipment with current.

From the Duty Specification, Application Engineering will determine and in this order.

- The Capacity of Nickel-Cadmium Vented Pocket-Plate cells for the battery.
- The cell design .and its RATED Ampere hours capacity.
- The Voltage / Current Characteristic for the DC Source.

Application Engineering consults the Performance Data in Chapters 3, 4 and 5 and co-relates it to the Performance requirements of the Duty Specification.
An acceptable solution may not be reached at the first attempt, and the Duty Specification, as originally drafted, may be beyond the capability of Nickel-Cadmium Vented Pocket-Plate cells to provide an economically approved installation.
In these circumstances' adjustment to one or other of the Specification details, for example the voltage limits Vmax or Vmin, may be possible so as to bring the Duty Specification more into line with the inherent electrical characteristics of the Nickel-Cadmium Vented Pocket-Plate Battery.

NUMBER OF CELLS FOR THE BATTERY
The number of cells which will comprise the battery is chosen by reference to the SYSTEM Duty as explained in the Specification, and to the Operational Mode which is applicable to it.

The following is a. working summary of the Three Operational Modes discussed in Chapter 5 Charging and their application to SYSTEM Duties.

1.40 volts-per-cell at the battery terminals.
A FLOAT voltage which is aligned with 80 % Charged; but a higher voltage needs to be applied temporarily to recharge the battery following even slight Discharges; this is referred to as a Boost Charge.
t
It is a typical arrangement for batteries which have Initiating and Standby functions which occur only on rare occasions, separated perhaps by weeks or months. Stationary Batteries which are part of Standby lighting and power, Engine-starting and Switch-gear control SYSTEMS come within this Operational Mode category, for example.

1.47 volts-per-cell at the battery terminals.
A FLOAT-CHARGE voltage which is aligned with 100 % Charged, and which can recharge the battery to that extent following even a complete Discharge of its Rated Ampere hours-capacity. It can provide a rapid return to 80 % Charged, but thereafter to 100 % Charged in a longer period of time. The speed of the return to 80 % Charged is controlled by the availability of current from the DC Source, the lower the current value the longer the time; but the time from 80 % Charged to 100 % Charged is unaltered.

It is a typical arrangement for batteries which have an Initiating as well as a Standby function, the Initiating function occurring frequently, and the Standby function rarely. Stationary Batteries which are part of Signalling systems on railways come within this Operational Mode category, for example.

1.53 volts-per-cell at the battery terminals.
A FLOAT-CHARGE voltage which is aligned with 100 % Charged, and which can recharge the battery to that extent following even a complete Discharge of its Rated ampere hours capacity, but in a

shorter period of time, both to 80 % Charged and to 100 % Charged, than with a FLOAT-CHARGE voltage of 1.47 volts-per-cell. The speed of the return to 80 % Charged is controlled by the availability of current from the DC Source, the lower the current value the longer the time: but the time from 80 % Charged to 100 % Charged is unaltered.
It is a typical arrangement for batteries which have an Initiating as well as a Standby function, with both functions occurring frequently. Mobile batteries which are part of control, lighting and engine-starting systems on wheeled-vehicles come within this Operational category, for example.

The SYSTEM function is explained in the Duty Specification, and is then related to one or other of the Three Operational Modes as is appropriate; from which it follows that the number of cells for the battery is

The SYSTEM voltage V / Operational Mode voltage-per-cell

The SYSTEM voltage V will generally be Vmax the highest permissible operating voltage of the Equipment with which the battery is to work, unless the battery is disconnected from the SYSTEM during charging, and which will be indicated in the Specification. It will be a FLOAT voltage or a FLOAT-CHARGE voltage in accordance with the Operational Mode voltage per cell which has been chosen by reference to the frequency of the functions.

The figure for Number-of-Cells needs to result in a whole number. Should this not be the case, a compromise adjustment to the SYSTEM voltage or to the voltage-per-cell of the Operational Mode, or to both, may be made. In one way, the SYSTEM voltage is retained and a slight increase or decrease accepted for the voltage-per-cell. Alternatively, the voltage- per-cell of the Operational Mode is retained and the SYSTEM voltage adjusted so that the figure for the Number-of-Cells becomes a whole number, and the chosen Operational Mode is not disturbed, which is preferable.

As explained in Chapter 5 Charging, 1.40, 1.47, and 1.52 are applicable to whichever design of cell, THIN, MEDIUM or THICK-PLATE is to be chosen, when Operational Mode voltages-per-cell are being selected.

AMPEREHOURS CAPACITY FOR THE BATTERY

The Ampere hours-capacity is a numerical value for C, in THIN, MEDIUM or THICK-PLATE design as may be appropriate, which is calculated by reference to Chapter Discharging, as being necessary to operate the equipment from the battery only, at the voltage, current, and for the time prescribed by the Duty Specification.

The calculated value for C, in ampere hours, is not necessarily the ampere hours required to meet the Duty Specification on the simple basis of multiplying the amperes by the hours. It is usually greater, and by an amount which relates to the position of the Duty in the Application Spectrum, which is discussed in Chapters 2, 3 and 4.

If the Duty tends towards the AMPERE SECONDS end, as this has been defined, only a small percentage of the calculated value for C will be utilised, and while cells in the THIN-PLATE design are the natural choice, they are not necessarily the most suitable in every case, and MEDIUM-PLATE or THICK-PLATE may be more economical.

If the Duty tends towards the AMPEREHOURS end, as this has been defined, a substantial percentage of the calculated value for C will be utilised, and while cells in the THICK-PLATE design arc a natural choice, some Duties may be served more economically by cells in the THIN-PLATE or MEDIUM-PLATE design.

In any event, the calculated value for C in ampere hours identifies the chosen cell by size, and in all considerations the numerical value for C needs to be within the feasible range of cell sizes, which is 5 ampere hours for the smallest, and 500 ampere hours for the largest, available in THIN, MEDIUM and THICK-PLATE designs.

The general principle which is followed to determine the numerical value for C in ampere hours is to superimpose the Duty Specification, in a suitable form, on whichever Graph in Chapter 4. Discharging is appropriate.

Vmin, the Lowest effective operating voltage mentioned in the Duty Specification, is the basic consideration but it needs to be expressed in terms of volts-per-cell in order to relate to the Performance Data in Chapter 4. Discharging.

Since the Number-of-Cells has already been decided by reference to the Operational Mode of the SYSTEM –

Lowest Volts per Cell Vmin = Vmin/Number of Cells

The Specification values for current and time do not change when the battery voltage Vmin is expressed as Volts-per-Cell Vmin.
The numerical figure in the Specification for the equipment amperes has reference to the name-plate voltage Ve; but the current is higher at Vmax and lower at Vrnin, by Ohm's Law.
The amperes corresponding to Ve are therefore in the nature of an average value, but for the purposes of applying Fig. 4.1 to Fig. 4.8 Chapter 4.

Discharging to the determination of a battery size, the amperes quoted in the Duty Specification are assumed to be of Constant value as are the currents in Fig. 4.1 to Fig. 4.8 - during the whole of the time in which the battery only is supplying current to the equipment.

The numerical value for C is to be such that by the end of the time-period specified, the Volts-per-cell, with the current still flowing, is not below Vmin.

Ampere seconds Specifications

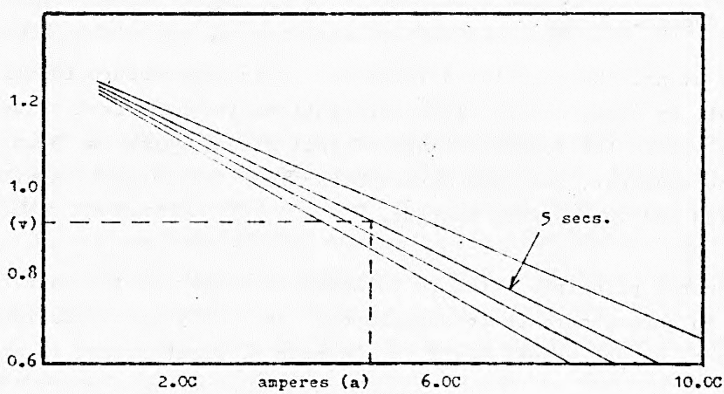


Fig. 6.2

Fig. 4.6 in Chapter 4. Discharging is applicable to Duty Specifications in the AMPERE Seconds category and has been reproduced, for ease of reference and explanation, as Fig. 6.2.

A typical Duty Specification in this category is superimposed, and in which

Vmin =	0.93 volts-per-cell
time =	5 seconds
current =	400 amperes

The horizontal projection of 0.93 volts-per-cell on the ordinate intersects with the 5 second line, and the intersecting point is projected downwards to the baseline which it meets at 5.0C amperes, and this establishes the relationship

amperes (a) = 5.0C amperes

Then since (a) in the Duty Specification is 400 amperes, the numerical value for C is

400 amperes/5.0 = 80 ampere hours

The ampere hours discharged are 400 amperes x 5 secs = 0.55
The percentage utilisation of C equals 0.55/80 x 100 = 0.7%

Although the natural choice of cell design is THIN-PLATE, the Duty Specification can be superimposed on similar Graphs in reference to MEDIUM and THICK-PLATE cells. The design which gives the lowest calculated number of ampere hours for C, with the highest percentage utilisation, will be the most economical choice.

Ampere hours Specifications

Fig. 4.1, Fig. 4.3 and Fig. 4.4 in Chapter 4. Discharging are applicable to Duty Specifications in the AMPERE HOURS category, and for ease of reference and explanation, Fig. 4.3 has been reproduced here as Fig. 6.3.

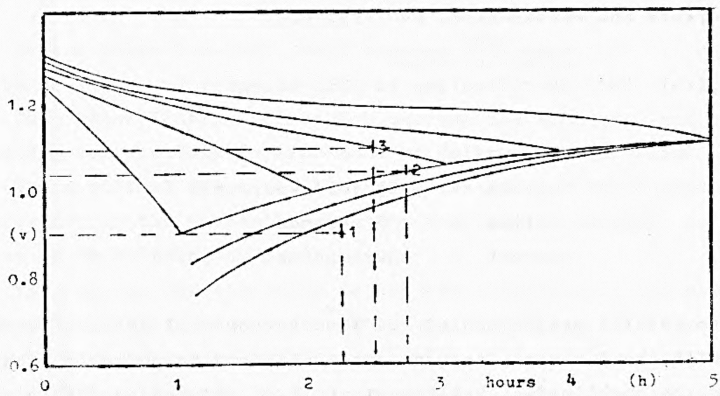


Fig. 6.3

Three typical Duty Specifications in this category have been superimposed, and the intersecting points of Vmin and (h) for each have been plotted and marked 1, 2 and 3 on Fig. 6.3.

Point 1.
Since this point - Vmin = 0.90 and h = 2.25 - is beyond the areas enclosed by the three end-point curves, its ordinate is to be extended vertically upwards so as to intersect the first and lowest curve; this brings Point 1. into the Performance Capability of THICK-PLATE cells.

The intersection is the termination of an interpolated Performance Curve which has the relationship

C = amperes (a) x 2.25 hours

Then if (a) in the Duty Specification is equivalent to 50 amperes constant current, the numerical value for C is

112.5 = 50 amperes x 2.25 hours

It is shown that the Specification requirement of 0.90 for Vmin is not feasible when (h) = 2.25 hours. The lowest is 0.94, but this allows a useful margin of voltage over the bare request of the Specification.

Greater voltage margins are obtained by using MEDIUM or THIN-PLATE cells, but the most economical design to fulfil the Specification is THICK-PLATE, since the calculated numerical value for C will be the same in each case.

Point 2.
Since this point - Vernon = 1.03 and (h) - 2.75- happens to fall on an end-point curve, it is the termination of an interpolated Performance Curve which has the relationship

C = amperes (a) x 2.75 hours

Then if (a) in the Duty Specification is equivalent to 30 amperes constant current, the numerical value for C is
137.5 = 50 amperes x 2.75 hours.

Point 3,
This point - Vmin = 1.09 and (h) = 2.5 - lies within the area of the end-point curves, but instead of falling on the termination of a Performance Curve, it falls on the curve itself.
Nevertheless, the numerical value for C is calculated in respect of the complete curve. In which case
C = amperes (a) x 3.00 hours.

Then if (a) in the Duty Specification is equivalent to 50 amperes constant current, the numerical value for C is
150 = 50 amperes x 3.0 hours.

While THICK-PLATE is the natural choice of cell design for Duty Specifications in the AMPEREHOURS category, Specifications are applied in turn to the Discharge Performances of THIN, MEDIUM and THICK-PLATE cells, so that the design which conforms most closely to the Duty Specification, and with the lowest numerical value for C, is chosen.

Intermediate Specifications

Fig. 4.5 in Chapter 4. Discharging is, for example, applicable to Duty Specifications in the INTERMEDIATE category, and has been reproduced, for ease of reference and explanation, as Fig. 6.4.

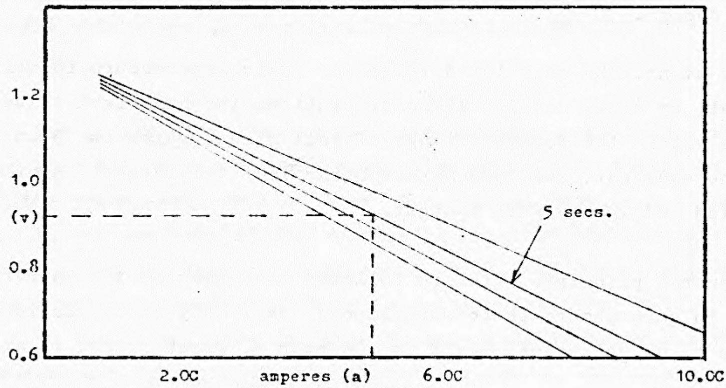


Fig. 6.2

Two typical Duty Specifications in this category have been superimposed, and the intersecting points of Vmin and (m) for each have been plotted and marked 1 and 2 on Fig. 6.4.

Point 1.

This point - Vmin = O.98 and (m) =20 - falls on the curve which represents the Performance of a current of

2.0C amperes

Then if the equivalent constant current of the Duty Specification is 150 amperes -

2.0C = 150 amperes

and the numerical value for C is -

75 = 150/2.0 ampere hours

In meeting the Specification, the cell chosen from Fig. 6.4 discharges 150 amperes for 20 minutes; this equal 50 ampere hours which is 50/75 = 66% utilisation.

The other two designs, when the same Specification is checked against their appropriate Graphs in the style of Fig. 6.4 may show a greater or a smaller percentage utilisation of their calculated values for C. The cell which has the greatest percentage is the most economical design.

Point 2.
This point - Vmin = 1.02 and (m) =10 - falls between the two Performance curves marked 2.0C and 2.5C, in which case an interpolation is made to establish the value for X in the relationship -

(a) = XC amperes

which is applicable to Point 2, and this is 2.25.
Accordingly, point 2 falls on a curve which represents the Performance of a current of -

2.25C amperes

Then if the equivalent constant current of the Duty Specification is 15C amperes -

2.25C = 150 amperes

and the numerical value for C is -

67 = 150/2.25 ampere hours

In meeting the Specification, the cell chosen from Fig. 6.4 discharges 150 amperes for 10 minutes; this equal 25 ampere hours, which is 25/67 = 37 % utilisation.
The other two designs, when the same Specification is checked against their appropriate Graphs in the style of Fig. 6.4 may show a greater or a smaller percentage utilisation of their calculated value for C. The cell which has the greatest percentage is the most economical design.

Multiple Duty Specifications

In a MULTIPLE DUTY Specification, a single battery performs two or more dissimilar duties, and either concurrently or consecutively. The possible duties are -
One or more in the AMPERESEC0NDS category.
One or more in the INTERMEDIATE category.
One or more in the AMPERE HOURS category.

The relevant Duty specification will indicate the current, voltage and time for each duty, and the sequence in which they are to occur.
MULTIPLE DUTY Specifications are set out in graphical form for ease of reference. Fig. 6.5, Fig. 6.7 and Fig. 6.10 represent typical Specifications, and the calculation of C for each is explained in detail.

The general principle to be followed in making the calculation is to regard the numerical value for C as the sum of the ampere hours required by each Duty, on the basis that each has its own separate battery.

Fig. 6.5. presents a sequence of One Duty in the AMPERE SECONDS category followed by Two dissimilar Duties in the AMPERE HOURS category.

The numerical value for C is to be such that the terminal voltage of the battery is not to be below 1.00 volts-per-cell – Vmin - at any time during the progress of the discharge, which when tabulated is -

150 amperes for 60 seconds, followed by
60 amperes for 1 hour, followed by
20 amperes for 2½ hours.

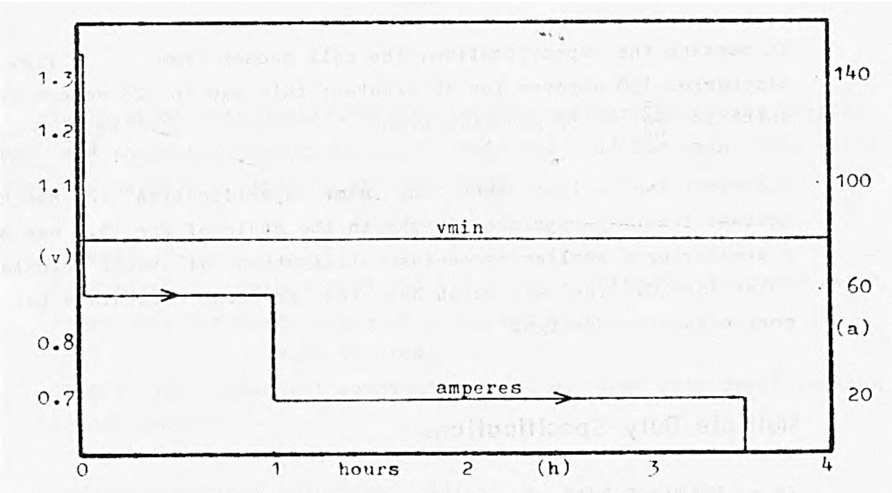


Fig. 6.5

For the First Duty, the ampere hours-capacity required is obtained from Fig. 4.6 Chapter 4. Discharging.
1.00 volts-per-cell on the ordinate is projected horizontally to intersect the 60 second Line, and the point of intersection projected vertically downwards meets the baseline where –

	(a)	= 3.4C
Accordingly,	(a)	= 150 amperes
	C	= 150/3.4
		= 44 ampere hours

For the Second Duty, the capacity needed is

60 amperes for 1 hour = 60 ampere hours

For the Third Duty, the capacity needed is

20 amperes for 2½ hours = 50 ampere hours

The initial estimate for the numerical value for C is then –

44 + 60 + 50 = 154 ampere hours

But the ampere hours consumed by the First, the AMPERE SECONDS Duty, are in fact only

150 amperes x 60 seconds = 2.5

Accordingly, the balance of the 44 ampere hours, namely 41.5, is available to contribute towards the 60 ampere hours required by the Second Duty. In which case, the next estimate for the numerical value for C becomes -

2.5 + (41.5 + 18.5) + 50 = 112.5

This result needs confirmation, or otherwise, that at any point during the total period of 5 hours 31 minutes, the battery terminal voltage does not fall below 1.00 volts-per-cell (Vmin), and this is judged by a graphical construction where the Three Duties are superimposed upon Fig. 6.6, which is Fig. 4.9 Chapter 4. and in which has been given the numerical value of 112.5 ampere hours.

To implement the procedure, the total ampere hours consumed to the end of each Duty are expressed as a percentage of 112.5 ampere hours so that the battery is -

After 60 seconds = 2.5/112.5 = 2.2 % Discharged

After 61 minutes = 62.5/112.5 = 55.5 % Discharged

After 211 minutes = 112.5/112.5 = 100 % Discharged

In Fig. 6.6 the Three Duties have been superimposed, by plotting the intersections of current and percent state-of-charge.

0.0 % Discharged and 150 amperes (1.32C)

2.2 % Discharged and 150 amperes (1.32C)

2.2 % Discharged and 60 amperes (0.54C)

55.5 % Discharged and 60 amperes (0.54C)

55.5 % Discharged and 20 amperes (0.18C)

100.0 % Discharged and 20 amperes (0.18C)

The intersecting points are joined as shown, and the values for (v) for each point which are read off the ordinate indicate the voltage at start and end of each Duty. It is seen that these voltages are all above the Lowest permissible of 1.00 volts-per-cell.

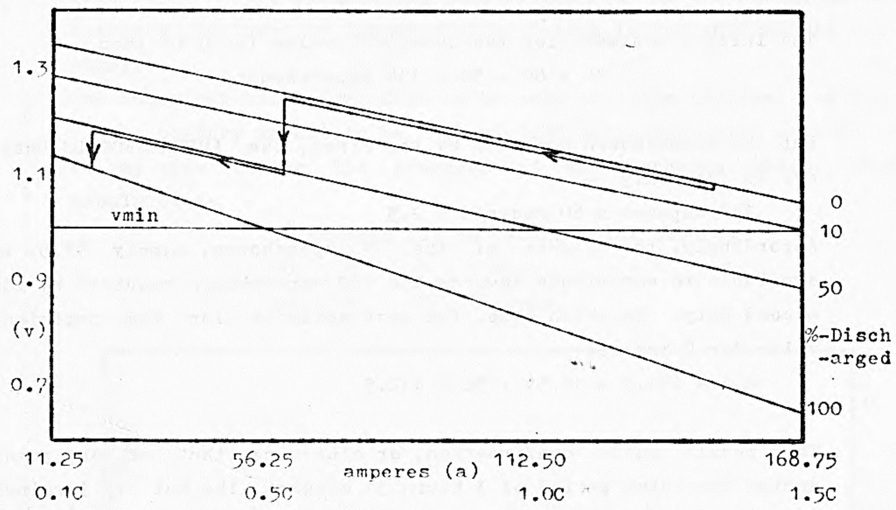


Fig. 6.6

The graphical construction in Fig. 6.6 indicates that a "numerical value for C of 112.5 ampere hours" will have a margin in voltage over Vmin of the Duty Specification, with the PLATE design which has the Discharge Characteristics of Fig. 4.6 and Fig. 4.9 Chapter 4. Discharging.
The margin of voltage will be different with both the other PLATE designs, and this is investigated by superimposing the Three Duties on to the Discharge Characteristics appropriate to these other designs in the style of Fig. 4.9. and in which C is given the same numerical value of 112.5.
The design which indicates a battery terminal voltage conforming most closely to Vmin of the Duty Specification will be the correct technical choice, with a numerical value for C of 112.5.

Fig. 6.7 presents a sequence of Two dissimilar Duties in the AMPERE HOURS category, followed by One Duty in the AMPERE SECONDS category.

The numerical value for C is to be such that the terminal voltage of the battery is not to be below 1.00 volts-per-cell - Vmin at any time during the progress of the discharge, which when tabulated is –

60 amperes for 1 hour, followed by
20 amperes for 2½ hour, followed by
150 amperes for 60 seconds.

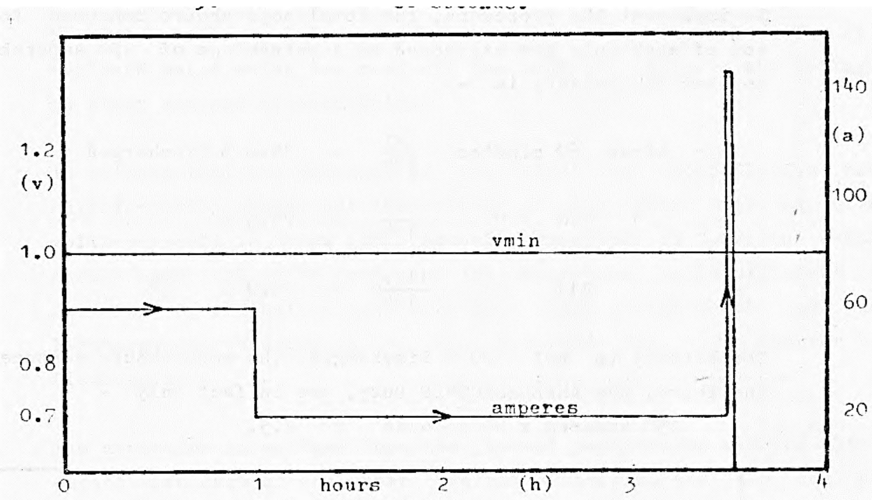


Fig. 6.7

For the First Duty, the capacity needed is -

60 amperes for 1 hour = 60 ampere hours

For the Second Duty, the capacity needed is -

20 amperes for 2½ hours = 50 ampere hours

For the Third Duty, the capacity needed is obtained from Fig. 4.6 Chapter 4. Discharging.

1.00 volts-per-cell on the ordinate is projected horizontally to intersect the 60 second line, and the point of intersection projected vertically downwards meets the baseline where

(a) = 3.4C

Accordingly, since (a) = 150 amperes

C = 150/3.4

= 44 ampere hours

The initial estimate for the numerical value for C is then –

44+60+50 = 154 ampere hours

This result needs confirmation, or otherwise, that at any point during the total period of 3 hours 31 minutes, the battery terminal voltage does not fall below 1.00 volts-per-cell (Vmin), and this is judged by a graphical construction where the Three Duties are superimposed upon Fig. 6.8, which is Fig. 4.9 Chapter 4. Discharging, and in which C has been given the numerical value of 154.
To implement the procedure, the total ampere hours consumed to the end of each Duty are expressed as a percentage of 154 ampere hours, so that the battery is

After 60 minutes 60/154 = 39.0 % Discharged
After 210 minutes 110/154 = 71.5 % Discharged
After 211 minutes 112.5/154 = 73.0 % Discharged

The battery is not 100 % Discharged. The ampere hours consumed by the Third, the AMPERE SECONDS Duty, are in fact only – 1

50 amperes x 60 seconds = 2.5.

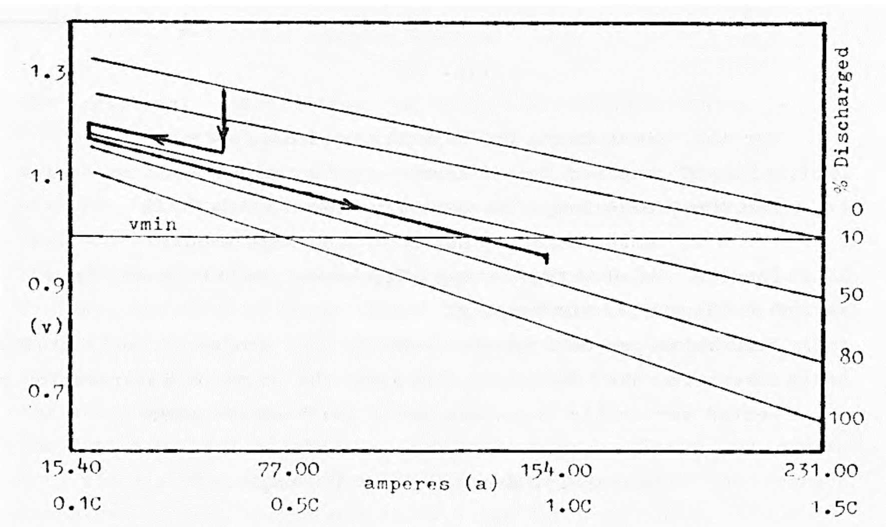


Fig. 6.8

In Fig. 6.8 the Three Duties have been superimposed, by plotting the intersections of current and percent state-of-charge

0.0 % discharged and 60 amperes (0.390C)
39.0 % discharged and 60 amperes (0.390C)
39.0 % discharged and 20 amperes (0.130C)
71.5 % discharged and 20 amperes (0.130C)
71.5 % discharged and 150 amperes (0.970C)
73.0 % discharged and 150 amperes (0.970C)

The intersecting points are joined as shown, and the values for (v) for each point which are read off the ordinate indicate the voltage at start and end of each Duty.
It is seen that the voltages of the First and Second Duties are satisfactorily above, but the voltage of the Third Duty, at O.96 volts-per-cell is below the Lowest permissible of 1.00; in which case a numerical value for C of 154 ampere hours is insufficient to meet the Specification Duty with the PLATE design which has the Discharge Characteristics of Fig. 4.6 and Fig. 4.9 Chapter 4. Discharging.

The deviation in voltage from the Lowest permissible will be different with each of the other Two PLATE designs, and this can be investigated by superimposing the Three Duties on to the Discharge Characteristics appropriate to these other designs, in the style of Fig. 4.9 and in which C is given the numerical value of 154 ampere hours.
The design which indicates a battery terminal voltage conforming most closely to Vmin of the Duty Specification will be the correct technical choice, with a numerical value of 154 ampere hours for C.

In the event that neither of the Three PLATE designs is able to meet the Duty Specification, a greater numerical value for C is necessary.
It is customary to increase the initial calculation of ampere hours in steps of 20%, re-tabulate the data at each step, then superimpose it upon Fig. 4.9 until the specified voltage-per-cell for Vmin is secured.
For example, 154 ampere hours + 20% = 185 ampere hours.
The total ampere hours consumed to the end of each Duty are then expressed as a percentage of 185 ampere hours, so that the battery is

After 60 minutes 60/185 = 32.5 % Discharged
After 210 minutes 110/185 = 50.5 % Discharged
After 211 minutes 112.5/185 = 61.0 % Discharged

The battery is not 100 % Discharged, the ampere hours consumed by the Third, the AMPERE SECONDS duty, are in fact only –

150 amperes x 60 seconds = 2.5

Fig. 6.9 is Fig. 4.9 Chapter 4. Discharging in which C has been given the numerical value of 185 ampere hours, and upon which the Three Duties have been superimposed by plotting the intersections of current and percentage state-of-charge.

0.0% discharged and 60 amperes (0.325C)
32.5 % discharged and 60 amperes (0.325C)
32.5 % discharged and 20 amperes (0.108C)
59.5 % discharged and 20 amperes (0.108C)
59.5 % discharged and 150 amperes (0.810C)
61.0 % discharged and 150 amperes (0.810C)

The intersecting points are joined as shown, and the values for (v) for each point which are read off the ordinate, indicate the voltage at start and end of each duty.

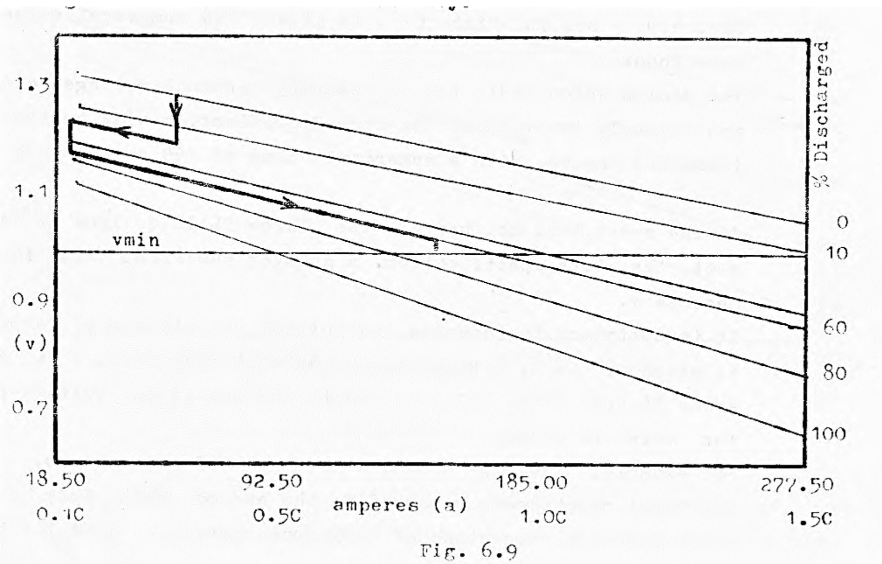


Fig. 6.9

It is seen that the voltages of the First and Second duties are satisfactorily above, and the voltage of the Third, at 1.02 volts-per-cell, is now, by a small margin, above the Lowest permissible of 1.00 required by the Specification Duty.
This has been achieved by raising the numerical value of C from 154 to 185 ampere hours, and with the PLATE design which has the Discharge Characteristics of Fig. 4.6 and Fig. 4.9 Chapter 4. Discharging.

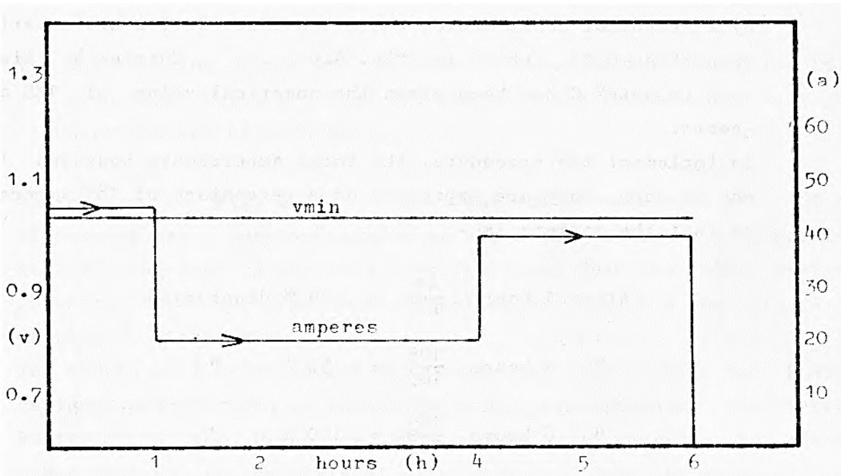


Fig. 6.10

Fig. 6.10 presents a sequence of Three dissimilar Duties in the AMPERE HOURS category.
The numerical value for C is to be such that the terminal voltage of the battery is not to be below 1.03 volts-per-cell - Vmin - at any time during the progress of the discharge, which when put into tabulated form is -

45 amperes for 1 hour, followed by
20 amperes for 3 hours, followed by
40 amperes for 2 hours.

For the First duty, the capacity needed is -

45 amperes for 1 hour = 45 ampere hours.

For the Second duty, the capacity needed is -

20 amperes for 3 hours = 60 ampere hours

For the Third duty, the capacity needed is -

40 amperes for 2 hours = 80 ampere hours

The initial estimate for the numerical value for C is then -

45+60+80 = 185 ampere hours

This result needs confirmation, or otherwise, that at any point during the total period of 6 hours, the battery terminal voltage does not fall below 1.03 volts-per-cell (Vmin), and this is judged by a graphical construction where the Three Duties are superimposed upon Fig. 6.11, which is Fig. 4.9 Chapter 4. Discharging in which C has been given the numerical value of 185 ampere hours.

To implement the procedure, the total ampere hours consumed to the end of each Duty are expressed as a percentage of 185 ampere hours, so that the battery is –

After 1-hour	45/185 =	24 % discharged
After 4 hours	105/185 =	57 % discharged
After 6 hours	185/185 =	100 % discharged

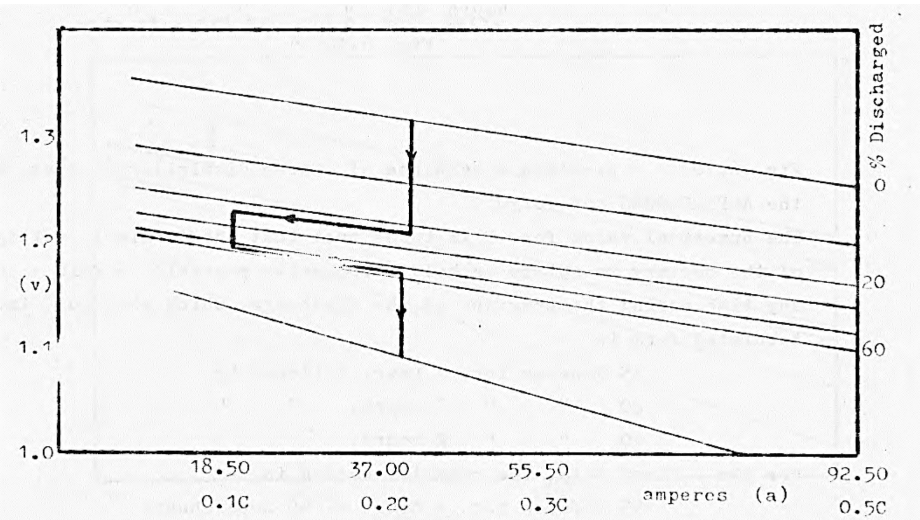


Fig. 6.11

In Fig. 6.11 the THREE duties have been superimposed by plotting the intersections of current and % State-of-Charge.

0.0 % discharged and 45 amperes (0.24C)
24.0 % discharged and 45 amperes (0.24C)
24.0 % discharged and 20 amperes (0.108C)
57.0 % discharged and 20 amperes (0.108C)
57.0 % discharged and 40 amperes (0.216C)
100.0 % discharged and 40 amperes (0.216C)

The intersecting points are joined as shown, and the values for (v) for each point which are read off the ordinate indicate the voltage at start and end of each Duty.

It is seen in Fig. 6.11 that the voltage-per-cell at 100 % Discharged has a substantial margin above the Lowest permissible of 1.03 required by the Duty Specification, with the PLATE design which has the Discharge Characteristics of Fig. 4.6 and Fig. 4.9 Chapter 4. Discharging.
The margin will be different with each of the other Two PLATE designs, and this can be investigated by superimposing the Three Duties on to the Discharge Characteristics appropriate to these other designs, in the style of Fig. 4.9 and in which C is given the numerical value of 185 ampere hours. The design which indicates a battery terminal voltage conforming most closely to Vmin of the Duty Specification will be the correct technical choice, with a numerical value of 185 ampere hours for C.

THE DC SOURCE

The DC Source is one part of the SYSTEM illustrated in Fig. 6.1 and it provides current to charge the battery, to operate the Equipment or Auxiliary Equipment as the case may be, and at the Operational Mode Voltages which are relevant to the Duty Specification.

The DC Source provides for SYSTEM operation by the Constant-Voltage Limited-Current method, in accordance with Fig. 5.12 and Fig. 5.20 to Fig. 5.24 Chapter 5. Charging, and the Operational Mode Voltage in the SYSTEM voltage.

CONSTANT-CURRENT and TAPER-VOLTAGE methods by themselves are NOT SUITABLE for SYSTEM operation, but they are used in conjunction with FLOAT and FLOAT-CHARGE SYSTEMS.

The feature of CONSTANT-VOLTAGE LIMITED-CURRENT is that the voltage at the Equipment terminals remains constant, which is desirable, and even when its amperes requirements are varying during normal operation of the SYSTEM, during both FLOATING and FLOAT-CHARGING. It also maintains precise and predictable control of battery charging.

Some Specifications may require the Operational Mode of FLOAT- CHARGE only; others may require the facility for an Operational Mode of FLOAT as well.

The capability of the DC Source in terms of Voltage and Current follows from the numerical figures which have already been established about the SYSTEM, namely

- The Operational Mode or Modes
- Number of cells in the battery
- Cell design and Ampere hours-capacity
- Equipment current at the highest Operational Mode Voltage

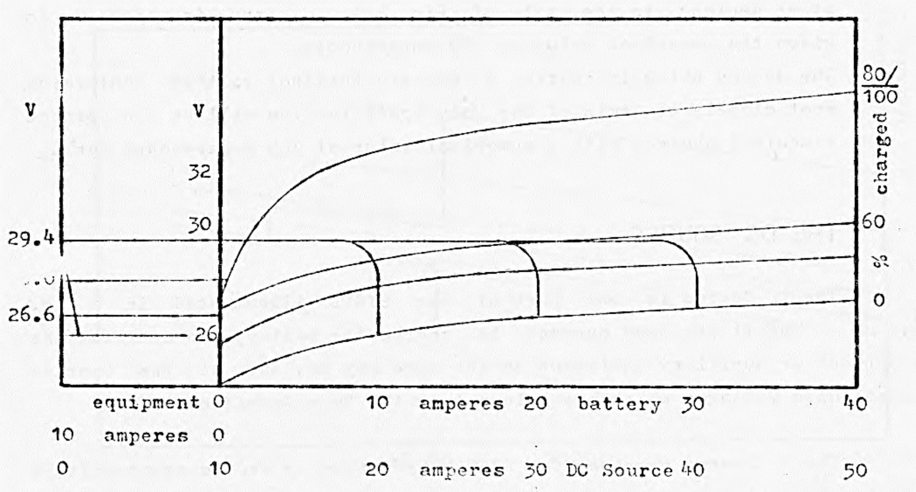


Fig. 6.12

A graphical construction in the style of Fig. 5.11 Chapter 5. Charging needs to be prepared and including for the numerical figures which are given by the SYSTEM details. This is Fig. 6.12 and in which for example –

Operational Mode	- FLOAT-CHARGE at 1.47 volts-per-cell
	- FLOAT-CHARGE at 1.40 volts-per-cell
Number of Cells	- 20
Ampere hour capacity C	- 100 in THICK-PLATE design
Equipment Current	- 10 amperes at 1.47 volts-per-cell

In Fig. 6.12 the left-hand ordinates are scaled in battery voltage, being the volts-per-cell of Fig. 5.11 Chapter 5. Charging multiplied by the number of cells, namely 20.
The baseline is scaled in amperes, C in Fig. 5.11 having been given the numerical value of 100 ampere hours. In which case, for example, 0.2C becomes 20 amperes.
The curves for percentage State-of-Charge will have reference to cells in THICK-PLATE design.

The FLOAT-CHARGE voltage is - 20 cells x 1.47 = 29 4 and it is represented by a horizontal line superimposed on Fig. 6.12 and originating at 29.4 volts on the left-hand ordinate.

The FLOAT voltage is - 20 cells x 1.40 = 28.0 and it is represented by a horizontal line superimposed on Fig. 6.12 and originating at 28.0 volts on the left-hand ordinate.

Whatever value is chosen for the Limited-Current, it must contain an allowance of 10 amperes for the equipment. If the Limited-Current is 30 amperes, for example, then the current available for battery charging is 20 amperes.
Accordingly, the line of length 30 amperes in Fig. 6.12 disposes 10 amperes to the left of zero for the equipment, and 20 amperes to the right of zero for battery charging.
Fig. 6.13 traces the progress of the Charging process outlined in Fig. 6.12 from the moment when the battery is in a Discharged condition until it is Charged, and when the Operational Mode is FLOAT- CHARGE at 29.4 volts-per-cell.

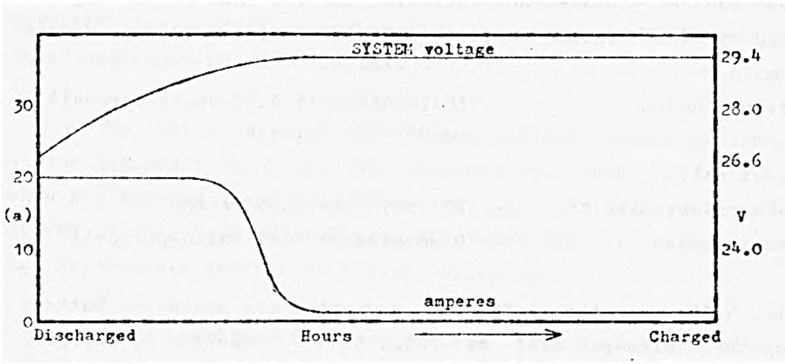


Fig. 6.13

In Fig. 6.13 one ordinate is scaled in amperes to correspond with the baseline of Fig. 6.12 while the other is scaled in SYSTEM voltage. The baseline is in hours.

The charging current remains constant at 20 amperes until 60 % Charged is reached, and during this time the SYSTEM voltage is rising from 26.6 to 29.4 volts. Thereafter, the voltage remains constant at 29.4 volts and the value of the current steadily declines to the steady-state value for 80 % to 100 % Charged.
During the whole of this time the DC Source has been supplying current to the equipment; initially at 8.70 amperes since the SYSTEM voltage is temporarily reduced to 26.6 volts, and the current is by Ohms Law proportional to the voltage, then rising to a constant 10 amperes when the battery has reached 60 % Charged and beyond as in Fig. 6.12.

But the battery is not necessarily always completely Discharged, it may on occasions only be partially Discharged.
In these circumstances the time period during which the charging current remains constant at 20 amperes is considerably shortened, it may even be zero time; and if the battery has been discharged by only a small percentage of its ampere hours-capacity, then the charging current will be no greater than the low steady-state value for 80 % to 100 % Charged.

It is the purpose of Application Engineering to select a DC Source which is the most economical, that is, the smallest in terms of voltage and current to meet the Duty Specification.

The DC Source is therefore given the lowest Numerical values for the Constant-Voltage and Limited-Current which are acceptable to the battery and to the SYSTEM.
For the battery, the minimum Constant-Voltage is 1.47 per-cell, and the minimum current 0.1C amperes, by which the battery can be restored to 100 % Charged, should it become deeply discharged.
When required and to suit the Duty Specification, the Constant- Voltage can be raised to 1.53 per-cell, with the current remaining the same at 0.1C amperes; similarly, the current values can be raised.
These adjustments, separately or together, provide for recharging in shorter periods of time.

The Limited-Current to be specified for the DC Source is therefore-

0.1C amperes minimum
plus
the Equipment amperes

The Time-for-Charge, from 0 % Charged, calculated in accordance with the explanation given with Fig. 5.12 Chapter 5. Charging is 52 hours, composed of 7 hours to reach 80 % Charged and a further 45 hours to reach 100 % Charged.
If, however, the chosen Limited-Current is 20 amperes instead of 30 amperes, then the maximum available current for battery charging is 10 amperes, also shown on Fig. 6.12; but it would take 13 hours to reach 80 % Charged and a total of 58 hours to reach 100 % Charged.
Again, if the Limited-Current is 40 amperes, that is 30 amperes available for battery charging, the time periods are 4.75 hours and 49.75 hours respectively.

In Float-Charged installations, the time to reach 80 % Charged is usually of more significance than the time to reach 100 % Charged, and Application Engineering will generally choose the DC Source on the former basis.

While higher currents shorten the time to reach 80 % Charged, the DC Source is less economical than if lower currents and longer times are acceptable. It is the responsibility of Application Engineering to decide and based upon the requirements of the installation under discussion, and whether STATIONARY or MOBILE. The latter benefits most by a rapid return to high State-of-Charge.

TEMPERATURE EFFECT

Fig. 6.2 to Fig. 6.13 refer to cells which are at the same temperature as the air in their immediate vicinity, in this case 20°C/ 68°F. and which in Storage Battery technology is defined as NORMAL.
But Nickel-Cadmium Vented Pocket-Plate batteries may be required to operate in temperatures above NORMAL, which are defined as HIGH, or in temperatures below NORMAL, which are defined as LOW.
Application Engineering consults Chapter 4 Discharging and Chapter 5 Charging, for Performance Data appropriate to the choice of the most suitable battery design and size, and particularly how this is influenced by the temperature specified.
The Operational Mode and number of cells are always based upon NORMAL temperature. The ampere hours-capacity for HIGH temperature is calculated as for NORMAL temperature, but it needs to be increased for LOW temperature so as to compensate for the reduction in Discharge Performance at LOW temperature.
In some situations, the same battery may be required to operate for part of the time in a LOW temperature and part of the time in a HIGH temperature. These temperatures may alternate in any period of 2*t hours, on the other hand they may be seasonal., Cold Winters and Hot Summers.
It is the responsibility of the Duty Specification to provide information on the environmental temperatures in which the battery will be required to operate, so that appropriate Performance Data is chosen to determine the most suitable battery design and size.

SYSTEMS IN SERVICE

While the foregoing paragraphs explain the Principles involved, and the use of Performance Data in the selection of Nickel-Cadmium Vented Pocket-Plate Storage Batteries to suit Duty Specifications, there are SYSTEMS in service which are well established on the basis of these Principles, and it is appropriate to consider several of these in detail.

Diesel Engine Starting
Switch-Gear Control
Rapid-Transit Rail Cars
Road-Rail Crossing Protection
Inverters

Diesel Engine Starting

Diesel Engines are often started electrically from storage batteries, and for the purposes of Application Engineering it is desirable to understand the arrangements, and the requirements which have to be met to ensure satisfactory starting.

The crucial requirement is for the engine to be rotated up to at least the minimum RPM at which it will FIRE, and then continue to run from its own fuel supply.

An electric motor coupled to the engine converts electrical energy from a storage battery into mechanical energy at the engine flywheel. The combination of battery and electric motor needs to provide sufficient torque to first of all overcome the static inertia of the engine, and this is known as the BREAKAWAY Phase of the starting process; it requires a large current from the battery but only for a fraction of a second.

Once the engine has started to rotate, it is to be accelerated within a few seconds to the RPM at which it will FIRE. In this time the current required from the battery becomes less. Moreover, as the current falls in value, the terminal voltage of the battery rises - it reached a low value during the BREAKAWAY Phase - and within a few seconds the current, voltage and engine speed stabilise. If the RPM is sufficient, the engine FIRES and continues to run from its own self-generated energy.

Although FIRING takes place in less than 5 seconds, and BREAKAWAY in less than 1 second, with an engine in good condition, it is desirable to provide margins of time to allow for the starting of an engine which in the course of usage has become less efficient, and in consequence may need a longer period in which to reach FIRING conditions. For this reason, it is customary for Specifications to be based upon 1 second for BREAKAWAY and 5 seconds for FIRING; and these times correspond with the presentation of Standard Performance Data, Fig. 4.6 Chapter 4 Discharging, and in particular to Specifications in the AMPERESECONDS category.

The BREAKAWAY torque and the FIRING torque each need to be expressed in terms of voltage and current; these form part of the Specification from which a Nickel-Cadmium Vented Pocket-Plate battery of adequate electrical capability to start the engine may be chosen.

The Specification so provided takes into account the electrical-mechanical efficiency of the electric motor starting system, and the electrical resistance of connecting cables between battery and motor.

In these circumstances, the voltages specified are those which the battery has to provide at its own terminals, and this is also the basis upon which Nickel-Cadmium battery Performance Data is presented in Chapter 4.

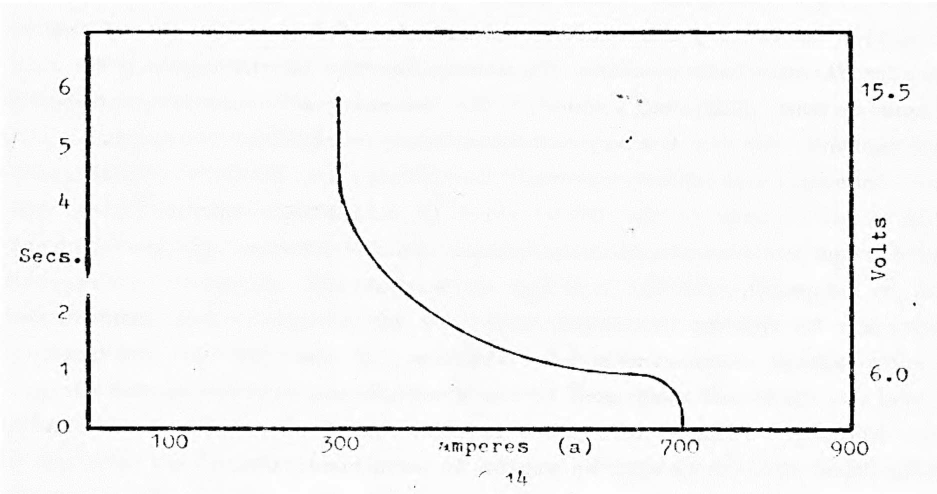


Fig. 6.14 is the form in which Engine Starting is expressed graphically. In this typical case it conveys that if a 24 Volt battery can provide 700 amperes at a terminal voltage of 6.0 volts for BREAKAWAY, followed without interruption by 300 amperes at 15.5 volts for the next 5 seconds, then the engine will be accelerated to a speed in RPM at which it will FIRE and continue to run. The ratio between BREAKAWAY and FIRING currents is usually of the order of 3 to 1.

The electric motor, the battery and the DC Source for charging the battery, form a SYSTEM, which is illustrated diagrammatically in Fig. 6.15.

In operation, the battery is switched to the motor for as long as is necessary for the engine to FIRE; afterwards it is switched to the DC Source for recharging.

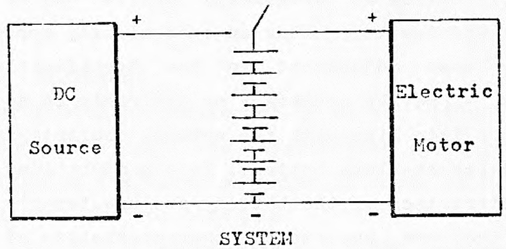


Fig. 6.15

The number of cells N, and the numerical value for the ampere hours capacity C for the battery are determined from Duty Specification details which are provided by the designers of the DC Source and the electric motor.

These are -

DC Source	- SYSTEM DC Voltage	- V
	Operational Mode	- FLOAT or FLOAT-CHARGE
Electric motor	- BREAKAWAY volts	- bV
	amperes	- ba
	FIRING volts	- fV
	Amperes	- fa

If V is a FLOAT Voltage, number of cells N = V/1.40

Alternatively -

If V is a FLOAT-CHARGE Voltage, number of cells N = V/ (1.47/1.53)

The calculation of a numerical value for C is in two stages

The ampere hours capacity bC needed for BREAKAWAY

and -

The ampere hours capacity fC needed for FIRING

The numerical value calculated for bC will not necessarily be the same as that calculated for fC; in these circumstances the higher value of the two is chosen as the numerical value for C, the ampere hours capacity of the battery. The justification is that in passing from BREAKAWAY to FIRING, the change in State-of-Charge of the battery is negligible, accordingly the higher numerical value as between bC and fC will meet both BREAKAWAY and FIRING.
The Duty Specification as originally drafted may be beyond the capability of Nickel-Cadmium to provide an economically approved installation.
Accordingly, some adjustment to the Specification details - voltages and currents - may be necessary or desirable so as to bring the Duty Specification more into line with the natural characteristics of the Nickel-Cadmium Vented Pocket-Plate battery. In considerations of this kind the electrical characteristics of the battery are unalterable and need to be calculated for what they are, whereas the characteristics of the electric motor can be modified by suitable changes to its design.
Fig. 4.6 Chapter 4. Discharging is appropriate for the calculation of numerical values for bC and fC where the battery is 100 % Charged when engine starting takes place.
If, however, the battery is expected to be Partially Discharged when engine starting takes place, then Fig. 4.8 Chapter 4, Discharging is appropriate for the calculation.
In each case, bV and fV need to be expressed as Volts-per-cell, bV/N and fV/N respectively, and since the Duty Specification is in the AMPERE SECOND category, the natural choice of cell design is THIN-PLATE.

BATTERY 100 % CHARGED

Fig. 4.6 has been reproduced here as Fig. 6.16 for ease of reference and explanation.

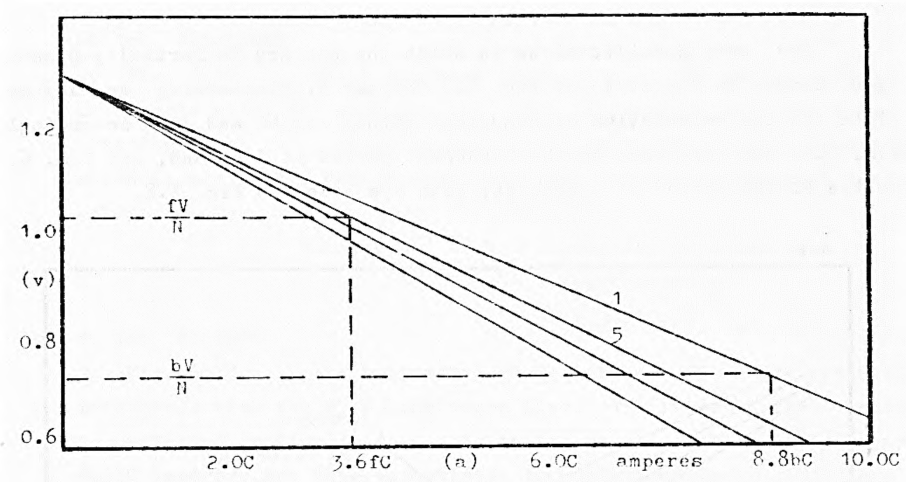


Fig. 6.16

bC for BREAKAWAY
The horizontal projection of bV/N on the ordinate intersects with the 1 second Line, and the intersecting point is projected vertically downwards to the baseline which it meets at 8.8bC amperes, and this establishes the relationship

ba amperes =	8.8bC amperes, in which case
bC =	bA/8.8 ampere hours

fC for FIRING
The horizontal projection of fV/N on the ordinate intersects with the 5 second Line, and the intersecting point is projected vertically downwards to the baseline which it meets at 3.6fC amperes, and this establishes the relationship

fa amperes =	3.6fC amperes, in which case
fC =	fb/3.6 ampere hours

If bC is greater than fC	bC = C
If fC is greater than bC	fC = C

In the event, however, of an unreasonably large difference between the numerical values calculated for bC and fC, a reappraisal of the Duty Specification is desirable, in order to bring the numerical values as near to equality as possible.

For Duty Specifications in which the battery is Partially Discharged, Graphs in the style of Fig.4.8 Chapter 4 Discharging are appropriate for the calculation of numerical values for bC and fC. Accordingly, Fig. 6.17 has reference to the BREAKAWAY period of 1 second, and Fig. 6.18 to the FIRING period of 5 seconds; both are based on Fig. 4.8.

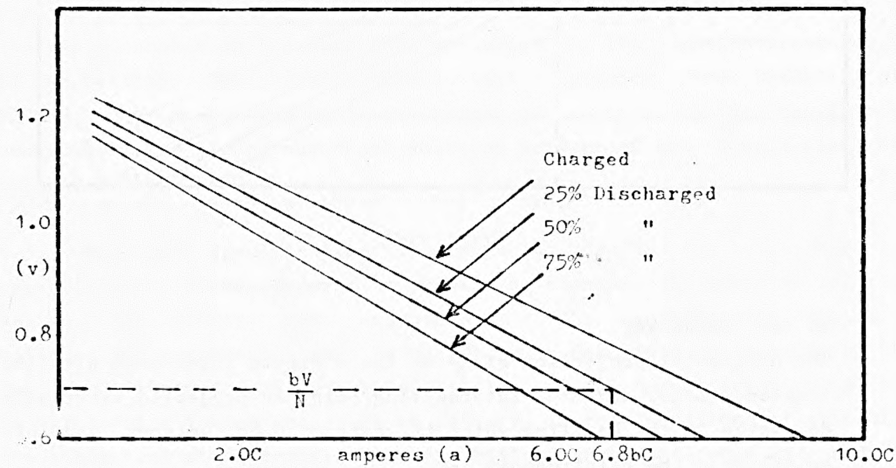


Fig. 6.17

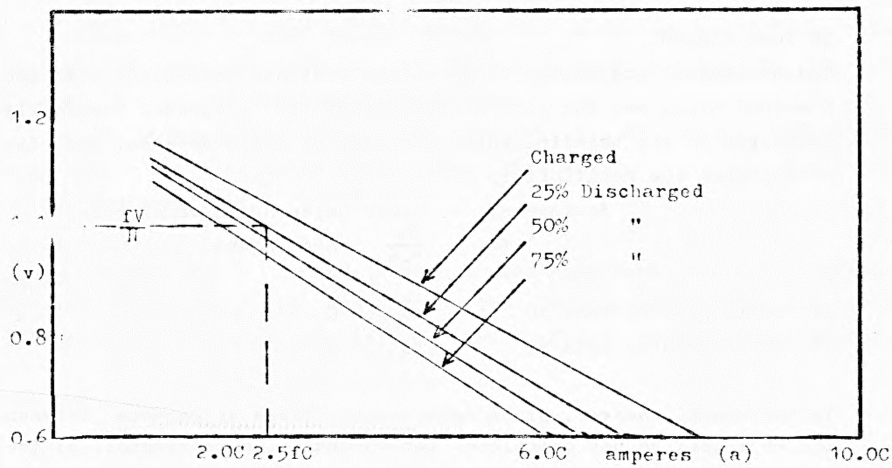


Fig. 6.18

bC for BREAKAWAY

In Fig. 6.17 the horizontal projection of bV/N on the ordinate intersects with, for example, the 25% Discharged Line. The intersecting point is projected vertically downwards to the baseline which it meets at 6.8bC amperes, and this establishes the relationship -

ba amperes	= 6.8bC amperes, in which case
bC	= ba/6.8 ampere hours

fC for FIRING

In Fig. 6.18 the horizontal projection of fV/N on the ordinate intersects with the 25 % Discharged Line. The intersecting point is projected vertically downwards to the baseline which it meets at 2.5fC amperes, and this establishes the relationship –

fa amperes	= 2.5 fC amperes, in which case
fC	= fa/2.5 ampere hours

If bC is greater than fC	bC = C
If fC is greater than bC	fC = C

In the event, however, of an unreasonably large difference between the numerical values calculated for bC and fC, a reappraisal of the Duty Specification is desirable, in order to bring the numerical values as near to equality as possible.

Some engines need to be started in temperatures below NORMAL, and which are defined as LOW, with the battery at the same temperature as the engine.

At LOW temperatures more energy needs to be provided by the Starting System to rotate the engine to FIRING speed than at NORMAL temperature. This means an increase in the RATED ampere hours capacity for the battery for two reasons

- Higher currents are required for BREAKAWAY and FIRING and

- The reduced Discharge Performance of Nickel-Cadmium Vented Pocket- Plate cells at LOW temperatures, for example, Fig.4.14 in Chapter 4 Discharging.

It is necessary, therefore, for the Duty Specification to indicate the temperature at which engine starting is required, and to quote the BREAKAWAY and FIRING voltages and currents applicable to that temperature, so that the battery size is chosen from Discharge Performance Data which is appropriate to the temperature.

The arrangement shown in Fig. 6.15 is basic only; typical SYSTEMS as used in industry are set out diagrammatically in Fig. 6.19 for a STATIONARY Installation, and in Fig. 6.20 for a MOBILE Installation.

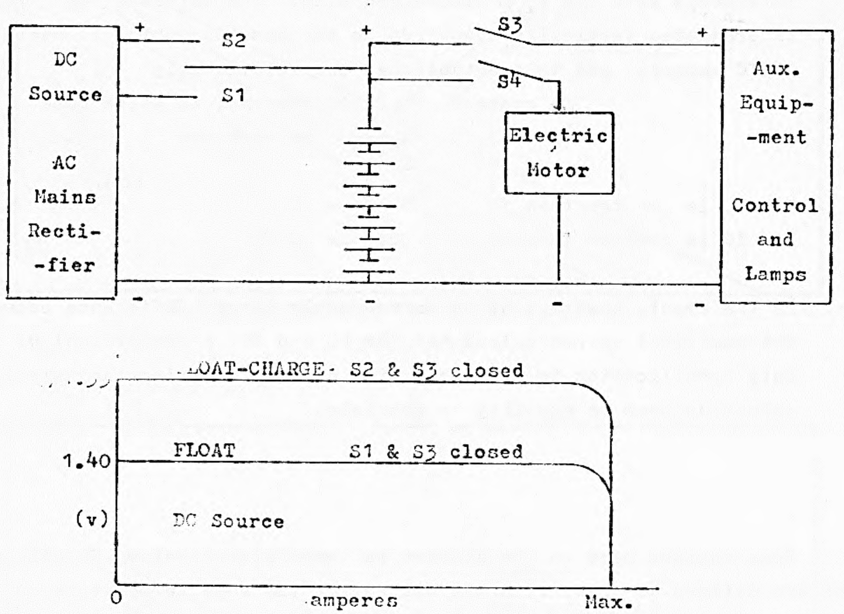


Fig. 6.19

Fig. 6.19 is a SYSTEM arrangement which is typical of a STATIONARY Installation, as this has been defined. The purpose of the battery is to start the diesel engine, which is likely, for example, to drive a Generator or Alternator to provide KW's of electrical power, or HP’s of mechanical power, for industrial purposes. Auxiliary equipment consists of control-gear and indicating lamps, requiring only a few amperes of current.

Prior to closing switch S4 to connect the battery to the electric motor in order to start the engine, the auxiliary equipment is energised from the battery by closing switch S3, and which is kept closed all the time the engine is running.
After the engine has started, the motor is disconnected and switch S2 is closed to recharge the battery from the DC Source, in the Operational Mode of FLOAT-CHARGE, Fig. 5.24 Chapter 5 Charging.
When recharge is complete, Switch S1 is closed so as to transfer the battery to FLOAT - Fig. 5-20 Chapter 5. Charging - which is the normal Operational Mode whilst the DC Source is functioning.
This has the advantage of the lowest rate of water loss from the electrolyte in the cells, so that the need for replenishment is much less frequent, which means reduced maintenance.
In both positions of the switch the DC Source provides the current required by the auxiliary equipment.
Typically, for a SYSTEM with a nameplate voltage of 24 volts, the battery consists of 18 Nickel-Cadmium Vented Pocket-Plate cells, with a FLOAT voltage of 25, and a FLOAT-CHARGE voltage of 27.5.
An adjustment to the calculated Ampere hours capacity for the battery is necessary in order to suit the Operational Mode of FLOAT at 1.40 volts-per-cell. In these circumstances Application Engineering depends upon only 80 % of the RATED Ampere hours being available for useful discharge duty, as explained in Chapter 5- Charging, and in reference to Fig. 5.23.

Accordingly -, Calculated Ampere hours/0.8 = C.

In a typical STATIONARY Installation, the DC Source is an AC Mains - Rectifier, and designed for control and battery charging by the Constant-Voltage Limited-Current method. Numerical values for voltage and maximum DC amperes need to suit the number of cells N, the ampere hours-capacity of the battery C, and the amperes required by the auxiliary equipment.
The DC Source is therefore developed along the lines of Fig. 6.12 and Fig. 6.13 and as explained in the accompanying text; except that the FLOAT-CHARGE Operational Mode may be 1.53 instead of 1.47 volts.
It needs to be adequate to recharge the battery should it become deeply discharged, and it is specified by giving numerical values to the Constant-Voltage and to the Limited-Current.

Constant-Voltage -	1.47 x N where engine-starting is occasional and ample time is available for recharging. 1.53 x N where engine-starting is frequent and time available for recharging is shorter.
Limited-Current -	Equipment amperes plus 0.1C amperes minimum for recharging the battery.

Stationary engines and their batteries are usually housed within traditional buildings and areas where the ambient air temperature is substantially NORMAL at all times; in which case the Duty Specification quotes the BREAKAWAY and FIRING voltages and currents which are applicable to NORMAL temperature, and battery sizes are chosen from Discharge Performance Data relevant to 20°C/68°F.

For other installations it is the responsibility of the Duty Specification to indicate the ambient temperature and quote BREAKAWAY and FIRING voltages and currents which are applicable to that temperature, so that battery sizes are chosen from Discharge Performance Data appropriate to that temperature.

Fig. 6.20 is a SYSTEM arrangement which is typical of a MOBILE Installation, as this has been defined, and which can have particular reference to a Railway Locomotive in which a diesel-engine provides the power for propulsion of the train.

The engine is coupled mechanically to an electric generator - the Main Generator - the DC output of which is fed to traction motors which drive the wheel axles through reduction gearing. This is described as Diesel-Electric Propulsion.

The engine is rotated for starting by ‘motoring* the Main Generator; that is to say, the generator has a special winding which when fed with an appropriate DC voltage and current converts the generator temporarily into an electric motor.

The DC voltage and current for starting the engine in this way is supplied from a storage battery

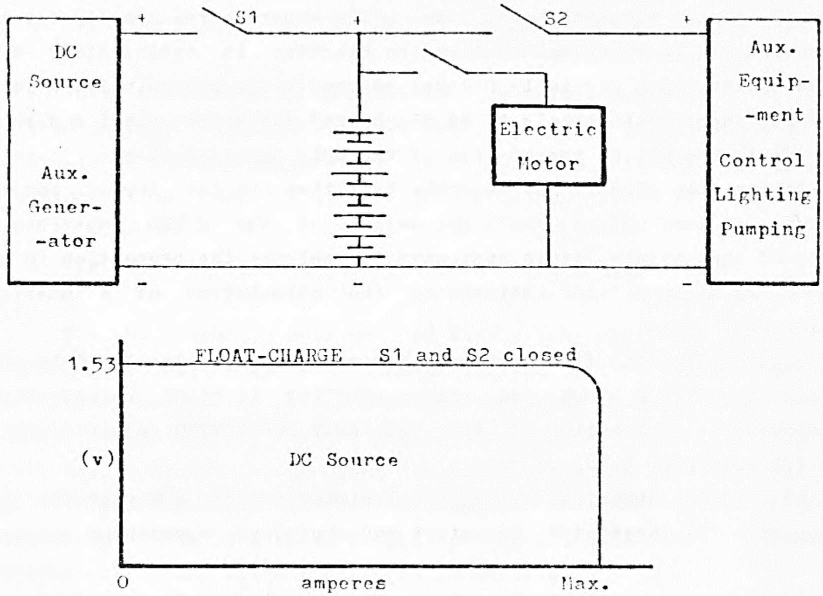


Fig. 6.20

Also coupled mechanically to the engine is a much smaller generator - the Auxiliary Generator - which is the DC Source for the control circuits, for excitation of the Main Generator, for lighting and for battery charging, whilst the engine is running.
The DC Source is regulated at a constant value of 7b volts or 110 volts. Both these SYSTEM voltages are in common use, and the choice is the prerogative of the locomotive builder.
Since the Installation is in the MOBILE category, automatic charging is a prerequisite for successful operation of the battery and the locomotive, in which case the Operational Mode is FLOAT-CHARGE and at 1.53 volts-per-cell, Fig. 5.24 Chapter 5. Charging.
For the 74 Volt SYSTEM, 48 Nickel-Cadmium Vented Pocket-Plate cells comprise the battery, and for the 110 Volt SYSTEM, 72 cells.
But the battery has other duties besides engine starting; these are in the pre-start period and in the period immediately following shut-down of the engine. In these periods the battery provides DC for control circuits and lighting, and for driving pumps; and the current may be required for up to 30 minutes.

Prior to starting the engine therefore, the battery has been discharged to some extent by pre-start and previous shut-down current requirements. In these circumstances, the RATED Ampere hours-capacity for the battery needs to be so chosen that engine starting is satisfactory even with the battery in a Partially Discharged condition; accordingly, a forecast of the ampere hours likely to be discharged during pre-start and shutdown is desirable during preparation of the Duty Specification.
At the same time, it is desirable that they are the lowest possible in number, and form only a small proportion of the RATED Ampere hours- capacity of the battery. It is customary to restrict the proportion to not more than 25 %% as a first estimate in the calculation of a numerical value for C.
Accordingly, the first estimate for a numerical value for C is such that when it is 25 % Discharged, engine starting is still satisfactory. This invokes the application of the BREAKAWAY and FIRING requirements to Fig. 6.17 and Fig. 6.18.
25 % of the numerical value so calculated is then a figure for comparison with the forecasted pre-start and shut-down ampere hour requirements.
If the forecast is equal or less, the numerical value for C already calculated is acceptable as the final choice of battery size.
If the forecast is greater, a reappraisal of the Auxiliary Equipment demands may effectively reduce the pre-start ampere hour requirement to at least equality with 25 % of C.

Alternatively, if reappraisal is not possible, an increase in the numerical value for the ampere hours capacity of the battery is necessary so that 25 % of the higher value is at least equal to the forecasted value pre-start and shut-down periods.

In any event, a judgment is necessary on the merits of each Installation, so that the smallest size of battery is selected, which is particularly desirable for MOBILE applications.

Immediately the engine has started, the battery is disconnected from the special winding on the Main Generator and is switched to the DC Source - the Auxiliary Generator - for recharging.
At the same time, the Auxiliary Generator takes over the control, lighting and pumping currents which were being supplied by the battery during the pre-start period. It also supplies DC for excitation of the

field windings of the Main Generator; a variable resistance in series with these windings regulates the amount of electrical power, which is delivered to the traction motors, and so control the speed of the locomotive.

While the engine is running, the Auxiliary Generator, the Battery and the Equipment which they serve are in parallel connection and form a SYSTEM with a common voltage at their terminals, and which is the FLOAT- CHARGE Operational Mode of 1.53 volts-per-cell, Fig. 5.24 Chapter 5.

Fig. 6.20 is a diagrammatic explanation of the SYSTEM.

The DC Source is designed to supply the Auxiliary Equipment, and to charge the battery by the Constant-Voltage Limited-Current method. The numerical value for the Maximum DC amperes needs to suit the ampere hours capacity of the battery and the amperes required by the Auxiliary Equipment; the DC Source is therefore developed along the lines of Fig. 5.12, Fig. 6.12 and Fig. 6.13, and as explained in the text which accompanies them, except that the FLOAT-CHARGE Operational Mode is 1.53 volts-per- cell, and the FLOAT Operational Mode is omitted.

The DC Source needs to be adequate to recharge the battery should it become deeply discharged and is specified by giving numerical values to the Constant-Voltage and to the Limited-Current.

Constant Voltage -	1.53xN
Limited Current -	Auxiliary Equipment Amperes plus 0.10C amperes minimum for charging

Mobile Installations operate in the OPEN-AIR and while the engine, equipment and battery are protected from the weather, they can assume the same ambient temperature as the outside air. This temperature can change between HIGH, NORMAL and LOW with the seasons, even between night-time and daytime in any season.

It is the responsibility of the Duty Specification to indicate the LOWEST ambient temperature likely to be encountered and to quote the BREAK - AWAY and FIRING voltages and currents applicable to that temperature, so that battery sines are chosen from Discharge Performance Data appropriate to that temperature.

Following the selection of the most suitable Nickel-Cadmium Vented Pocket-Plate Battery to meet the Duty Specification, a detailed Technical Description is prepared for the use of all concerned with the manufacture, installation and maintenance of the Battery and its DC Source.

The chosen cell is identified by the Type Number appropriate to its design and ampere hours capacity, typically from Fig. 2.8 Chapter 2. Mechanical Design. This Tabulation, which happens to refer to steel-cased cells in hardwood trays, provides relevant details on Battery dimensions and weight, so that suitable arrangements can be made delivery and installation.

Cell Type Number	-	AB-C-S
Ampere hour capacity	-	C
Number of cells	-	N
Number of cells in each tray	-	n
Number of trays	-	N/a
Dimensions	-	l mm x w mm x h mm for each tray L mm x W mm x H mm for the battery when the trays are placed side-by-side
Weight	-	kg for each tray
	-	Kg for the battery
Electrolyte	-	volume in each cell cc volume above plates cc height above plates mm
Charging	-	NORMAL 0.2C amperes for 7 hours at 1.40 to 1.70 volts x N
	-	SYSTEM Float / Float-Charge from a DC Source with a Limited-Current output of XC amperes at 1.40 / 1.47 - 1.53 volts x N

Switch Gear Control

Storage Batteries provide the DC electrical energy which operates the electro-mechanical devices which CLOSE and OPEN the heavy- -duty Switchgear which controls the distribution of AC Power over National Grid Networks.
A SWITCH consists of one set of contacts which can be moved to mesh with another and corresponding set of contacts, which are fixed, and so CLOSE an AC Power Circuit, in single or multi-phase; and be withdrawn to OPEN the Circuit.

These movements in either direction are controlled electro-mechanically by separate DC Solenoid Mechanisms energised by Storage Batteries and are initiated by manual push-button or remote automatic switching.
The closing movement is made by energising one solenoid against a powerful helical spring, which is then held compressed, by a latch, so that no further current is required from the battery once the SWITCH is closed.

To open the SWITCH, the latch is tripped by energising the other solenoid, and the stored mechanical energy in the compressed spring is released to separate the moving and fixed contacts positively and at high speed.
Because of the need to compress a powerful spring, a much larger amount of energy is required from the battery to close the SWITCH than to open it. The ratio between energy-to-close and energy-to-open is of the order of 100 to 1, in which circumstances the battery size is based upon the energy to close the SWITCH and no finite allowance is made for the energy required to open the SWITCH.

The battery is connected to a DC Source provided by an AC Mains Rectifier, and even when the DC Source is functioning, the battery provides the current - of the order of several hundred amperes - needed to energise the solenoids which close SWITCHES positively and rapidly, within 1 second of time. It is more economical to obtain currents of this magnitude from a rechargeable storage battery than from a DC Source which will by itself, provide these high value currents, and which are in the AKPERE3EC0NDS category of the Application Spectrum.

It is regular engineering practice, as well as being economical, for the same battery to serve several SWITCHES in the same location. In addition, two or more SWITCHES may require to be closed simultaneously,

in which ease the battery needs to provide the appropriate high value current. Again, the battery may have to clone a group of SWITCHES not necessarily requiring the same solenoid current value; typically, upwards of 10 closings each of 1 second duration and at 5 second intervals.
Moreover, the battery provides the energy for closing and opening during periods when for some reason the DC Source has temporarily ceased to function.

The main purpose of the DC Source is to charge the battery, but it has an auxiliary purpose as well, and this is to provide current to low- -voltage coloured switchboard lamps which indicate SWITCH positions Red for Closed, Green for Open - and to relays and manual switches associated with SWITCH-Control. These duties are also served by the battery whilst the DC Source is temporarily not available.

The DC Source, the Battery and the Auxiliary Equipment are in parallel connection and form the SYSTEM which is illustrated diagrammatically in Fig. 6.21.

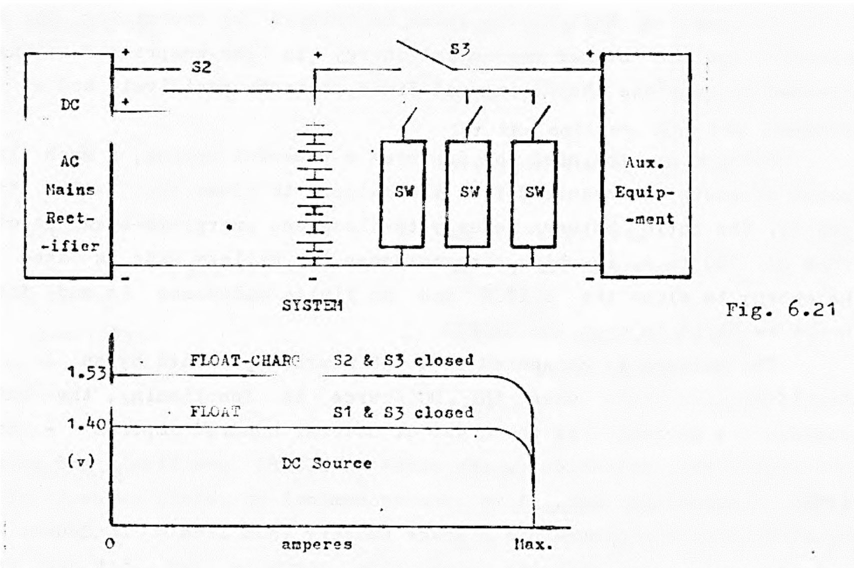


Fig. 6.21

While the DC Source is functioning, the normal Operational Mode in FLOAT. This has the advantage of the lowest rate of water loss from the electrolyte in the cells, so that the need for replenishment is less frequent, which makes for reduced maintenance.
For charging the battery following reinstatement of the DC Source after a prolonged failure, the Operational Mode is changed temporarily to FLOAT-CHARGE by manual or automatic switching.
The day-to-day closing and opening operations are unpredictable in frequency, but are acceptable during FLOAT, since they discharge the battery by only a small percentage of its Ampere hours-Capacity, which is soon replaced by a maintenance procedure which changes FLOAT to FLOAT- - CHARGE for a few hours, at regular intervals, in the order of several weeks, by manual or automatic switching.

For Switch Solenoids and Auxiliary Equipment, 110 Volts DC and 220 Volts DC are in universal use as Nameplate Voltages. Their highest permissible operating Voltages are 140 and 280 respectively, and these are adopted for SYSTEM FLOAT-CHARGE Voltages.
Accordingly, the Operational Mode for the purpose of selecting the number of cells is 1.53 volts-per-cell.
In which case
92 cells for the 110 Volt battery
When Charged, the battery is switched to the Operational Mode of FLOAT, at 1.53 volts-per-cell.
In which case –

140 volts / 1.53 volts = 92 cells for the 110-volt battery
and
280 volts / 1.53 volts = 184 cells for the 220-volt battery

When charged, the battery is switched to the operational mode of FLOAT, at 1.40 volts per cell.
In which case -

FLOAT = 129 volts for the 92-cell battery
and = 258 volts for the l84 cell battery

These voltages are at the battery terminals, and are applicable to all three cell designs, THIN, MEDIUM and THICK-Plate.
The Ampere hours Capacity is related to the period of time for which the battery is expected to provide current to the Auxiliary Equipment, and to the incidence and number of SWITCH closings, whilst the DC Source is temporarily not available.

The time period is usually specific and in terms of several hours and the incidence of the closings may be as a group or distributed haphazard over the period. Since there are so many possible variations it is customary to consider that they all occur at the end of the period, and to determine the Ampere hours Capacity for the battery on this basis.

Solenoids, if they are to operate positively and rapidly, require a DC voltage at their terminals, whilst the current is passing, which is within a defined lower limit of their Nameplate Voltage. This is generally 90 for a 110 Volt solenoid, and 180 for a 220 Volt solenoid.

Moreover, it is characteristic of Switch-Gear Installations that, while the Battery, the DC Source and Auxiliary Equipment are close together in the physical sense, the Switches themselves may be some distance away, many metres in some cases.

In these circumstances, the voltage-drop in long connecting cables between the battery and the solenoids may be appreciable and need to be allowed for so that the voltage at the solenoid terminals is not below the minimum necessary for satisfactory Closing of the Switch.

Accordingly, the battery terminal voltage is to be the voltage required at the solenoid, plus the voltage-drop in the connecting cables.

While the lowest voltage permissible at the solenoid can be quoted precisely, there may be some difficulty in prescribing the battery terminal voltage, in view of the diverse environmental circumstances in which Switchgear is installed.

It has become conventional therefore to create Three Standards of Reference, and these relate to the electrical performance of the Nickel- Cadmium Vented Pocket-Plate cell itself.

These Standards are the Discharge Voltages 1.14,1.10 and 1.05.

For 92 cells the corresponding battery terminal voltages are -

105, 100 and 96.

For 184 cells the corresponding battery terminal voltages are -

210, 200 and 192.

It is the responsibility of the Duty Specification to indicate which of these voltages is appropriate, the decision being related to the length and size of connecting cables between Switchgear and Battery, and the magnitude of the currents which they have to carry. Where their length is short, 96 and 192 volts respectively are probably acceptable, otherwise 105 and 210 volts may be necessary at the battery terminals, so as to

provide not less than 90 and 180 volts respectively at the terminals of the solenoids, whilst the closing currents are passing.
These voltages are applicable to all three cell designs, THIN, MEDIUM and THICK-Plate.

Each Duty Specification needs to provide relevant details of the proposed Switch-Gear Installation so that the Ampere hours capacity for the battery can be calculated. Typical Details are –

Nameplate DC voltage		-	110
Highest permissible Operating DC voltage		-	140
Lowest permissible DC voltage at battery terminals		-	100
Maximum Closing current for 1 second	amperes	-	150
Number of Switches to be Closed consecutively at 1	Minute intervals	-	30
Switchboard current	amperes	-	4
Duration of failure of DC Source	hours	-	5
Operational Mode	FLOAT volts	-	129
	FLOAT-CHARGE volts	-	140
Number of cells in the battery		-	92

The Performance required from the battery during the period when the DC Source is not available is set out graphically in Fig. 6.22 for ease of reference and explanation and is marked “Specification”. The ordinate is battery terminal voltage, the baseline is scaled in Hours to 5 hours, and in seconds from 5 hours onwards. The voltage of 129 at zero hours indicates that the battery is in the Operational Mode of FLOAT at time of failure of the DC Source.

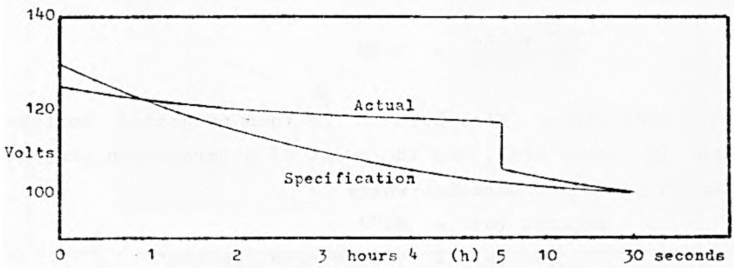


Fig. 6.22

The battery - 92 Nickel-Cadmium Vented Pocket-Plate cells - needs to have sufficient residual ampere hours so that after providing amperes for 5 hours to the Switchboard, which totals 20 ampere hours, it is capable of Closings, each of 150 amperes, without the battery terminal voltage falling at any Time below 100 volts.
For calculation purposes, the 30 1 second Closings at 1-minute intervals are compounded into a continuous period of 30 x 1 sec. = 30 seconds; but the current is still 150 amperes, and the lowest voltage is still 100.
The residual ampere hours needed are obtained from Fig. 4.6 Chapter 4. Discharging, and which is reproduced here as Fig. 6.23.

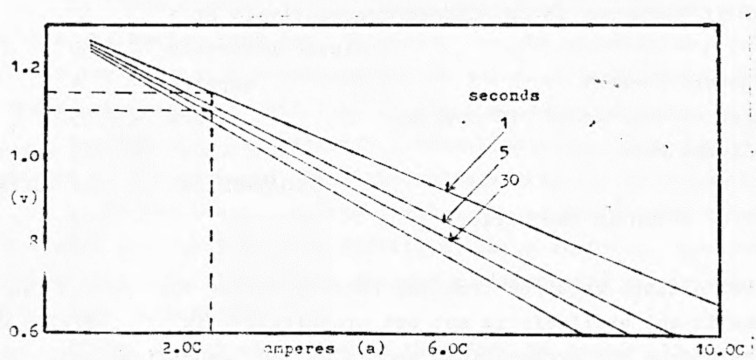


Fig. 6.23

So as to be applicable to Fig. 6.23 the Lowest permissible voltage of the Duty Specification is converted to Volts-per-cell.

100 volts / 92 cells = 1.10

on the ordinate of Fig. 6.23 is then projected horizontally to meet the 30 second Line, and the point of intersection projected vertically downwards meets the baseline where

amperes (a)	= 2.5C
but (a)	= 150 amperes, so that
C	= 150/2.5
	= 60 which are the residual ampere--hours

necessary for Closing the Switches.

The point of intersection has also been projected vertically upward to meet the 1 second Line, and this intersection projected Horizontally to the ordinate, where it reads 1.14 volts-per-cell, which is 105 volts for 92 cells.

The battery voltage during the 1st. Closing is therefore 105 volts, and during the 30th. Closing, 100 volts.

The first estimate for the number of Ampere hours to meet the Duty Specification is

20 for the Switchboard ♦* 60 for Closing = 80 ampere hours.

This result needs confirmation that at any moment during the total period of 5 hours 30 minutes, the battery terminal voltage does not fall below 100 volts, which is 1.10 volts-per-cell.
The Switchboard current of amperes is now being provided by 80 ampere hours, in which case in the relationship -

amperes (a)	= C/(h)
when (a)	= 4 amperes
and C	= 80 Ah
then (h)	= 80/4 = 20 hours
and b amperes	= C/20 amperes

Accordingly, the Switchboard current discharges the battery at amperes, but for 3 hours only.

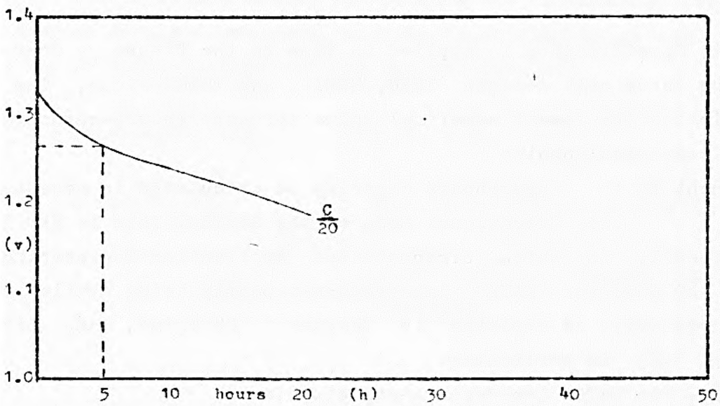


Fig. 6.24

The Discharge Characteristic at C/20 amperes in Fig. 4.4 Chapter 4. Discharging is reproduced for easy reference and explanation, as Fig. 6.24.

In Fig. 6.24 5 hours on the baseline is projected vertically upward to intersect the C/20 curve, and the point of intersection is projected horizontally to meet the ordinate. It reads 1.26 volts-per-cell, which is 116 volts for the 92-cell battery and is substantially above the Lowest permissible voltage of 100. This is advantageous in that the brilliance of the Switchboard lamps is sustained. At zero hours the volts-per-cell is 1.32, which is 122 volts for the 92-cell battery.
The performance of 80 ampere hours is superimposed graphically on to Fig. 6.22 and is marked ’Actual’ in order to compare it with the 'Specification’.

The battery terminal voltage drops from the Operational Mode of FLOAT at 129 volts to 122 volts when the Switchboard current starts, and by the end of 5 hours it has fallen to 116 volts. The Closings start immediately after the 1st. Closing the battery voltage drops to 105 and is the 30th. and last values.

This therefore confirms that 92 Nickel-Cadmium Vented Pocket-Plate cells of 80 ampere hours capacity will provide 4 amperes for 5 hours, then 150 amperes for 1 second repeated 30 times at 1 minute intervals, without the battery terminal voltage falling below 100 volts; the cells having the Discharge Characteristics represented by Fig. 4.4 and Fig. 4.6 Chapter 4. Discharging.

If the Duty Specification is applied in turn to the Discharge Characteristic of the three cell designs THIN, MEDIUM, and THICK-Plate, the design which indicates the lowest numerical value for Ampere hours capacity will be the most economical choice

An adjustment to the ampere hours capacity so calculated is necessary for the Operational Mode of the SYSTEM. This is FLOAT at 1.40 volts-per-cell, in which circumstances Application Engineering relies upon only 80 % of the RATED Ampere hours capacity being available for useful discharge duty, as explained in Chapter 5- Charging, and in reference to Fig. 5.23 in particular. Accordingly, the RATED Ampere hours capacity is -

80 ampere hours / 0,8 = 100 ampere hours

While the standard approach to Multiple Duty Specifications is by the method described in the text with reference to Fig. 6.7 and Fig- 6.8 this is not always feasible or necessary; especially where there are only Two Duties in the Specification, and where the currents and times differ widely in value.

Specifications relating to Switch-Gear Duties are cases in point, and Fig. 6.22, Fig.6.23 and Fig. 6.24 with their associated text explain the simpler and more direct approach to calculating a numerical value for Ampere hours capacity; and being less rigorous than the method described in Fig. 6.7 and Fig. 6.8 the numerical value is likely to be higher, but it can provide a useful margin of safety in battery size.

The DC Source provided by the AC Mains-Rectifier is designed to supply the Auxiliary Equipment, and to charge the battery by the Constant- Voltage Limited-Current method. The numerical value for the Maximum DC amperes needs to suit the Ampere hours capacity of the battery and the amperes required by the Auxiliary Equipment; the DC Source is therefore developed along the lines of Fig. 6.12 and Fig. 6.13 and as explained in the associated text; except that the FLOAT-CHARGE is 1.53 volts-per-cell. Fig. 6.21 is a diagrammatic explanation of the SYSTEM.

The DC Source needs to be adequate to recharge the battery should it become deeply discharged and is specified by giving numerical values to the Constant-Voltage and the Limited-Current.

Constant-Voltage	-	1.53 x N
Limited-Current	-	Auxiliary Equipment amperes plus 0.1C amperes minimum for charging

When Charged, the battery is switched back to the Operational Mode of FLOAT at 129 volts. The current available to the Charged battery is now very much reduced, which is the intention, while the Switchboard current is still being provided by the DC Source.

Switch-Gear Batteries and Auxiliary Equipment are usually housed in traditional buildings and areas where the ambient air temperature is substantially NORMAL at all times; with the Switches in the OPEN and at the same temperature as the surrounding air, which may be LOW, NORMAL or HIGH according to the season and time of day.

It is the responsibility of the Duty Specification to indicate the LOWEST ambient open-air temperature likely to be encountered and to quote the Solenoid Closing and Opening currents applicable to that temperature; although battery sizes are chosen from Discharge Performance Data appropriate to the inside temperature of the building.

Following the Selection of the most suitable Nickel-Cadmium Vented Pocket-Plate Battery to meet the Duty Specification, a detailed Technical Description is prepared for the use of all concerned with the manufacture, installation and maintenance of the Battery and its DC Source.

The chosen cell is identified by the Type Number appropriate to its design and ampere hours capacity, typically from Fig. 2.8 Chapter 2. Mechanical Design. This Tabulation, which happens to refer to steel-cased cells in hardwood Trays, provides relevant details on battery dimensions and weight, so that suitable arrangements can be made for delivery and installation.

Cell Type Number	-	AB-C-S
Number of Cells	-	N
Ampere hours-capacity	-	C
Number of cells in each tray	-	n
Number of trays	-	N/n

Dimensions	-	1 mm x w mm x h.mm for each tray L mm x W mm x H mm for the battery when the trays are placed side-by-side
Weight	-	kg for each tray Kg for the battery
Electrolyte	-	volume in each cell cc volume above plates cc height above plates mm
Charging	-	NORMAL 0.2C amperes for 7 hours at 1.40 to 1.70 volts x N SYSTEM Float / Float-Charge from a DC Source with a Limited-Current output of XC amperes at 1.40 / 1.47 - 1.53 volts x N

Rapid-Transit Rail Cars

Rapid-Transit Rail Cars are passenger carrying coaches which run on steel track rails and are driven by self-contained electric traction motors. These motors receive power either from the track rails or from a cable suspended above and in the same direction as the track. 65O and 1500 are commonly used voltages where the power is DC and supplied from the track, and 25iOOO volts single-phase 50 Hz where the power is AC and supplied from the overhead cable.

Each Rail Car is provided with a Low-Voltage DC Source derived from the traction power supply. Its purpose is to provide for Interior and Marker Lighting. Telecommunications and the Control of auxiliary equipment such as Brake-gear, Door-opening and closing, and Switchgear; these comprise a Low-Voltage DC Circuit.

Low-Voltages in common use are volts and 110 volts, obtained DC / DC motor-generators or from AC / DC static-rectifiers, mounted on the car.

A storage battery is permanently connected across the Low-Voltage DC Circuit, and its function is to provide current to this whenever the Low-Voltage DC Source fails for any reason during service running.

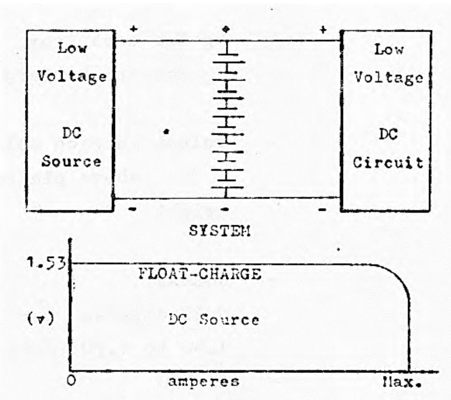


Fig. 6.25

After fulfilling this Standby function, the battery is recharged automatically, that is without manual intervention, from the same Low Voltage DC Source, when this has been restored, and concurrently with the DC Source resuming the supply of power to the DC Circuit.
The Low Voltage DC Source, the Battery and the Low Voltage DC Circuit are in parallel connection, and this arrangement comprises the SYSTEM which is shown diagrammatically in Fig. 6.25.
The DC Source is designed to supply the DC Circuit, and to charge the Battery by the Constant-Voltage Limited-Current method. The Constant - Voltage is the SYSTEM Voltage, and which is the maximum which can be tolerated by the Low-Voltage DC Circuit on the Rail Car.

Rail Cars do not usually operate continuously for the whole 24 hours in any day, and opportunities for the Battery to discharge can occur during periods when Cars are stationary and disconnected from their Power supply. The Battery may be used for lighting, testing and communications, with no recharging to compensate. But the operating circumstances are such that the Battery needs to be restored quickly to High State-of- Charge once service running is resumed, in which case it is FLOAT-CHARGED at the Operational Mode Voltage of 1.55 volts-per-cell which ensures rapid return to 80 % Charged and to 100 % Charged; this is particularly necessary after a Standby Duty has been fulfilled. The features of this Operational Mode are discussed in Chapter 5 Charging, and earlier in this Chapter.

In these circumstances –

For the 40 Volt SYSTEM	40 volts / 1.53 volts	= 26 cells
and –		
For the 110 Volt SYSTEM	110 volts / 1.53 volts	= 72 cells

These figures are applicable to all three cell designs, THIN, MEDIUM and THICK-Plate.

The Ampere hours-capacity is related to the period of Standby Time for which the Battery is expected to provide current to the Low Voltage DC Circuit, and to the magnitude and character of the current or currents which are included in the Duty Specification, which will also indicate the Lowest Voltage permissible at the Battery terminals during the Standby Period.

The Specification may include for one duty only – SINGLE DUTY - or two or more dissimilar duties - MULTIPLE-DUTY.
A Specification for a SINGLE-DUTY simply states numerical values for a Current in amperes, a Time in hours, and the Lowest-Voltage permissible at the end of the Standby Period.
This DUTY is then superimposed upon the appropriate Graph of Discharge Performance, Chapter 4. Discharging, and the numerical value for the Ampere hours capacity is determined by the principles explained in reference to Fig. 6.3.
Specifications for SINGLE-DUTIES are usually in the AMPERE HOURS category of the Application Spectrum, with THICK-Plate the most economical Cell design.
Specifications for MULTIPLE DUTIES state the numerical values for Current and Time for each separate Duty, and the Lowest-Voltage permissible at any given moment during the Standby Period.
Fig. 6.5, Fig. 6.7 and Fig. 6.10 are in the typical style of MULTIPLE-DUTY Specifications, and the principles of determining numerical values for Ampere hours capacity are explained in the text associated with these Graphs.

AMPERE HOURS and AMPERE SECONDS are possible categories in the Application Spectrum, and the most economical Cell design may be either THIN, MEDIUM or THICK-Plate, depending upon which category has the predominant influence.
The numerical value initially calculated for the Ampere hours capacity maybe acceptable though from the point of Battery bulk and weight; a smaller size may need to be used, with the wattage of lighting fittings permanently reduced to suit, or the total Equipment current requirements restricted in some way at times of failure or non-availability of the Low- Voltage DC Source.
Moreover, the larger the Ampere hours-capacity, the larger does the source need to be in terms of current, bulk and weight; this may also be unacceptably high in relation to the general design and layout of the Rail Car and its Equipment. A compromise may be necessary.

Nickel-Cadmium Vented Pocket-Plate Batteries in present day Rail Cars have Ampere hour capacities which range from 40 to 300, which indicates the lack of standardisation and the diverse nature of Duty Specifications as between different countries and in different locations in the same country.

The Low-Voltage DC Source is designed to supply the DC Circuit with current, and to charge the Battery by the Constant Voltage Limited Current method. The numerical value for the Limited-Current needs to suit the Ampere hours capacity of the Battery and the amperes required by the Equipment; the DC Source is therefore developed along the lines of Fig. 6.12 and Fig. 6.13 and as explained in the text which accompanies them; except that the FLOAT CHARGE Operational Mode is 1.53 volts-per-cell, and the FLOAT Operational Mode is omitted.

Fig. 6.25 is a diagrammatic explanation of the SYSTEM.

But a prerequisite is a rapid return to at least 80 % Charged after a deep discharge, in which case Time is the crucial factor in the choice of amperes for battery charging, and it is the function of the Duty Specification to indicate the Time period which is estimated to be available or acceptable.

The relationship between Amperes and Time-to-reach 80 % Charged is tabulated, for example in reference to Fig. 5.12 Chapter 5. Charging, and from which is extracted –

At 1.0C amperes	-	2.00 hours approximately
At 0.5C amperes	-	3.00 hours approximately

The DC Source is then specified by giving numerical values to. the Constant-Voltage and to the Limited-Current.

Constant-Voltage	-	1.53 x N
Limited-Current	-	Equipment amperes plus 0.50/1.0C amperes for charging

Rapid-Transit Rail Cars operate in the Open-Air and while the Battery and the Low-Voltage DC Source and Equipment are protected from the weather, they can assume the same temperature as the outside air. This temperature can change between HIGH, NORMAL and LOW with the seasons, even between night-time and daytime in the same season.

It is the responsibility of the Duty Specification to indicate the Lowest temperature likely to be encountered, so that battery sizes are chosen from Discharge Performance Data appropriate to that temperature.

Following the selection of the most suitable Nickel-Cadmium Vented Pocket-Plate Battery to meet the Duty Specification, a detailed Technical Description is prepared for use by all concerned with the manufacture, installation and maintenance of the Battery and its DC Source.
The chosen cell is identified by the Type Number appropriate to its design and amperehour6-capacity, typically from Fig. 2.8 Chapter 2. Mechanical Design. This Tabulation, which happens to refer to hardwood TRAYS, provides relevant details on battery dimensions and weight, so that suitable arrangements can be made for delivery and installation.

Cell Type Number	-	AB-C-S
Ampere hours capacity	-	C
Number of Cells	-	N
Number of Cells in each tray	-	n
Number of trays	-	N/n
Dimensions	-	1 mm x w mm x h mm for each tray
	-	L mm x W mm x H mm for the battery when the trays are placed side-by-side
Weight	-	kg for each tray Kg for the battery
Electrolyte	-	volume in each cell cc volume above plates cc height above plates mm
Charging	-	NORMAL 0.2C amperes for 7 hours at 1.40 to 1.70 volts x N SYSTEM Float-Charge from a DC Source with Limited-Current output of XC amperes at 1.53 volts x N

Road Rail Crossing Protection

Where Motor-Roads and Railroads cross each other on the same level, means are provided to indicate to approaching road-vehicles whether it is safe to continue and pass over the rail-tracks*
In the simplest arrangement, a visual warning of danger is given by red-lights and a swinging pendulum, augmented by an aural warning in the form of a bell; one set of Warning Equipment on opposite sides of the rail-track.
In a more elaborate arrangement, these signals are supplemented by Barriers, each a wooden Boom festooned with red-lights and pivoted at one end, which are lowered into the path of the Motor-Road traffic, compelling it to come to a standstill. The Booms are raised when the danger of collision between Rail and Road vehicles has passed, and the time duration of the operation is several minutes.

All the Equipment is electrically operated, and the warnings are initiated automatically by the leading Rail-Vehicle as it approaches the CROSSING and are cancelled by the last Rail-Vehicle as it leaves the CROSSING.
The electrical power to the Red-Lights, Pendulum, Bells and Boom operating mechanism is supplied by a Low-Voltage DC Source, commonly 12 or 24 Volt, consisting of an AC Mains-Rectifier.

A storage battery is permanently connected across the Low-Voltage DC Circuit, so as to provide power for the continued operation of the Warning Equipment, and without interruption, when for any reason the DC Source has failed.
When the DC Source has been restored, the battery is automatically recharged, that is without manual intervention, and concurrently with the DC Source resuming the supply of power to the Warning Equipment. In these circumstances the DC Source provides for battery charging by the FLOAT-CHARGE Constant-Voltage Limited-Current method.

The DC Source, the Battery and the Warning Equipment are in parallel connection, and they constitute the SYSTEM which is illustrated diagrammatically in Fig. 6.26. The Battery is FLOAT-CHARGED at an Operational Mode Voltage which is compatible with the Equipment style and the environmental circumstances.

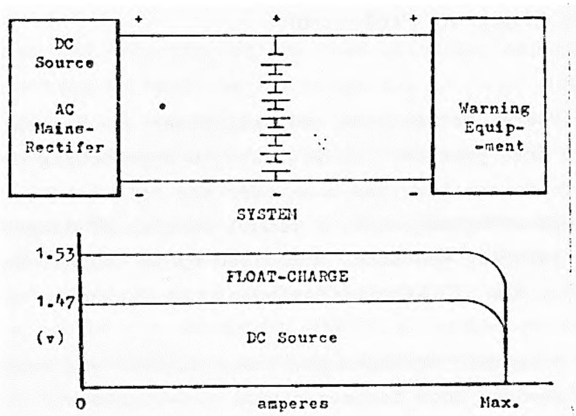


Fig. 6.26

The simplest Warning arrangement - Red-Lights, Pendulum and Bell - may be adequate for remote areas where Road and Rail traffic flow is infrequent; in which case long periods of time are available for charging the Battery following failure of the DC Source, and charging currents of low relative value can be used.

The Operational Mode of 1.47 volts-per-cell is acceptable for long term charging and at this voltage a high State-of-Charge can be reached and maintained with a low rate of water loss from the cells, and which contributes towards minimum maintenance.

In areas where Road and Rail traffic flow is frequent, the more elaborate arrangement of Boom, Pendulum, Red-Lights and Bell is installed. The crucial consideration for maximum reliability is to ensure that the Battery is returned quickly to high State-of-Charge following a failure of the DC Source. this requires charge currents of higher relative value, and FLOAT-CHARGE Operational Mode Voltage; 1.53 volts-per-cell is desirable in these circumstances.

The Rated Ampere hours capacity for the Battery needs to be sufficient to meet the power requirements of the Warning Equipment over the period of failure of the Low-Voltage DC Source.

A crucial consideration in preparing the Duty Specification is the estimate of the possible duration of the failure period, and of the number of Warning operations to be allowed for during the period. It is common practice to regard 24 hours as a reasonable period, and it allows time for

a visit by maintenance staff, if necessary.
For the simplest Warning arrangement in a remote area, it is feasible to allow for one operation every hour, which is 24 operations over the 24-hour period. For the more elaborate Warning arrangement in a busy traffic area, the frequency is likely to be several operations every hour.

Details of a Typical Installation of Red-Lights, Pendulums and Bells are

Nameplate DC Voltage	- 24 volts
Highest Permissible Operating DC Voltage	- 30. volts
Lowest Permissible DC Voltage at Battery terminals -	- 22 volts
Average Operating current	- 15 amperes
Number of Operations per hour each lasting 5 minutes	- 1
Duration of failure of DC Source	- 24 hours
Operational Mode	- FLOAT-CHARGE

The appropriate Operational Mode Voltage is 1.47 volts-per-cell, in which case the number of cells will be 30/1.47 But 130/1.47 = 20.4 which is not a whole number as the figure needs to be. The nearest is 20 cells, which when FLOAT-CHARGED at 1.47 volts-per-cell gives 29.4 volts, and which becomes the Operational DC Voltage of the SYSTEM.

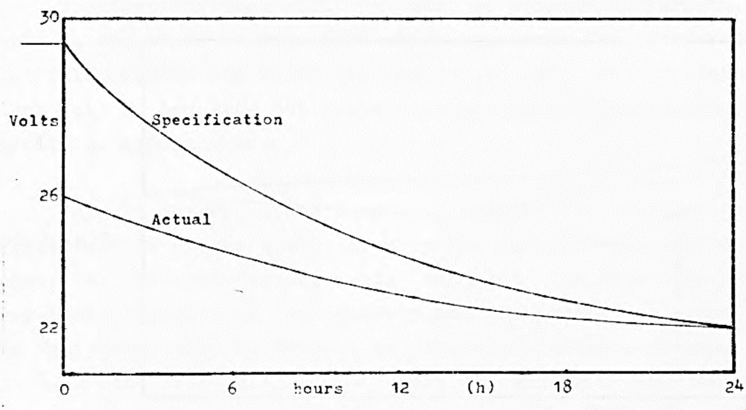


Fig. 6.27

The Performance required from the Battery during the period when the DC Source is not available is set out graphically in Fig. 6.27 and is marked 'Specification'. The ordinate is Battery voltage, the base4ine is scaled in hours to a maximum of 24. Once every hour, the Warning Equipment requires 15 amperes for 5 minutes, and at the end of 24 hours, the Battery terminal voltage is to be not less than 22.
In Fig. 6.27 the voltage at zero hours is 29.4, which indicates that at time of failure of the DC Source, the Battery is being FLOAT-CHARGED at the Operational Mode of 1.47 volts-per-cell.
For the purpose of selecting a numerical value for the ampere hours capacity to meet this Performance, the 24 5-minute Warnings are compounded into a continuous period of -

24 x 5 minutes
= 120 minutes
= 2 hours

The current is still 15 amperes, and the Lowest-Voltage still 22.
The equivalent of 2 hours, 15 amperes and 22 volts is then referred the appropriate Standard Cell Performance Data of Chapter 4.
Fig. 4.1 is appropriate and for ease of reference and explanation has been reproduced here as Fig. 6.28. So that its ordinate may be applicable, the Battery voltage needs to be converted to volts-per-cell which is

22 volts / 20 cells = 1.10

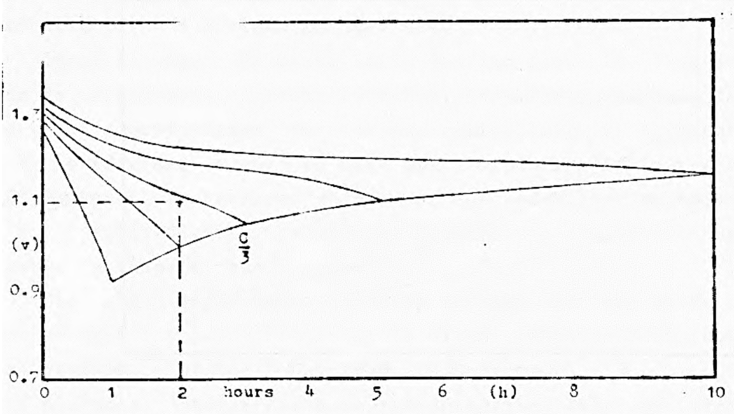


Fig. 6.28

In Fig. 6.23 1.10 volts-per-cell on the ordinate is projected horizontally to intersect with the failure period of 2 hours projected vertically upward from the baseline. The point of intersection falls close to the curve marked C/3 amperes.

Equating C/3 amperes with the Warning current of 15 amperes,

C = 45 ampere hours

The interpretation of this result is that a Nickel-Cadmium Vented Pocket-Plate Battery of 20 cells 45 ampere hours-capacity will provide 15 amperes for 5 minutes once every hour for 24 hours, without the terminal voltage falling below 22 volts; the battery in this case having the Discharge Characteristics of Fig. 4.1.

The Performance of 45 ampere hours capacity is the portion of the curve marked ~ amperes in Fig. 6.28 from zero hours to 2 hours. It is superimposed on Fig. 6.27 in decompounded form to show 1 Warning operation per hour for 24 hours and is marked 'Actual' in order to compare it with the 'Specification'. The Battery terminal voltage drops from the Operational Mode of FLOAT-CHARGE at 29.4 volts when the DC Source fails; thereafter it falls gradually to 22.0 volts after 24 Warnings have been given.

The Specification will, however, be applied in turn to the separate Graphs in the style of Fig. 6.28 which represent the Performance of cells with THIN, MEDIUM and THICK-Plates; these will show different numerical values for C, and from which the most economical Design and ampere hours capacity will be chosen.

The DC Source is designed to supply the Warning Equipment with current, and to charge the Battery by the Constant-Voltage Limited-Current method. The Limited-Current needs to suit the numerical value of the ampere hours capacity of the Battery and the amperes required by the Warning Equipment; the DC Source is therefore developed along the lines of Fig. 6.12 and Fig. 6.15 and as explained in the accompanying text; except that the Operational Mode Voltage may be 1.53 instead of 1.47, and the FLOAT Operational Mode is omitted. Fig. 6.26 is a diagrammatic explanation of the SYSTEM.

The DC Source needs to be adequate to recharge the battery after it has become deeply discharged; it is specified by giving numerical values to the Constant-Voltage and to the Limited-Current.

Constant Voltage	-	1.47 x N where there is ample time for recharging 1.53 x N where rapid recharging is desirable
Limited-Current	-	Equipment amperes plus 0.1C amperes minimum for charging

Road-Rail Warning Equipment operates in the Open-Air and while the DC Source, Control-Gear and Battery are protected from the weather, they can assume the same temperature as the outside air. This temperature can change between HIGH, NORMAL and LOW with the seasons, even between night-time and daytime in any season.

It is the responsibility of the Duty Specification to indicate the LOWEST temperature likely to be encountered, so that battery sizes are chosen from Discharge Performance Data appropriate to that temperature.

Following the selection of the most suitable Nickel-Cadmium Vented Pocket-Plate Battery to meet the Duty Specification, a detailed Technical Description is prepared for the use of all concerned with the manufacture, installation and maintenance of the Battery and its DC Source.

The chosen cell is identified by the Type Number appropriate to its design and Ampere hours Capacity, typically from Fig. 2.8. Chapter 2. Mechanical Design. This Tabulation, which happens to refer to steel-cased cells in hardwood TRAYS, provides relevant details on battery dimensions and weight, so that suitable arrangements can be made for delivery and installation.

Cell Type Number	-	AB-C-S
Ampere hours Capacity	-	C
Number of cells	-	N
Number of cells in each tray	-	n
Number of trays	-	N/n
Dimensions	-	1 mm x w mm x h mm for each tray L mm x W mm x H mm for the battery when the trays are placed side-by-side
Weight	-	kg for each tray Kg for the battery
Electrolyte	-	volume in each cell cc volume above plates cc height above plates mm
Charging		NORMAL 0.2C amperes for 7 hours at 1.40 to 1.70 volts x N SYSTEM Float-Charge from a DC Source with Limited-Current output of XC amperes at 1.47/1 .53 volts x N

Static Inverters

An Inverter is a Static Unit which accepts DC Power and by means of semi-conductor devices, converts it to AC Power.
It enables Equipment which can function only from AC, to continue to operate during periods of non-availability of their normal AC Supply, from DC Power provided by a Storage Battery.
So that this Standby feature is constantly available, the Inverter is a permanent part of the power supply arrangements for the Equipment. That is to say, the Equipment is supplied even under normal circumstances from the AC output of the Inverter.

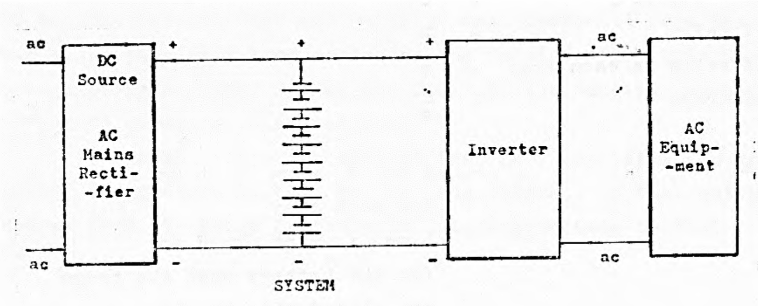


Fig. 6.29

The Equipment, Inverter, Battery and DC Source comprise a SYSTEM which is illustrated diagrammatically in Fig. 6.29.

The DC input to the Inverter is normally supplied by the DC Source which is the DC output of an AC Mains-Rectifier. The Storage Battery is connected across the DC Source, and when there is any interruption in power flow, the battery continues to supply the Inverter, and without a break.

The battery fulfils a Standby function, for Time Periods of 15 minutes, 30 minutes, 1 hour, 2 hours, 3 hours or as may be specified.

During the Standby, the Inverter characteristically draws DC Power from the Battery on a Constant-Watts basis. That is to say, as the Battery discharges and its terminal voltage falls, the current taken by the Inverter increases, so that the product of Voltage and Current, namely the Watts, remain substantially Constant.

Inverter SYSTEMS prefer the smallest possible fall in DC Voltage during transfer from the AC Mains-Rectifier to the Battery. This is arranged for by FLOATING the Battery at 1.40 volts-per-cell, and this is the Operational Mode of the SYSTEM.
The number of cells and a numerical value for the Ampere hours Capacity for the Battery are determined from the Duty Specification details which are provided by the designers of the Inverter, the AC Equipment and the DC Source. These are –

Inverter -	Nameplate DC Voltage	- Ve
	Highest permissible Operating DC Voltage	- Vmax
	Lowest permissible Operating DC Voltage	- Vmin
	Standby Period in hours or minutes	- (h) or (m)
	Average Standby DC Power in watts	- W
DC Source	Operational Mode	- FLOAT

Since the Operational Mode is FLOAT, the number of cells N is Vmax/1.40, and it is the same whether THIN, MEDIUM or THICK-Plate design is chosen for the Battery.

The numerical value for the Ampere hours Capacity is determined by reference to Fig. 4.13 Chapter 4. Discharging, and which for ease of explanation has been reproduced as Fig. 6.30.

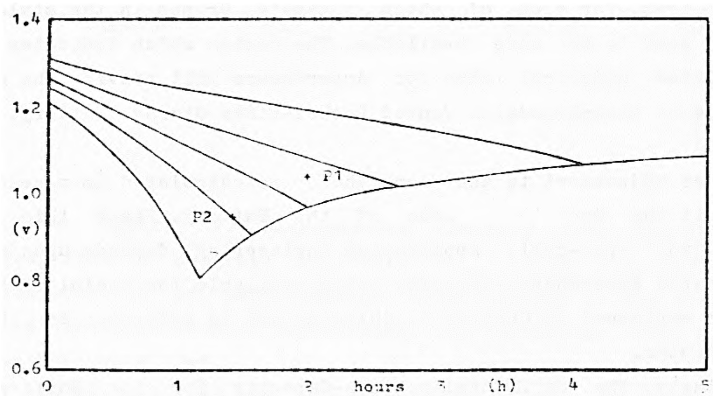


Fig. 6.30

So that Fig. 6.30 may be applicable, the Duty Specification details need to be converted into terms of Volts-per-cell and Watts-per-cell.

Volts-per-cell	Vmin	= Vmin/N
Watts-per-cell	w	= W/N

In Fig. 6.30 the volts-per-cell on the ordinate is projected horizontally to intersect with the Standby Period projected vertically upwards from the baseline. The point of intersection may or may not fall on one of the standard curves.
Point P1 for .example falls between two standard curves; in which case an interpolation is made to establish the numerical value - in watts-per-ampere hour - of the curve upon which the point lies.

The Watts-per-cell of the Duty Specification is equated with the numerical value of the curve upon which the point of intersection falls.

Point P2 for example is the intersection of 0.95 volts on the ordinate and 1.4 hours on the baseline, and falls on the curve representing 0.83 watts-per-ampere hour, in which case the numerical value for the Ampere hour Capacity is
Watts-per-cell from the specification/0.83 watts-per-ampere hour

This procedure is followed in reference to THIN, MEDIUM and THICK-Plate designs, for each of which separate Graphs in the style of Fig 6.3 need to be made available. The design which indicates the lowest calculated numerical value for Ampere hours will provide the most economical size of Nickel-Cadmium Vented Pocket-Plate Storage Battery.

A further adjustment to the Ampere hours so calculated is necessary in order to suit the Operating Mode of the Battery. Since this is FLOAT at 1.40 volts-per-cell, Application Engineering depends upon only 80 % of the Rated Ampere hours Capacity being available for useful Discharge as explained in Chapter 5 Charging and in reference to Fig.5.22 in particular.
Accordingly, the RATED Ampere hours Capacity for the Battery is

calculated ampere hours/0.8 = C

The DC Source F in Fig. 6.31 is designed to supply the Inverter with current at the Operational Mode Voltage, which is also the highest permissible Operating DC Voltage, Vmax = 1.40 x N.
But this is a FLOAT Voltage, and too low for battery charging, in which case an arrangement is adopted where a higher voltage is applied to the Battery, while the Inverter continues to be supplied with current at its Operational Mode Voltage, Vmax.
This is the scheme explained by Fig. 5.22 Chapter 5. and repeated for ease of reference as Fig. 6.31.

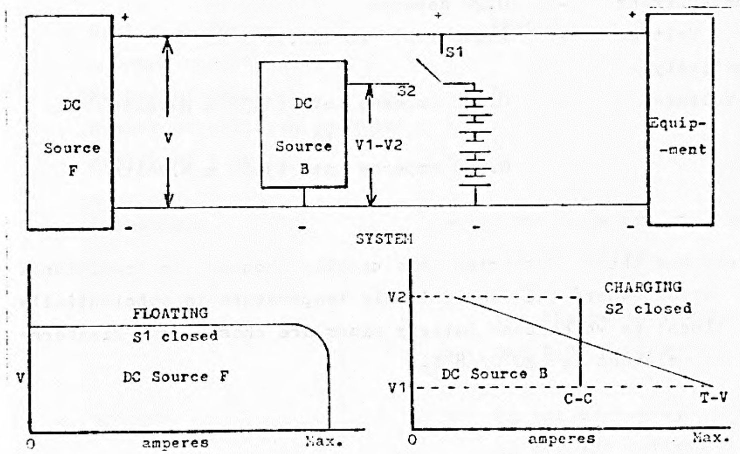


Fig. 6.31

The Battery is disconnected entirely from the SYSTEM and is charged from a separate DC Source - B in Fig. 6.31 - by the Constant-Current or Taper-Voltage method as may be the most convenient, as explained in Chapter 5. Charging, in particular Fig. 5.16 and its accompanying text.
In the meantime, the Inverter is supplied with current from its regular DC Source - F in Fig. 6.31 - at its normal Operational Mode Voltage.

On completion of the charge, the Battery is reconnected to the SYSTEM, as illustrated in Fig, 6.31.

DC Source F is specified by

Constant-Voltage	-	1.40 x N
Limited-Current -	-	Equipment amperes

DC Source B needs to be adequate to recharge the battery after it has become deeply discharged; it is specified by giving numerical values to the method selected, Constant-Current or Taper-Voltage.

Constant Current	-	0.2C amperes
Voltage	-	(1.40 x N) to (1.70 x N)
Alternatively -		
Taper-Voltage	-	0.28C amperes at (1.35 x N) volts
		to
		0.05C amperes at (1.60 x N) volts

Inverters and their Batteries are usually housed in traditional buildings and areas where the ambient air temperature is substantially NORMAL at all times; in which case Battery sizes are chosen from Discharge Data relevant to 20°C/68°F.

Following the selection of the most suitable Nickel-Cadmium Vented Pocket-Plate Battery to meet the Duty Specification, a detailed Technical Description is prepared for the use of all concerned with the manufacture, installation and maintenance of the battery and its DC Source.

The chosen cell in identified by the Type Number appropriate to its design and ampere hours capacity, typically from Fig. 2.8 Chapter 2. Mechanical Design. This Tabulation, which happens to refer to steel-cased cells in hardwood TRAYS, provides relevant details on Battery dimensions and weight, so that suitable arrangements can be made for delivery and installation.

Cell Type Number	-	AB-C-S
Ampere hours Capacity	-	C
Number of cells	-	N
Number of cells in each tray	-	n
Number of trays	-	N/n
Dimensions	-	1 mm x w mm x h mm for each tray L mm x W mm x H mm for the battery when the trays are placed side-by-side
Weight	-	kg for each tray Kg for the battery
Electrolyte	-	volume in each cell cc volume above plates cc height above plates mm
Charging		NORMAL 0.2C amperes for 7 hours at 1.40 to 1.70 volts x N SYSTEM FLOAT from a DC Source with Limited-Current output of XC amperes at 1.40 volts x N

7 Installing

Satisfactory installation arrangements are as important to the well-being and future performance of a Nickel-Cadmium Vented Pocket -Plate Battery as the choice of correct design and size of cell, and the effectiveness of the associated charging and control equipment. It is part of the process of Application Engineering to ensure that the battery is adequately protected from any adverse effects which the immediate environment may have upon it.

Stationary and Mobile Batteries - as these have been defined operate in entirely different physical environments; in which case they each need installation arrangements which are appropriate to their special circumstances.

There are basic principles which apply to both classes of battery, however, and these are

- PROTECTION - The battery needs to be protected from dirt and damp.
- ACCESS - Easy access to the battery, in particular to its top, is essential for inspection and servicing.
- VENTILATION - Means need to be provided for removing safely, the gases which are evolved during charging.

Care taken in these respects will ensure a battery installation which has the highest standard of reliability, the longest working life, is easy to service and economical to maintain.

STATIONARY BATTERIES

Stationary batteries are classified by physical standards, into Large and Small.

In general, large bulk and weight is associated with High values for Voltage and Ampere hours; batteries of 110 Volts and upwards, of 100 to 500 ampere hours-capacity, for example, come within the category of Large.

Low Voltage batteries are relatively much smaller in bulk and lighter in weight; batteries of 50 Volts and below, and of 5 to 100 ampere hours-capacity are, for example, classified as Small.

Large stationary batteries are accommodated in traditional buildings in which case they have ready-made protection against the weather and are easily kept free from dirt and damp.

The TRAYS of cells comprising the battery are placed on open, preferably wooden stands, not only to bring the cell tops to a convenient height for servicing, but because airspace so created beneath the battery provides desirable and effective electrical insulation from ground. It also provides for the circulation of ventilating air.

Fig. 7.1 is a typical example of a Stationary battery on a wooden stand and consisting of steel-cased cells in hardwood TRAYS. A height clearance of 300 mm from the floor is common, and when added to the height of the battery itself - which will not normally exceed 500 mm - the top of the battery is at a level which is convenient for easy servicing. It is feasible to arrange for access to one side of the battery only; the other side may be placed close to a wall.

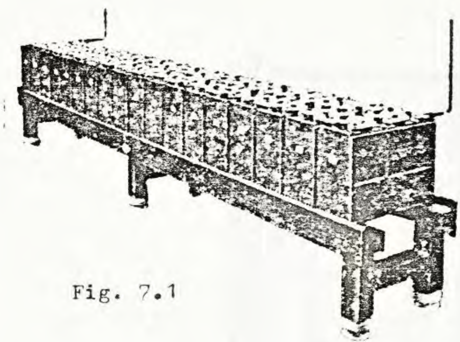


Fig. 7.1

Battery of
90 cells 80 amperehours
in
18 - 5 cell TRAYS
on
wooden stand
Length 2900 mm
Width 220 mm
Height 600 mm

During charging, large batteries release gas in sufficiently great volume to warrant the provision of controlled ventilation for the purpose of removing the gas-from the building, for dilution and dispersal in the outside air.

Forced ventilation by power-driven fans is desirable for the larger batteries; airbricks and grill-vents set high in the walls of the room will Induce natural ventilation in the case of other sizes.

The purpose is to prevent an accumulation of gas in the building; the gas is a mixture of hydrogen and oxygen in explosive proportion, which if ignited by spark or flame could cause damage to property and injury to personnel. Ventilation in quantitative terms is discussed in Chapter 9. APPENDICES.

Small stationary batteries housed in traditional buildings have ready-made protection against the weather and are easily kept free from dirt and damp. They can be placed on open wooden stands in the same way as for Large batteries. Fig. 7.1, but the smallest may be placed simply on open shelves attached to a wall.

Alternatively, they may be accommodated within floor-standing sheet steel cabinet3, for the sake of neatness and protection from unauthorised interference; access to the battery being through vertical hinged lockable doors. Ventilation of the interior of the cabinet is necessary and is provided by low-down air inlets and high-up outlets.

As a further convenience, the associated charging and control equipment may be incorporated in the cabinet as well, and Fig. 7.2 is typical of such an arrangement.

38 cells 120 ah.
in
Indoor Cabinet
Length 750 mm
Width 500 mm
Height 1400 mm

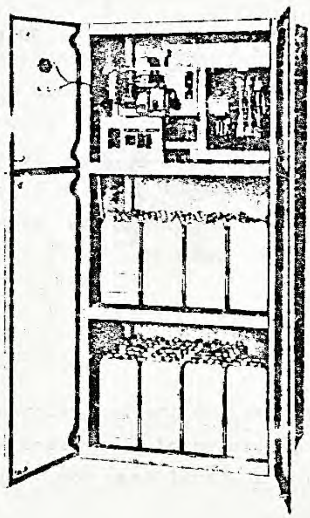


Fig. 7.2

The volume of gas produced during charging is relatively small compared with that from Large batteries; in which case the normal venting arrangements for the building are sufficient for safe disposal of gas generated during charging. Moreover, the gas is odourless and uncontaminated.

Nevertheless, the standard rules for battery operation in confined spaces are to be observed, in that sparks or flame are not allowed within the immediate vicinity of the tops of the cells, so that there is no danger of explosion by igniting the gases generated during charging.

When operated in outdoor situations, away from traditional buildings, Small batteries are housed in ground-standing cabinets made from weatherproof materials, and are accessible through hinged lockable and watertight doors, and Fig. 7.3 is a typical example.

Ventilation of the interior of the cabinet is necessary and is provided by low-down air inlets and high-up outlets; these are suitably shrouded on the outside to prevent the ingress of storm water to the cabinet.

While this arrangement releases gas generated during charging to the outside atmosphere, another equally important function is to deter condensation from settling on the inside of the cabinet, and the battery, by allowing an upward flow of outside air.

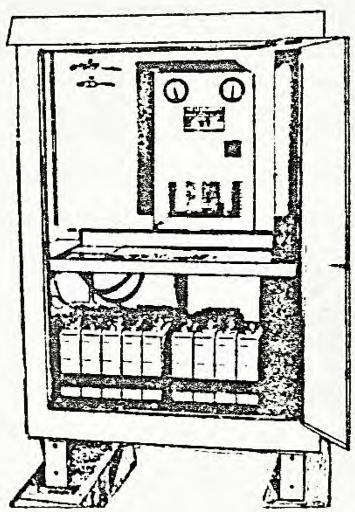


Fig. 7.3

MOBILE BATTERIES

Mobile is the description given to Nickel-Cadmium Vented Pocket- Plate batteries which are carried on vehicles, and where the battery performs an auxiliary function as distinct from providing electrical energy for propulsion of the vehicle.

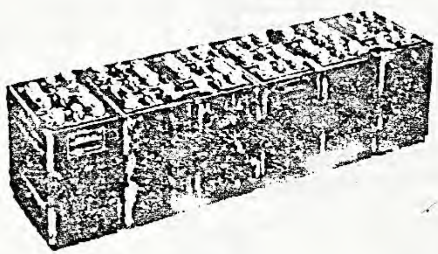
They are housed in compartments fabricated from the same structural material as the vehicles themselves, usually steel. Moreover, since space is restricted, the compartment is close fitting to the battery, for the sake of lowest possible bulk.

Battery compartments are generally designed and mounted so that the battery is accessible from outside the vehicle; being on top of, or slung underneath, its main frame. Some vehicles may, however, house the battery in a compartment within their main body shells.

The TRAYS of steel-cased cells comprising the battery are placed side-by-side, and the length dimension of the battery is the width of one TRAY multiplied by the number of TRAYS, while thewidth of the battery is the length of one TRAY.

The number of TRAYS, and the number of cells in each TRAY are so chosen as to give battery length and width dimensions which are compatible with those of the space assigned for battery accommodation on the vehicle.

Fig 7.4 is a typical vehicle auxiliary battery consisting of 18 Steel-cased cells arranged in 6 TRAYS each for 3 cells.



Battery of
18 cells 140 ah.
in
3 cell TRAYS
Length 960 mm
Width 335 mm
Height 370 mm

Fig. 7.4

The battery compartment is usually mounted with its length parallel to the front-to-back centre-line of the vehicle, and the battery is held firmly in place by horizontal wooden packing strips between itself and the inside walls of the compartment; the battery also stands on wooden strips.

The general arrangement of the battery and its packing strips are shown typically in Fig.7.5

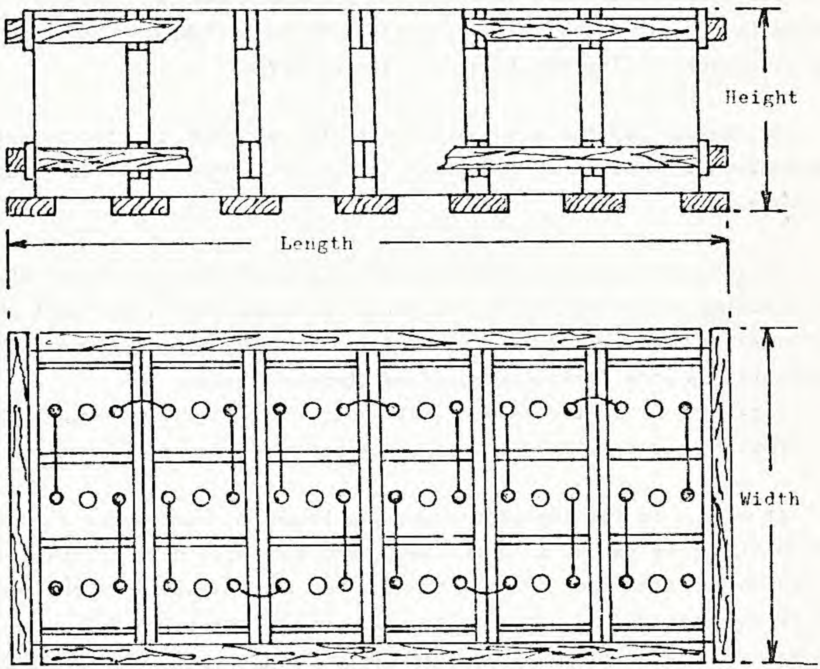


Fig. 7.5

The dimensions of the base area of the inside of the compartment allow for airspaces of at least 25 mm to each of the four sides of the battery, and the purpose of the horizontal wooden strips is to provide these.

These strips - at least 25 mm thick - prevent movement of the battery whilst the vehicle is in motion and are fastened to the walls of the compartment. The airspaces so created allow for ventilation and are additional insulation between the Steel-cased cells and the steel compartment.

The wooden strips on which the battery stands are at least 25 mm thick. They are preferably placed across the width of the compartment, each one supporting the bottom edges of adjacent TRAYS, but still leaving substantial airspaces underneath the battery. They keep the bottom of the battery dry, should water or other liquids find their way into the compartment.

All wooden strips are impregnated with a preservative against rot.

Moreover, it is good practice to provide holes at least 25 mm in diameter in the bottom of the compartment, in the airspaces beneath each TRAY; these holes allow any liquid to drain away.

The height for the airspace above the battery in its compartment is determined by whether the battery is to be serviced from the side or from above.

If access to the top of the battery is to be from the side, through a horizontally hinged drop-down door or a removable plate, at least 150 mm but preferably 300 mm of air-space height is desirable to allow for the comfortable and safe manipulation of maintenance tools.

Fig. 7.6 is a cross section view of a typical arrangement of this kind, the compartment being slung beneath the main frame of the vehicle.

If access to the top of the battery is to be from above, a minimum of 50 mm air-space height is sufficient, and this will also provide adequate mechanical clearance between the tea of the battery and the underside of the compartment lid. For this arrangement Fig. 7.7 is a cross-section view of a typical layout; in this case the compartment is mounted on the top of the in frame of the vehicle. The sloping lid allows quick disposal storm water. Lids need to make watertight joints where they meet battery compartments, so as to prevent storm water and vehicle cleaning water - which often has an acid content - from entering and wetting the battery.

Ventilation of the compartment is necessary so that the gases produced during charging can escape, and not be allowed to accumulate in the airspace above the battery; otherwise conditions become ideal for an explosion, should a spark occur inside the compartment for any reason. It is also necessary so as to create a draught of air upwards through the closed compartment which will discourage internal condensation and keep the battery dry.

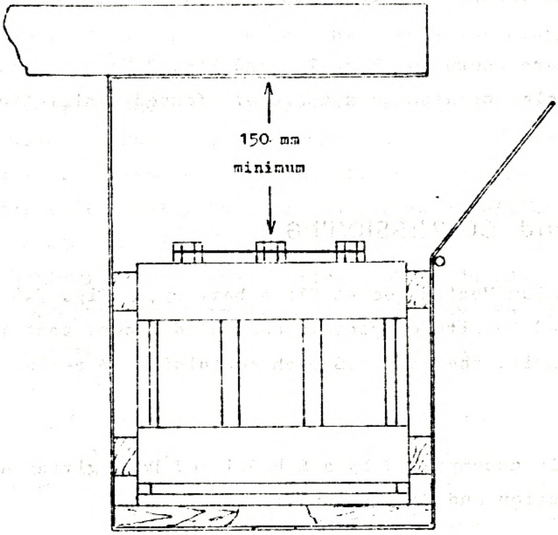


Fig. 7.6

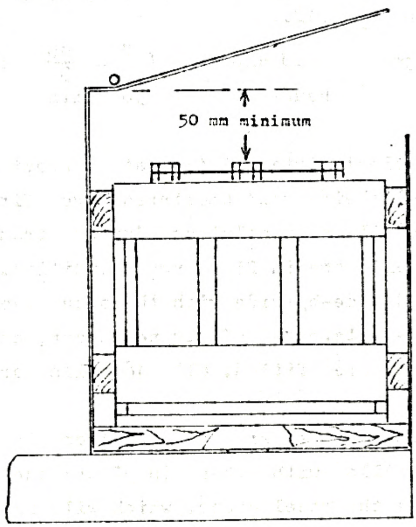


Fig. 7.7

The drain holes in the bottom of the compartment form the inlet of the ventilating system; the outlet is a row of holes, equivalent in area, to the drain holes, drilled along the top edge of the compartment walls, and suitably shrouded to prevent entry of storm water and vehicle washing- down water.

These holes are shown in Fig 7.6 and Fig 7.7; moreover the motion of the vehicle creates a measure of forced ventilation through the compartment.

ERECTION and COMMISSIONING

A Nickel-Cadmium Vented Pocket-Plate battery, Fig 7.4 for example, is delivered to site completely assembled except that for ease of handling during transit, the 6 TRAYS each containing 3 cells are packed separately.

The battery is accompanied by a Schedule of Data giving appropriate information for Erection and Commissioning

Schedule of Data

Name Plate Capacity	-140 ampere hours
Number of Cells	- 18 in 6 TRAYS of 3 cells each
Layout Drawing	- ABC15
Commissioning Charge	- 28.0 amperes (C/5 = 140/5) for 7 hours at 25 to 30 volts

The cells are filled with electrolyte solution at correct level above the tops of the plates inside; their vent apertures are firmly plugged with solid stoppers so that spillage of solution during transit is prevented, in addition the cells are in Discharged condition.

The 6 TRAYS are placed side-by-side with the open +ve terminal of each adjacent to the open -ve terminal of its neighbour, and when the inter-TRAY cable connections are fitted, all 18 cells are in series connection.

At this stage the solid stoppers are removed from the cell vents. It is dangerous to charge cells with these in place; the gas pressure produced internally will bulge the steel cases, which will not only loosen the pin separators between the plates, but personnel may be injured when the stoppers are eventually removed.

The hinged vent caps are closed down and kept closed while the battery receives its Commissioning Charge.

The +ve and -ve terminals of the battery are connected to an adjustable source of DC Power which will provide a constant 28 amperes at a voltage of 25 at the start of the charging period and rising to 30 volts towards the end of 7 hours.

The trend of the voltage rise during the period is in accordance with Fig. 5.1 in Chapter 5. Charging.

With all cells gassing freely during the last 2 hours, this confirms that individually they are in the same percentage State-of-Charge which in this case is 100 %.

The battery has then received a NORMAL Charge, as this has been defined in Chapter 5. Charging, and is ready to be connected into Operational Service.

9 Appendices

INTERNAL RESISTANCE and IMPEDANCE

Battery Internal Resistance is not to be confused with Battery Impedance.

Resistance is associated with DC Voltages and Currents and implies an Ohms Law relationship in terms of voltage, current and resistance.

Impedance, on the other hand, is concerned with inductance and capacitance, which are associated with AC Voltages and Currents.

The Internal Resistance of a battery is the arithmetical sum of the internal resistance of each of the cells comprising the battery.

The Impedance is a variable quantity which is influenced by the and shape of the cells in the battery, and especially by their disposition electrically to each other.

The direct measurement of Internal Resistance by meter is not possible; it is calculated from DC Voltages and Currents recorded during a laid down test procedure and is quoted in ohms. Impedance is measured directly by an AC Bridge method and is also quoted in ohms.

Internal Resistance

A British Standard Specification sets out a testing procedure in determining a Figure for Internal Resistance. It provides a basis for comparison, and a means of evaluating the equivalent products of different manufacturers; it ensures the maintenance of standards of quality and performance. Absolute values for Internal Resistance, when quoted, are valid only for the method by which they are measured and are qualified by a statement to this effect.

BSS 683-1936 is the British Standard Specification referred to, and its Test Procedure is set out as follows -

Three similar cells are connected in series and tested as a battery, and at NORMAL Temperature, 20°C/65°F.

After a NORMAL Charge, the battery is discharged for one hour at a Constant-Current of 0.1C amperes through an appropriate load resistance. C is the numerical value of the battery capacity in ampere hours.

Without interrupting the discharge, the current value is rapidly increased to 0.2C amperes (A1) by decreasing the load resistance, and after an interval of not more than 5 minutes the current value is reduced rapidly to 0.05C amperes (A2) by increasing the load resistance.

When the currents have changed to A1 and A2, the battery terminal voltages V1 and V2 are noted and recorded. The Internal Resistance R is then obtained from the formula

R = (V2 - V1)/3(A1 - A2)

= ohms-per-cell

The Test Procedure is illustrated in Fig. 9.1

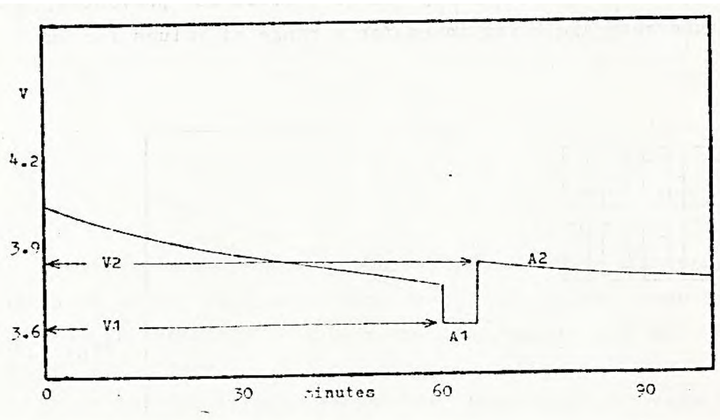


Fig. 9.1

It is to be noted that the voltages V1 and V2 are on-load voltages that is to say, they are measured whilst the discharge current is flowing. Open-Circuit Voltages are excluded from the Test Procedure; such voltages as discussed elsewhere, have a propensity for instability. A more favourable situation is therefore created by arranging for (A1 - A2) to be the difference between two unequal discharge currents; V1 and V2 are then the voltages corresponding to these currents, and by this means, unreliable figures are eliminated from the Test Procedure.

Impedance

Impedance is present in the Nickel-Cadmium Vented Pocket-Plate cell by virtue of the steel construction, but it can be considered quantitatively only on the basis of a complete battery of cells.

The Impedance effect is created by the physical disposition of the cells relative to each other, as well as by the arrangement of their connecting cables. A change in the physical layout of the cells will alter the Impedance of the same battery.

Moreover, Impedance is a function of Frequency (Hz), which adds a further parameter in the determination of a Figure, in ohms, for the Impedance of a battery.

The battery to be measured is divided into two banks, each having the same number of cells. The +ve terminal of one bank is connected to the +ve terminal of the other bank. The two open -ve terminals are connected to the appropriate arm of an AC Bridge; by this arrangement the flow of DC current in the battery-bridge circuit is prevented, whilst Impedance measurements are being taken for a range of values for Hz.

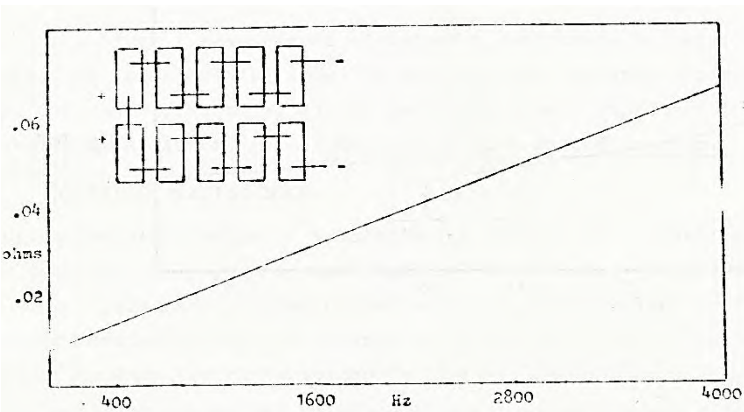


Fig. 9.2

Users of batteries are interested in a frequency range of up to 5000 Hz. and as an indication of Impedance values which appertain to a specific layout, a typical relationship between ohms and Hz is shown in Fi g 9.2.

In Fig. 9.3 Impedance figures are given for another battery of the same ampere hours capacity and number of cells but having different dimensions.

The difference between the measured figures for Impedance is significant as between one battery and the other.

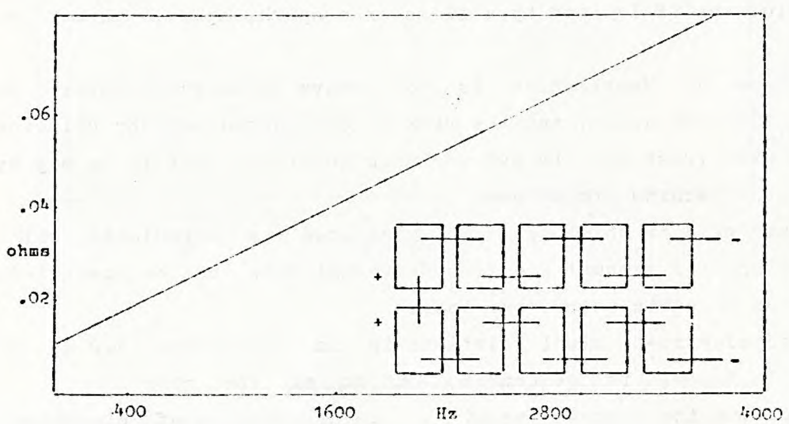


Fig. 9.3

The inference from these observations is that if battery Impedance is likely to affect the performance of the Equipment associated with the battery, it is necessary to take a specific measurement of the Impedance of the actual battery in its proposed cell design and layout.

In any event, figures quoted for Impedance are necessarily accompanied by a statement of the environmental conditions and layout of the battery at the time of measurement, and the method of measurement.

VENTILATION

The oxygen and hydrogen gas-mixture which is evolved whilst Nickel-Cadmium Vented Pocket-Plate cells are being charged will explode with violence if ignited by a flame or a spark, however these are caused.

The purpose of Ventilation is to remove these gases before an explosive situation can arise, and the risk is eliminated only by dilution of the mixture with fresh air in overwhelming quantity, that is to say by its removal to the outside atmosphere.

The volume rate at which gas is generated is calculable, which enables the ratings for exhaust and forced-draught fans to be specified; these ratings are in cubic-metres-per-hour.

The basic electro-chemical relationship is that when 1.0 cc of water is electrolysed, it generates 1865 cc of the oxygen/hydrogen mixture at NTP and the process requires one ampere hours of electrical energy.

This needs to be translated into practical terms which will enable ventilation requirements to be specified in relation to the number of cells in the battery, its ampere hours capacity and the Operational Mode of Charging. It is therefore expressed as –

“One cc of water is electrolysed into 622 cc of gas at NTP during one hour by a current of one ampere.”

The rate of generation of gas by each cell is-

622 x overcharge current in amperes= cc per hour

and by the battery –

cc per cell per hour x number of cells = cc per hour

Fig. 9.4 is Fig. 5.19 Chapter 5 Charging, to which a straight line relationship has been added.

One ordinate is still volts-per-cell (v) and the baseline still includes for overcharge currents up to 0.10C amperes. The other ordinate is scaled in cc of gas per cell per hour, and the straight line represents the linear relation between overcharge amperes and rate of gas generation.

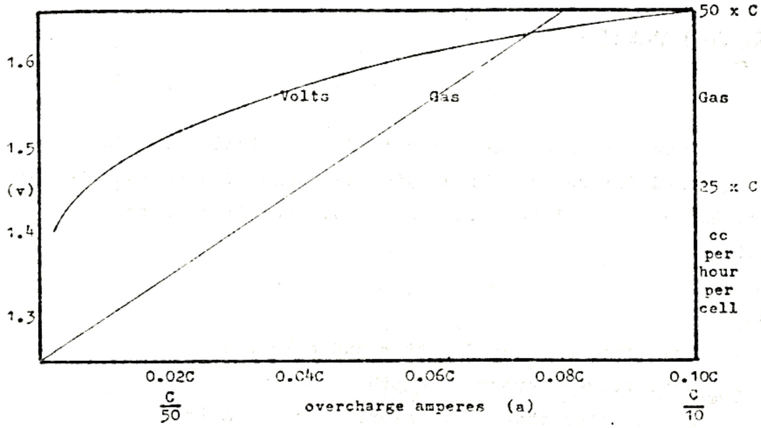


Fig. 9.4

Fig. 9.4 therefore indicates, for any selected voltage-per-cell, the corresponding overcharge amperes, and then from the straight-line relationship the corresponding volume of gas per cell per hour, both in terms of the Symbol C.

When a numerical value for ampere hours is given to C, the volume of gas per cell per hour multiplied by the number of cells in the battery is a numerical figure with which to specify a Fan Rating for ventilation of the battery accommodation space. Good practice in the choice of Fan Rating will, however, allow a margin over the calculated requirement.

Where ventilation by natural draught is depended upon, as for Mobile batteries, the rule-of-thumb for the area of the inlet and outlet air-vent openings in the accommodation space is to allow at least 6.25 sq. cm for each cell in the battery, the justification for this choice is that the area of the vent opening in the top of each cell is of the order of 6.25 sq. cm, but good practice will allow for a margin over the bare calculated requirement.

APPROVED WATER

Water which has been purified by distillation or by ion exchange is Approved for replenishing Nickel-Cadmium Vented Pocket-Plate cells and for mixing electrolyte solutions, provided it conforms with the following analysis.

Description	Free from suspended matter and colourless when viewed through a depth of 300 mm.
Conductivity	No greater than 0.1 micro-mhos per metre
Total Solids	Not greater than 20.0 parts per million
Chloride	Not greater than 10.0 parts per million
?	Not greater than 10.0 parts per million
?	Not greater than 5.0 parts per million
Manganese	Not greater than 0.1 parts per million
Lead	Not greater than 2.5 parts per million
Calcium	Not greater than 10.0 parts per million
?	Not greater than 10.0 parts per million
Zinc	Not greater than 2.5 parts per million
Nitrogen-Oxide	Not greater than 3.0 parts per million

Please note that three of the impurities were unreadable on the original document, so I have put a '?' in their place. – A Green

NOMENCLATURE

C - a Symbol for any numerical value of ampere hours between 5 and 500.

X - a number - whole, fraction or decimal,

x - multiplied by N - number of cells.

For a single cell		for a battery of N
a	amperes	a
XC	amperes in terms of C	XC
V	volts	v x N
vmax	maximum volts	vmax x N
vmin	minimum volts	vmin x N
w	watts	w x N
a x v	watts	a x v x
C x X	watts in terms of C	C x X x
h	hours	h
ra	minutes	m
s	seconds	s
a x h	ampere hours	a x h
ah	ampere hours	ah
a x m	ampere minutes	a x m
am	ampere minutes	am
a x s	ampere seconds	a x s
as	ampere seconds	as
X x C	ampere hours in terms of C	X x C
r	ohms	r x N
X/c	ohms in terms of C	X/C x N

V - operating voltage of DC System.

Ve - nameplate voltage of Equipment.

Vmax - highest permissible Equipment DC voltage, a plus limit on Ve.

Vmin - lowest permissible Equipment DC voltage, a minus limit on Ve.

NTP - Normal Temperature and Pressure,

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