Lead-Acid Battery:

Reserve Batteries for Bell System Use: Design of the New Cell

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A new cylindrical lead-acid battery has been developed to provide reserve power to sustain telephone service during power-failure conditions. We discuss in this paper the usage of batteries in the modern telephone plant, review the difficulties encountered with existing cell designs, describe in detail special features of the new design, and outline the scope of the overall development program.

I. INTRODUCTION

For more than 100 years, lead-acid batteries have dominated the field of practical rechargeable batteries. In its modern form, the lead-acid battery is derived from Faure[1] and Sellon[2] who introduced the concept of a conducting lattice-like grid to provide electrical contact and mechanical containment of the particulate pastes of the positive and negative electroactive species. Despite a century of evolution which has seen this battery system optimized for automotive starting, lighting and ignition (SLI) service and become the primary industrial battery system for both stationary (communication) and traction (fork-lift truck, etc.) usage, modern cell designs differ only slightly from Faure's original proposals.

In contrast to the deep-cycle service of industrial truck batteries, and the high-rate discharges typical of batteries for SLI usage, batteries for telephone service are continuously trickle-charged, or "floated" under conditions designed to maintain them in a full state of charge, ready for instantaneous use, should commercial power fail. Discharges are infrequent and at relatively low rates. Bell System requirements emphasize long life and high reliability in the unique float charge use-mode and strive to avoid the economic penalties of excessive maintenance.

Despite these major differences in use-mode, batteries for telephone service differ basically only in their wide size range (50 AH to 7000 AH) and lower specific gravity acid (1.210) from those used for SLI or traction service. Figure 1 shows a representative telephone stationary battery design. The major structural element is the lead alloy grid, a lattice-like frame which serves as the mechanical retainer and electrical contact to the positive and negative active material pastes. Lead oxides mixed with sulfuric acid and water, are pasted into these grid frames and, after drying, converted via electrolytic oxidation or reduction to the positive lead dioxide or negative "spongy" lead electrochemically active species. Microporous separators are interspersed between each pair of positive and negative plates to provide electronic insulation while permitting ionic transport. The separators may be supplemented in some designs by fiberglass mats designed to entrap positive active

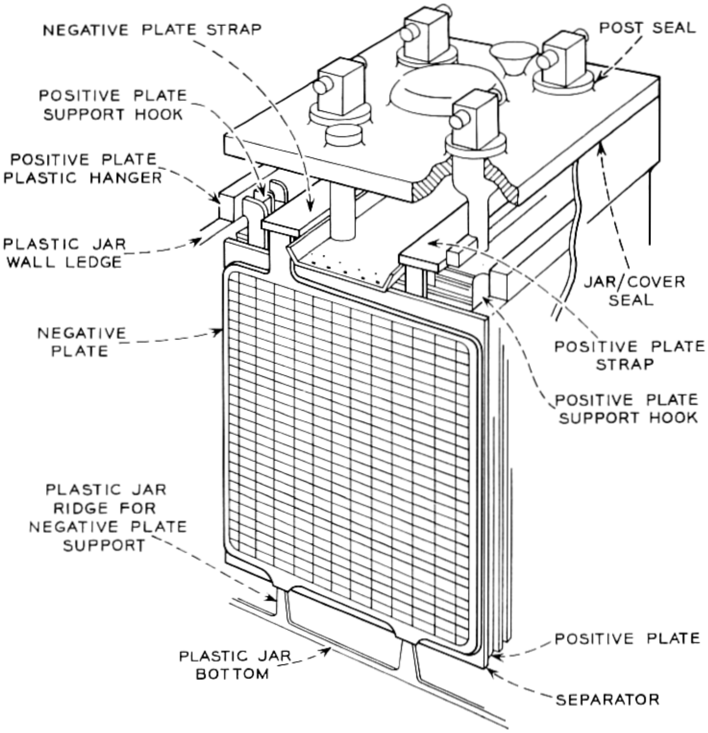

Fig. 1—Typical Pb-acid battery for telephone reserve use.

material which may shed during charge-discharge cycling. In cell elements made up of groups of positive plates with interleaved negative plates and separators, electrodes of like polarity are electrically and mechanically joined by torch-welding to a lead-alloy connecting strap. This in turn is joined to a terminal which projects, via a feed-through seal, through the cell cover, forming the external terminal contact. The entire vertically disposed cell element may either rest on the cell bottom (suitably elevated by ridges to allow collection of shed active material sediment without causing inter-electrode shorts) or be suspended from the jar wall or cell cover.

Because the element weight is supported by the grid frames, the structural integrity of the grid frames has required that soft lead be metallurgically hardened, usually by the incorporation of 3–12 percent Sb, which forms a binary eutectic at 13 percent Sb and produces an increase in tensile strength from 1780 to 7280 psi, and an order of magnitude increase in creep strength. While early workers recognized the effectiveness of Sb in providing the required degree of mechanical hardening (and improving the casting qualities of the grid), the electrochemical activity of the Sb additive was not clearly identified and understood until the mid 1930s, when its influence on the behavior of the negative plate was elucidated by Crennel and Milligan.[3] (The significant reactions which govern the behavior of the lead-acid battery in discharge, recharge and overcharge are shown in Table I.) Haring and others[4] documented the corrosion and dissolution of Sb from the positive grid, its transport through the separator as a complex Sb ion and its redeposition on the negative plate. There it provided sites which facilitated hydrogen evolution (depolarization) on charge and promoted a local action type of self-discharge which ultimately resulted in irreversible sulfation and failure of the negative plate. Thomas and Haring[4] proposed the use of electronegative alkaline earth elements as non-depolarizing alloying additions and in 1948 reported on successful long-term experiments with batteries whose grids were hardened by inclusion of 0.05 to 0.10 percent Ca.[5] These workers demonstrated that cells fabricated with these Pb/Ca alloy grids, when maintained continuously on trickle or "float" charge showed no depolarization or sulfation of the negative plates after a nine-year float test. In this test, a new life limiting process resulted, that is, corrosion and growth of the positive grid in the highly oxidizing environment of float charge usage. Their life tests indicated a critical sensitivity of the corrosion and growth processes to small variations in the alloy composition and to the metallurgical soundness of the casting.[6] The Ca alloy addition in-

TABLE I—REACTIONS IN THE LEAD-ACID BATTERY

Primary Charge-Discharge Reactions	
At the Positive Electrode:	$PbSO_4 + 2H_2O \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftarrows}} PbO_2 + 4H^+ + SO_4^{=} + 2e^-$
At the Negative Electrode:	$PbSO_4 + 2e^- \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftarrows}} Pb + SO_4^{=}$
On Overcharge	
At the Positive Electrode:	$2H_2O \overset{\text{Charge}}{\rightleftarrows} O_2 + 4H^+ + 4e^-$
	$Pb + 2H_2O \overset{\text{Charge}}{\rightleftarrows} PbO_2 + 4H^+ + 4e^-$
At the Negative Electrode:	$2\ H^+ + 2e^- \overset{\text{Charge}}{\rightleftarrows} H_2$

creased the difficulty of grid casting because of its narrow melting range and caused significant analytical and control problems to be introduced into the casting process. The manufacturing problems were successfully overcome and batteries containing lead-calcium grids were introduced into widespread Bell System use in 1950.

During this same period container materials suitable for use in the acidic electrolyte evolved from fragile and expensive glass and ceramics through hard rubber into current polystyrene-based polymers capable of high-speed injection moldings which permitted wide flexibility in jar-and-cover design and resulted in significant economies. Adhesive sealing of containers and covers and sealed feed-through terminals produced cells which eliminated the possibility of internal element maintenance and repair. Elimination of Sb and its depolarization of the hydrogen evolution reaction allowed cells to float at substantially lower currents resulting in a marked decrease in frequency of water additions. These changes stimulated expectations of decreased battery maintenance by telephone company personnel.

In the 20 years since the introduction of the lead-calcium battery, Bell System battery usage has increased by more than an order of magnitude and has been accompanied by significant changes in power plant design and usage.

We discuss in this paper the ways batteries are used in the modern telephone plant, review the difficulties that have been experienced with existing cell designs, describe a new cell which has been designed to minimize these problems, and outline the scope of the program for its development.

II. BATTERY USAGE

In order to assure uninterrupted telephone service, a continuous, uninterrupted supply of electrical power must be provided. This power is normally purchased from the electric utility serving the area of operation but it is clear that sufficient power must be available to run the plant even during periods when the commercial power is unavailable. Each telephone installation must therefore be provided with a source of reserve power having sufficient capacity to carry the plant through the duration of commercial power interruption.

A typical central office power system is shown schematically in Fig. 2. The telephone plant load is primarily dc and it is this portion of the installation which must be provided with no-break power. A small amount of ac is often included in the plant load. In normal operation the ac load is supplied directly by the commercial source and the dc load by a system of rectifiers driven from the commercial source. Building services such as general lighting and air-conditioning are also supplied directly. The battery is kept connected to the plant at all times and is floated at full charge by the rectifiers.

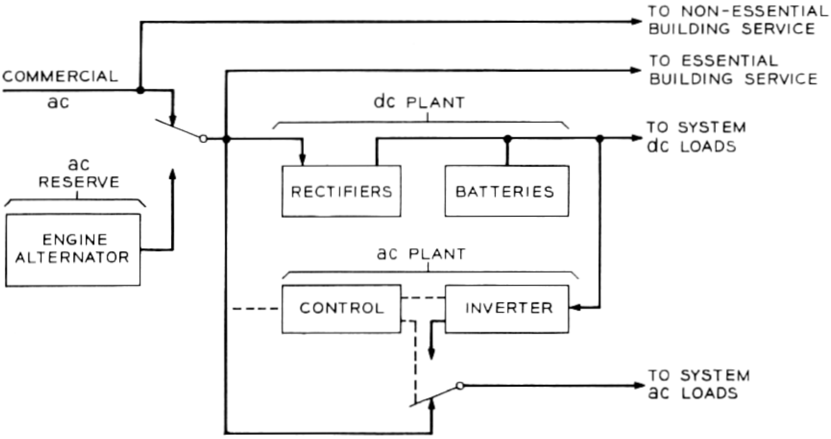

Fig. 2—Telephone office power plant.

In the event of a failure of commercial power, the commercial source is disconnected from the plant and an appropriate alarm is registered. The reserve engine-alternator is then started (either automatically or manually) and, when up to speed, connected to the load. Depending on conditions, the time interval between the onset of the power failure and the load pickup by the reserve engine can vary from less than a minute to more than an hour. During this time interval, the battery provides all the dc power to run the telephone plant. AC power for the telephone equipment is also supplied by the battery through dc–ac inverter plants. This arrangement allows the dc load to be drawn from the batteries without interruption and with minimal switching transients.

The amount of battery reserve which must be provided is highly dependent on the precise conditions of the installation. The significant factors are plant voltage, load current, and required battery reserve time.

While central offices operate principally at 24 and 48 volts, there are a variety of other voltages needed for PBXs, transmission systems and other special services. Table II is a tabulation of the dc voltages for which standard battery plants are presently provided. It also shows the number of cells connected in series to achieve these voltages. Roughly speaking, the number of cells is half the plant voltage (2 volts per cell). However, many plants are provided with additional emergency

TABLE II—DC VOLTAGES OF STANDARD BATTERY PLANTS

Nominal Voltage	Number of Cells
12V	6
24V	9 10 11 12 13 14
48V	23 24 27
130V	63 66 67 69 70
152V	70

TABLE III—POWER OUTAGES IN TELEPHONE OFFICES

No. of Outages Per Year	Duration of Each Outage (% of Total Reported Outages)			
	0–10 Min.	10–60 Min.	1–3 Hr.	>3 Hr.
1–5	37	35	12	5
6–10	3	1	0.5	0
10–20	1	0	0	0
>20	5	0.5	0	0

or "end" cells which are switched onto the end of the battery string during longer discharge periods to maintain the plant voltage within the required limits. This permits the cells in the main battery to discharge to a lower voltage (1.75 V/cell) and thus utilizes the battery more completely.

The current drain on these plants can be anywhere up to 10,000 amperes. The battery string is designed to supply this load for the duration of the expected outage. The amount of reserve time provided depends largely on the local office environment. For plants with good reserve engine back-up located in an area where power failures are historically rare and of short duration, the reserve time provided may be as low as two hours. On the other hand, unattended remote locations without engine back-up (community dial offices, mountaintop relay stations, and so on) may be engineered to run for days on the battery alone. Results of a recent battery survey provided significant statistical information on power outages. These are tabulated in Table III. Large area power failures, such as the Northeast blackout of November 1965, provided practical demonstration of the importance of the reserve battery plant.

The cells we currently use for this service have capacities ranging from 50 to 7000 ampere-hours as tabulated in Table IV. Generally speaking, the smallest available cell having enough capacity to provide the necessary reserve time is used. If the required reserve capacity exceeds that available from a single battery, as many as 8 multiple strings are used in parallel.

Cells of 4000- to 7000-ampere-hour capacity are used in the larger offices. These "tank" cells are of hard rubber case construction and are floor mounted. Cells in the 180- to 1680-ampere-hour range have polystyrene-based plastic cases and are mounted on shelf-type battery racks, generally two tiers high. The smaller 50- and 100-ampere-hour cells currently have polystyrene-based or polypropylene plastic cases

TABLE IV—CELL CAPACITIES USED

Ampere Hours
50
100
180
240
300
420
540
660
840
1080
1320
1680
4000
5000
6000
7000

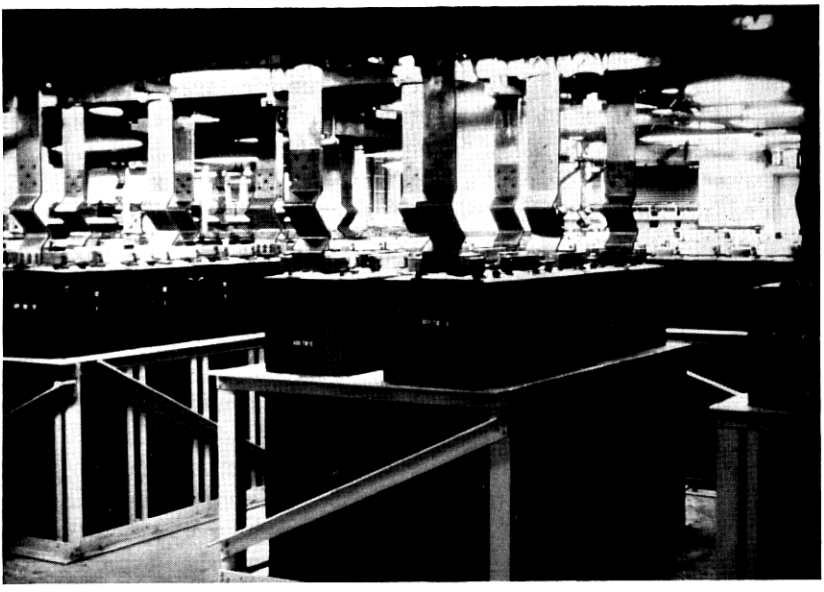

Fig. 3—Central office battery plant with 7000-AH Tank cells.

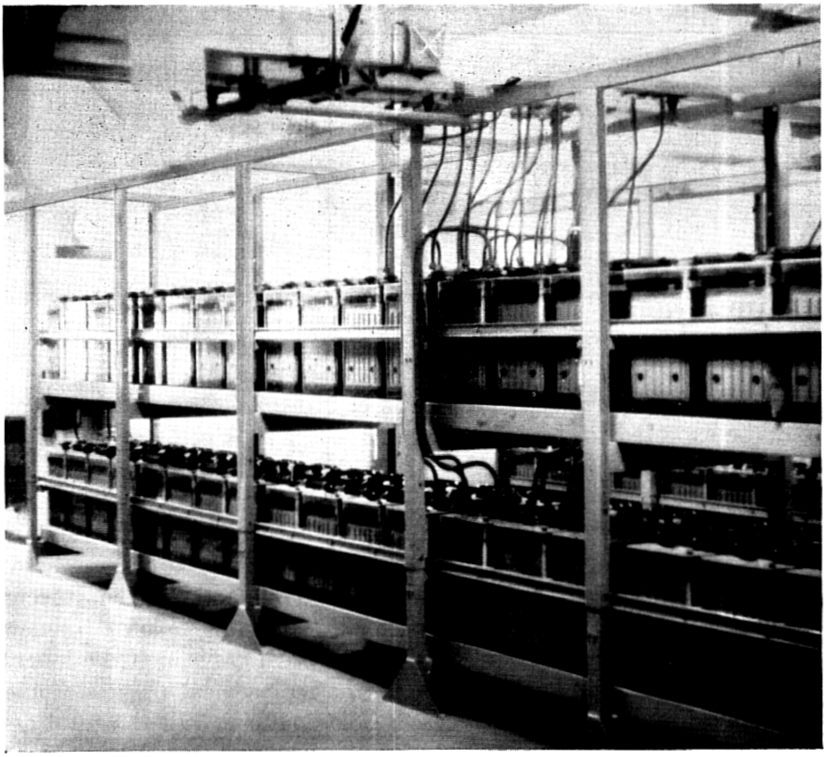

Fig. 4—Central office battery plant with 1680-AH plastic jar cells.

and may be shelf-mounted either on battery racks or in relay racks. Typical central office battery plants are shown in Figs. 3 and 4.

More than half the cells we use are in the 180- to 1680-ampere-hour range. Table V shows the number of lead-calcium cells of this type purchased by the Bell System in 1968. Lead-antimony cells in these sizes accounted for less than 5 percent of the 1968 business. The use of the Pb/Ca cells seems fairly well distributed over the range of sizes with two exceptions. There is a small bulge at 300 to 400 ampere-hours and a much larger one at 1680 ampere-hours. The 1680-AH cells provide more capacity per dollar than any of the other sizes available (including the tank cells) but their use in plants requiring more than five parallel strings is not recommended because of increased maintenance costs. If the maintenance cost of the new cell is lowered as anticipated, this

TABLE V—LEAD-CALCIUM CELLS PURCHASED BY BELL SYSTEM IN 1968

Ampere Hours	No. of Cells
180	7000
240	7150
300	10250
420	14850
540	6600
660	6400
840	5000
1080	5000
1320	4000
1680	43000
Total	109,250

restriction may be relaxed and purchases of the 1680-ampere-hour cell would be expected to rise at the expense of the tank cell.

It is estimated that a total of 1,000,000 to 1,250,000 cells in the 180- to 1680-ampere-hour range are presently in service. It is anticipated that the Bell System demand for these cells will remain at approximately the present level in the immediate future. By the mid 1970s purchases of the new cell are expected to reduce the demand for the current product to virtually zero. The replacement of existing cells by the new cells will continue at least until the mid 1980s after which the longer life of the new cells will take effect and the replacement market should essentially disappear for many years. It is doubtful that the total demand for the new cell will drop however, since the expected demand for new plant should take up the slack.

In this size range, 11 different capacities are furnished in both lead-calcium and lead-antimony grid systems by three manufacturers. The multiplicity of available battery configurations, materials systems and element designs which result from our "end-requirement" specifications create significant problems in the design of mounting and interconnecting arrangements needed to incorporate them into the telephone plant and result in significant confusion in development of suitable practices for their maintenance and use.

In the early 1950s, the Bell System battery plant was relatively small and usage was uncomplicated. Rapid system growth has resulted in continuous expansion to keep pace with new system demands for power and has introduced requirements for offices resistant to earthquake and nuclear attack.[7] Reliability, long life, low maintenance, and thus low annual costs have become increasingly important as size and variety of plant usage has increased. Realization of these objectives has been complicated by the complexity and multiplicity of installation configurations and compromised by performance deficiencies of the cells currently in use.

III. BATTERY PERFORMANCE IN THE BELL SYSTEM

The introduction of the lead-calcium alloy grid into the manufacture of Bell System batteries in 1950 was accompanied by a significant departure in specification practice. In addition to providing end-requirement electrical and mechanical specifications and "design life" objectives, close control was established over the composition of the Ca grid alloy. This was soon followed by specification and control of composition and properties of the polystyrene-based polymers introduced for battery jars and covers. Significant BTL materials development effort was involved in both these programs. Control of all other details of cell design, materials selection and manufacture was retained by the manufacturers, who were free to initiate changes for cost reduction and product improvement, subject to Western Electric Company and BTL approval. The lack of a proven accelerated aging technique made it difficult to predict the ultimate life of the original designs, or the impact of these changes on the long-term performance of cells which had an anticipated 25-year life expectancy. Field performance problems usually appeared slowly over periods of five to ten years and such early failures as did occur were often considered as isolated manufacturing defects in the absence of widespread field complaints.

In the early 1960s, several serious fires in telephone battery plants became the object of significant telephone company and BTL study. Extensive postmortems of damaged batteries, coupled with simulations in a mock-up battery plant at Murray Hill established conclusively that electrolyte leakage to grounded metal battery racks could produce arcing which might result either in an explosion of hydrogen/oxygen mixtures trapped beneath the cell cover, or in direct ignition of the flammable polystyrene-based plastic jar-and-cover materials. Acid leakage from faulty jar-cover or terminal-cover seals, or from cracked jars was found to be particularly hazardous in higher voltage (> 48 V) battery plants.

More detailed examination revealed that in most cases, leakage could be directly attributed to stresses resulting from corrosion and growth of the positive grid.[8] Corrosion causes the lead-alloy grid to be continually oxidized to PbO_2. The larger specific volume of the oxidized material creates stresses which cause the grid to grow, crack and

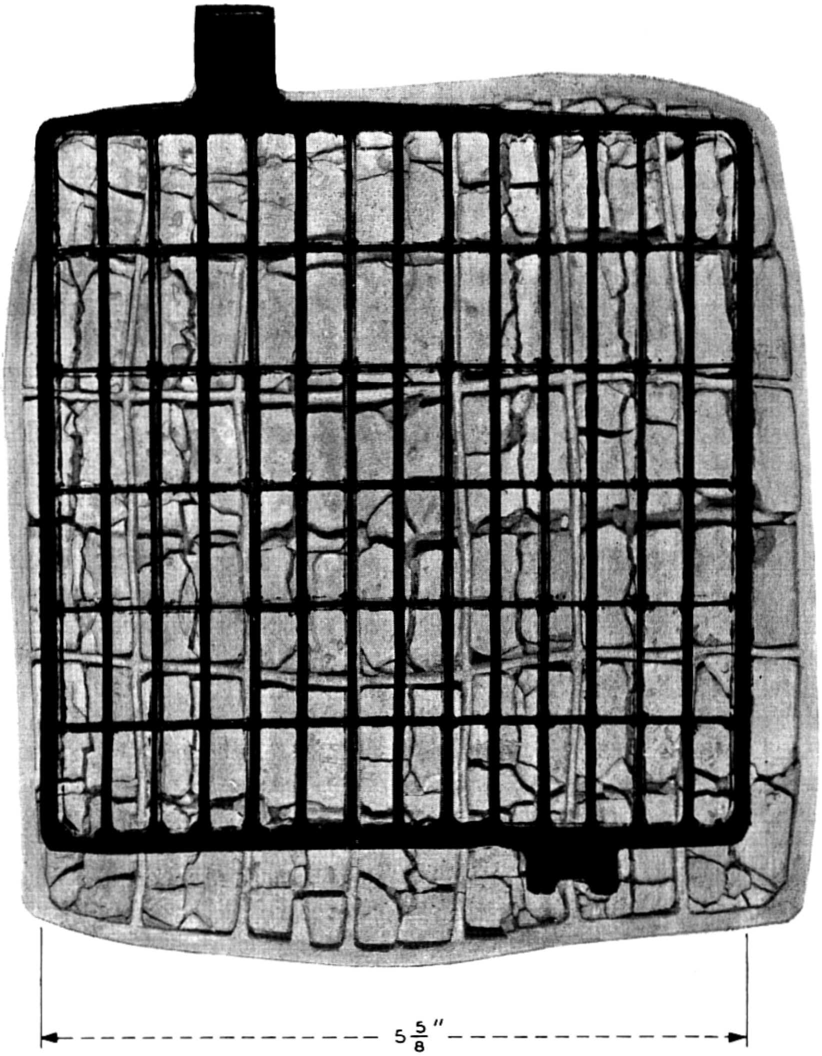

Fig. 5—Corroded positive plate with original grid overlaid to indicate initial dimensions.

eventually lose contact to the active material. The extent of this growth is seen in Figure 5. It shows a corroded and grown positive plate with the original lead-calcium alloy grid overlaid to indicate the initial dimensions. Simulated growth-stress studies revealed the stress-sensitive, brittle polystyrene jars to be incapable of resisting these growth stresses, once grid growth had progressed to the point of contact with the jar walls. Initial stress-induced crazing (Fig. 6) was usually followed by jar fracture (Fig. 7). Likewise, vertical growth stressed and ruptured jar-cover and post-cover seals (Fig. 8). Many examples of each type of failure were found in field examination of telephone battery plants.

Recognition of the mechanical consequences of grid growth stimulated additional concern over the electrochemical integrity of the telephone battery plant. The loss of grid-pellet contact which occurs during grid

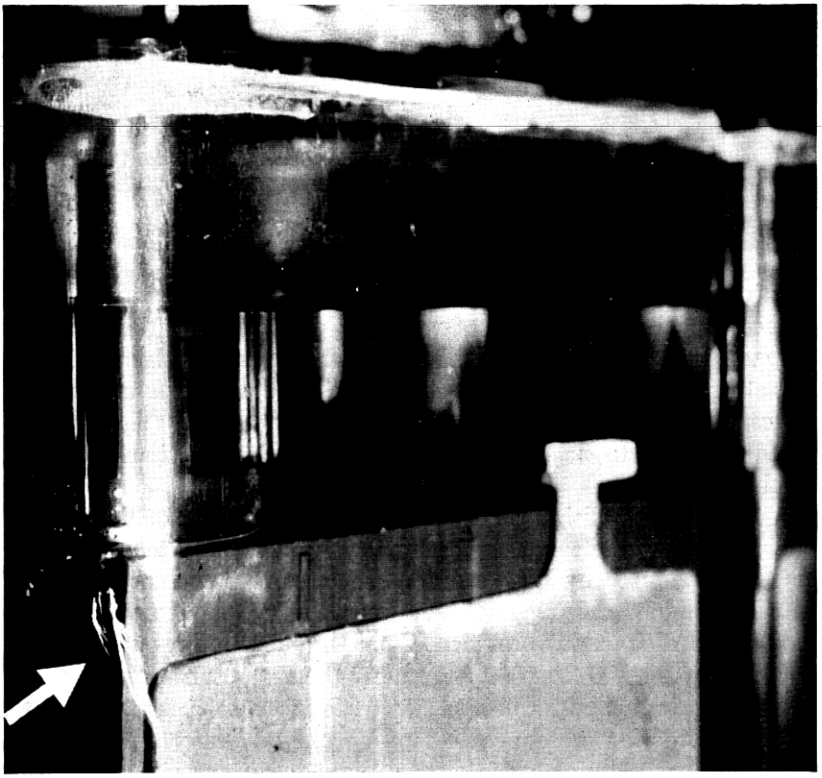

Fig. 6—Crazing in plastic jars.

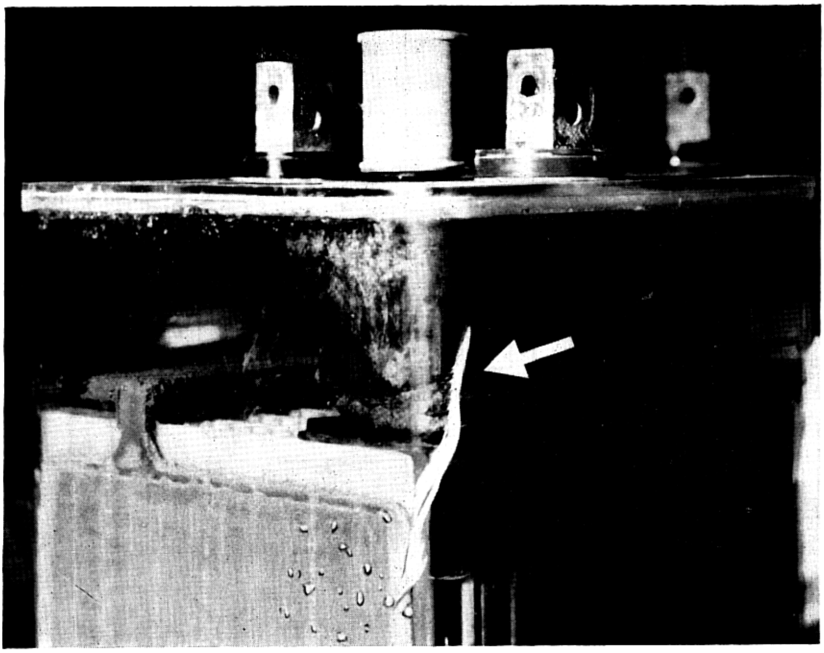

Fig. 7—Crack resulting from craze of Fig. 6.

growth is clearly visible in Fig. 5 and results in severe capacity loss.

Since capacity tests were not routinely performed by the telephone companies to assess the capabilities of their reserve battery plant, a pilot study involving about 50 cells of various ages and manufacturers was carried out with the Pacific Telephone Company. This study revealed capacity to be degrading much more rapidly than had been anticipated.

In order to establish a more accurate understanding of the existing capabilities of the telephone reserve battery plant, an extensive survey was then organized by BTL and implemented with the cooperation of AT&T. Random sampling of cells in all telephone companies (including Bell of Canada) provided discharge information on more than 5000 cells in the 180- to 1680-AH range. Data was taken by telephone company personnel on forms specifically designed to facilitate transfer to punch cards for subsequent computer analysis. Information on cell type, age and manufacturer, battery plant location, type and usage, power-failure statistics and many other parameters were obtained in addition to cell capacity, mechanical conditions and maintenance information. Computer correlation, analysis and display techniques were used extensively in reviews of this material for both telephone company personnel and individual battery vendors. The results indicated that the life expectancy of lead-calcium cells in system usage would generally fall far short of the anticipated design goal of 25 years to 90 percent of initial capacity with the best designs likely to achieve an average life of no more than 15 years to 75 percent capacity. There was considerable variability in performance and aging characteristics among the various suppliers' products with the earlier, more conservatively engineered designs showing the best long-term performance. In addition it was found that design changes had generally resulted in significant degradation of capacity-aging characteristics with some cells (repre-

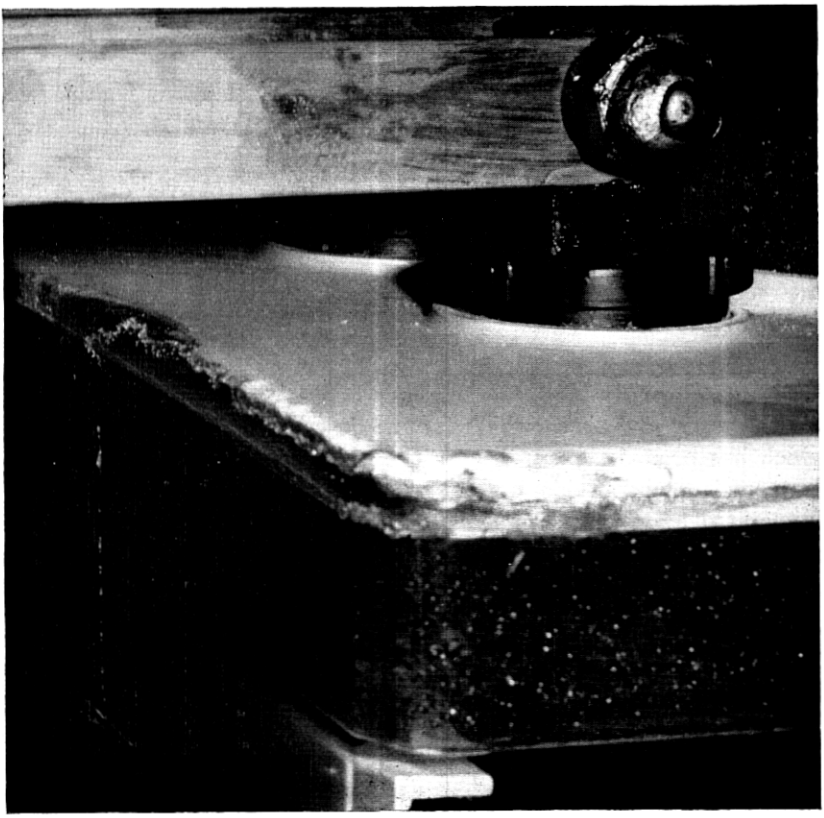

Fig. 8—Cracked and leaking jar-cover seal.

senting a large fraction of the installed plant) fading to less than 50 percent capacity within seven years. Mechanical failures were found to be common to all designs and in many cases had passed unrecognized by telephone company personnel except in catastrophic cases.

While demonstrating the degraded capability of the telephone battery plant, the battery survey documented the need for closer specification and control of cell design, materials and processes in order to insure performance in accord with system objectives. These two factors, coupled with inventory, supply, installation and usage problems resulting from the multiplicity of codes and configurations, stimulated a thorough reexamination and revision of the entire philosophy of Bell System battery design, procurement and use, with the ultimate goal of minimizing the annual cost of battery power to the telephone plant. Specifically, a multifaceted program was initiated in 1964 with the following objectives:

(*i*) To design a lead-acid battery optimized for telephone float service which would incorporate long life ($>$ 30 years) and freedom from mechanical defects.
(*ii*) To provide for close specification of and control over design, materials, processes and components, with the ultimate objective of providing a device in which all facets were controlled and understood.
(*iii*) To introduce standardization and reduction of codes and configurations by adoption of a single unified design.

IV. FEATURES OF THE NEW DESIGN

This paper and those which follow, describe the new lead-acid cell which has been designed; discuss the new processes which have been developed; and provide details of cell performance characteristics, accelerated aging studies and field trial behavior which document its compatibility with the existing telephone power plant and provide a basis from which predictions of life and reliability may be made.

The cell design contains several novel features:

(*i*) The grids are made of pure lead for minimal corrosion and growth and are stacked in a self-supporting structure to minimize distortion.[8]
(*ii*) The grids are conically shaped, for maximum strength, with grid members specially designed to grow in a cooperative, phased manner which provides improved grid/paste contact throughout life and results in a significantly improved capacity aging characteristic.[8]
(*iii*) A new positive paste material, tetrabasic lead sulfate with rod-

like particles which interlock for maximum mechanical stability has been introduced.[9]

(*iv*) Jar and cover are made of a new, transparent, flame-retardant rigid polyvinyl chloride (PVC) material which combines low-cost fabrication, improved impact and craze resistance and increased ease of sealing.[10]

In order to allow reliable fabrication and performance of this design, several new processes have been introduced. These include:

(*i*) A lead-joining technique which provides welded flaw-free positive plate interconnection bonds in multiple, at high speeds compatible with economic manufacturing technology.[11]

(*ii*) A technique for *in situ* casting of a lead-antimony connection rod which provides mechanical and electrical interconnection of the negative plates.

(*iii*) A heat-sealing technique which utilizes directed black body absorption of infrared radiation for localized melting and bonding of the jar-cover sealing surfaces, providing a jar-cover seal capable of supporting over 100 times the weight of the battery.[12]

(*iv*) A redundant post-cover sealing system which provides a rigid epoxy corrosion-restraint sheath on the lead post and is flexibly coupled to the cover to allow stress-free movement of the cell element within the jar.[13]

Central to the development of this new design and the new processes which it incorporates and to our ability to predict its long-term performance was the successful development of techniques for accelerated aging of the electrochemical element, associated materials and supporting systems. Use of elevated temperature aging to predict corrosion, growth and capacity behavior of the electrochemical element, is discussed in detail.[8] Accelerated aging techniques for predicting plastic creep,[10] acid dissolution and interaction effects are also described.[14] Accelerated voltage stressed post-seal corrosion studies are also reported.[13]

Detailed studies of cell charge-discharge and float characteristics are presented in addition to results of initial field trials in working telephone offices.[15]

In this section of the paper we describe the design and construction features of the new cell in some detail. The detailed technical programs which resulted in specific design features are described in the companion articles in the series.

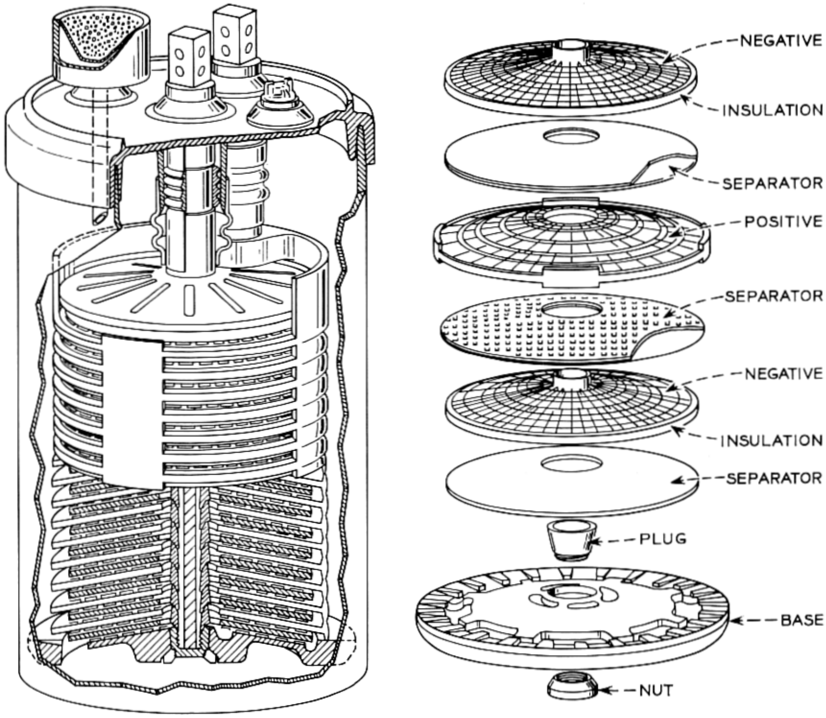

Fig. 9—The Bell System Battery—cutaway and exploded view.

V. CELL DESIGN

Figure 9 shows the new cylindrical cell design in both cutaway and exploded views. Figures 10 and 11 show the pure-lead positive and negative grids in more detail. The plates are conical, cupped to a 10° angle, and stacked, pancake fashion, one upon the other. Microporous rubber separators and fiberglass mats, conically shaped, are interleaved between each pair of positive and negative plates to provide electronic insulation and prevent shorting while allowing ionic and gas transport. Plastic insulating details protect the outer ring of the negative and inner hub of the positive from metallic shorts. The element stack nests on a conically shaped hard rubber base, into which is inserted a blind lead plug secured by means of a hard rubber nut. The upper surface of the lead plug is shaped to receive the conical central hub of the bottom negative plate. The other negatives nest similarly at the center via their conical hubs, forming a hollow central core. A hard rubber cap provides compression to the top negative plate. The lower end of the negative post is conically shaped to nest in the hub of the top negative plate. After stack assembly and after insertion of a copper rod for conductivity, the entire negative group, including plates, plug and post are interconnected by a so-called "center pouring" process. This process, shown schematically in Fig. 12, introduces molten lead-antimony alloy at the base of the core through a tube which is withdrawn at a controlled rate. Heated nitrogen introduced through the same tube serves both to preheat the core and to prevent oxidation of the lead surfaces. After filling and solidification, this results in a mechanical and electrical connecting rod which is metallurgically bonded to the lead hubs.

The positive plates have vertical connector tabs at their periphery and are joined after assembly by a welding process. All early cells were made with a heliarc welding process which provided only a partial depth bond and was quite time consuming. A new bonding technique has been developed to provide full depth, flaw-free bonds at speeds compatible with manufacturing technology.

In this technique the cell stack is turned with its axis horizontal and

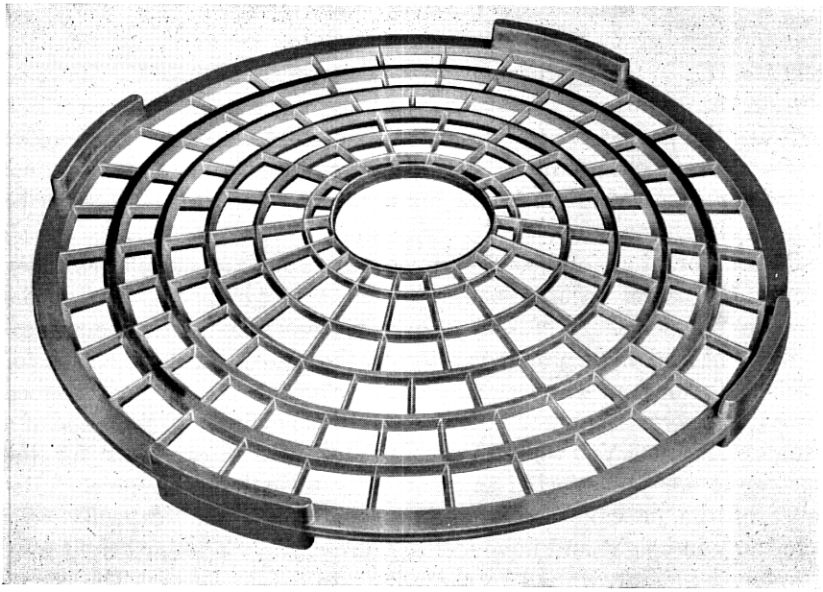

Fig. 10—Positive grid.

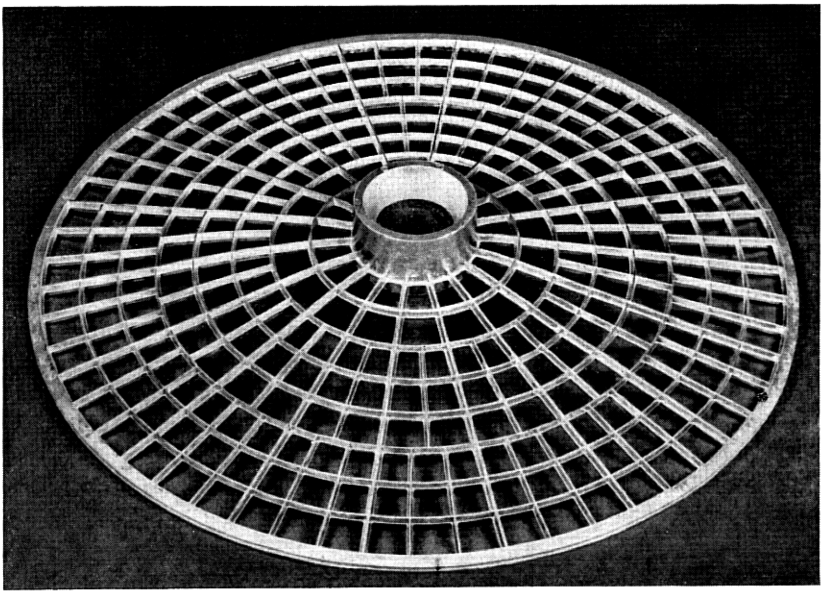

Fig. 11—Negative grid.

a heated tip is passed through from underneath to melt the junction of each pair of positive connector tabs. A curved insulating block which contains the heated tip acts as a traveling mold to contain the molten lead and provide a solidified bond of the same curvature as the original connector tabs. Multiple heads allow at least ten connections to be bonded simultaneously.[11]

Percolation of gas and electrolyte occurs through an annular chimney around the center negative connector and through spaces between the tabs on the periphery of the positive plates. The ten degree conical angle combined with proper venting at the central annulus allows for efficient circulation. The welded unitized element, compressed between the hard rubber cap and base, rests in a simple cylindrical jar made of a flame-retardant PVC which serves primarily as a container for the electrolyte and is subjected therefore only to hydrostatic forces.[10] Because of the pancake stacking arrangement, different capacity cells differ only in height and have identical-sized grids. The jar height may therefore be simply varied to accommodate different sizes. The cover, also made of PVC, provides a heat-sealed shear bond for maximum strength and reliability of the jar-cover seal.[12] For ease of clean-up and maintenance a dam at the outer edge of the cover contains any electrolyte spillage which might result from specific gravity measurements. In addition, the cover overhangs the jar, thus providing an umbrella action to minimize the possibility of electrolyte spillover accumulating at the seal area. (Acid accumulation at jar-cover seals has proved to be a major cause of fire in batteries of conventional design throughout the Bell System.) Post seals incorporate a rigid epoxy sheath to provide a long leakage path which is coupled to the cover via flexible rubber bellows backed up by a piston-cylinder, accordion-ring type seal to allow for vertical movements which result from any shock incurred during shipment and installation and for vertical element

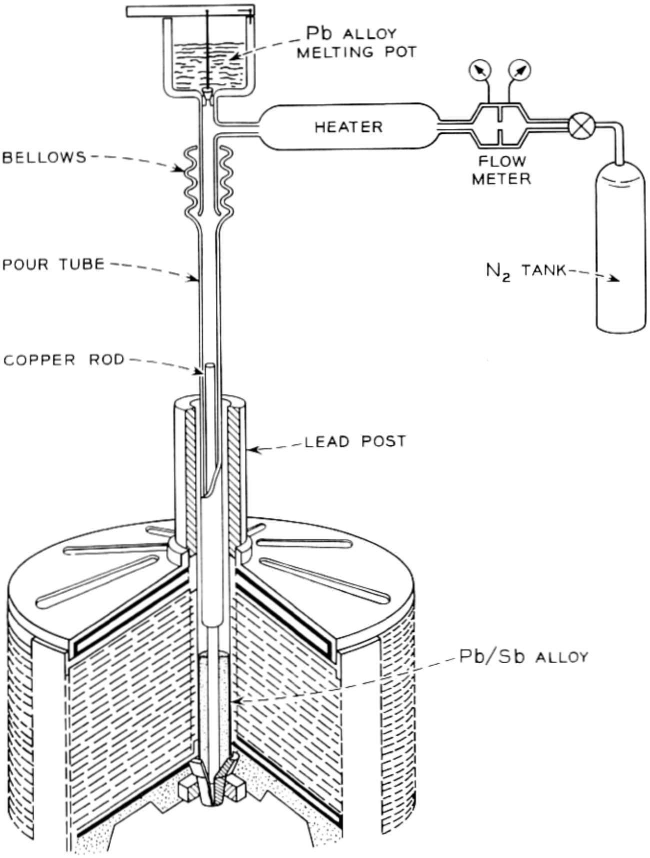

Fig. 12—Centerpouring process—schematic.

growth without overstressing the cover, jar-cover or post seals.[13] The vent incorporates a microporous diffuser which also serves as the funnel for water additions. This has the advantage of retaining all acid condensation and of allowing frequent rinsing and dissolution of salt deposits during normal water addition maintenance. The threaded copper rod inserts have been utilized directly as the terminals for cell interconnections in the early field trial cells. In later designs they will be covered by lead-antimony terminal details cast onto the positive post during fabrication and onto the negative as part of the center pouring operation.

The circular design results from our attempt to minimize the corrosion and control the growth at the positive electrode which is the major life-determining process of lead-acid batteries in telephone float service. The circular conical plates, stacked pancake fashion and joined into a rigid unitized structure, provide a structure of sufficient strength and of minimal loading on the individual elements to allow us to capitalize on the superior corrosion and growth behavior of pure lead which is too soft for use in conventional designs.[8] In this design the stacking arrangement results in loadings of a few pounds per square inch in the most extreme case, well within the long-term creep capability of the pure-lead material. In addition, the circular design allows us to control the contact between the lead grid and the positive paste pellet in such a way as to minimize the capacity loss which occurs in rectangular grids as growth causes the grid to break away from the active material pellet.[8]

A further improvement in grid/paste contact is made possible by the introduction of a new positive active material, tetrabasic lead sulfate.[9] A process has been developed to synthesize this material in the form of interlocking, rod-like particles which minimize shedding and provide optimal grid/paste contact since they do not shrink away from the grid during the pasting, drying or formation processes.

Cells incorporating these features have been built at a battery Design Capability Line (DCL) for laboratory, accelerated and field tests over a size range from 200 to 1000 AH embodying 10.5″ diameter grids which have evolved through three generations of design. Other cells have been built in sizes up to 1680 AH embodying two generations of grids approximately 13″ in diameter. A 1680-AH preproduction prototype design is currently being built at the DCL on prototype manufacturing equipment designed by Western Electric Company. Several hundred of these cells will be furnished to the telephone companies for

TABLE VI—LEAD-ACID CELL FIELD TRIALS

Date	Location	Company	Battery
1/30/69	Murray Hill, N. J.	N. J. Bell Tel. Co.	48V
2/7/69	Gouldsboro, Pa.	AT & T Long Lines	12V
3/21/69	Shirley, N. Y.	AT & T Long Lines	12V
4/11/69	Noyack, N. Y.	AT & T Long Lines	12V
9/16/69	Dover, Missouri	AT & T Long Lines	24V

an extensive field trial during 1970. Specifics of an initial field trial which was instituted in 1969, are shown in Table VI.[15] Figure 13 shows the assembled element of the 420-AH 11″ grid cell furnished for this early trial. Figure 14 shows the completed cell, housed in the same size jar which can contain the elements of the 1680-AH preproduction prototype cell made with 12.5″ diameter positive grids. The 1680-AH cylindrical cell will be electrically interchangeable with and will fit into the same rack space as the conventional 1680-AH designs.

These initial trial cells have furnished important materials and design feedback;[14] demonstrated the durability of the cell in shipment, handling and installation; and, most importantly, served to facilitate operating company acceptance of the new design.

VI. SUMMARY

To provide correction to difficulties observed with commercial cell designs in Bell System use, a new cell has been developed. It utilizes pure-lead grids to minimize grid corrosion and increase cell life. The conical grids are stacked in a self-supporting structure to minimize stress and allow use of the soft lead material. Improved contact to the positive active material results both from grid design and from the use of interlocking particles of a new positive paste, tetrabasic lead sulfate. Rigid, flame-retardant PVC jar-and-cover materials provide improved mechanical strength to the container system and permit introduction of a high reliability jar-cover heat seal. New post seal technology minimizes the possibility of corrosion of the post-connector contact surface during cell life. A Design Capability Line has been established to facilitate introduction of this design into commercial manufacture. Early cells, made at this facility on hand tooling, have been successfully introduced into a limited field trial. A preproduction design is currently being built for a more extensive trial using prototype manufacturing

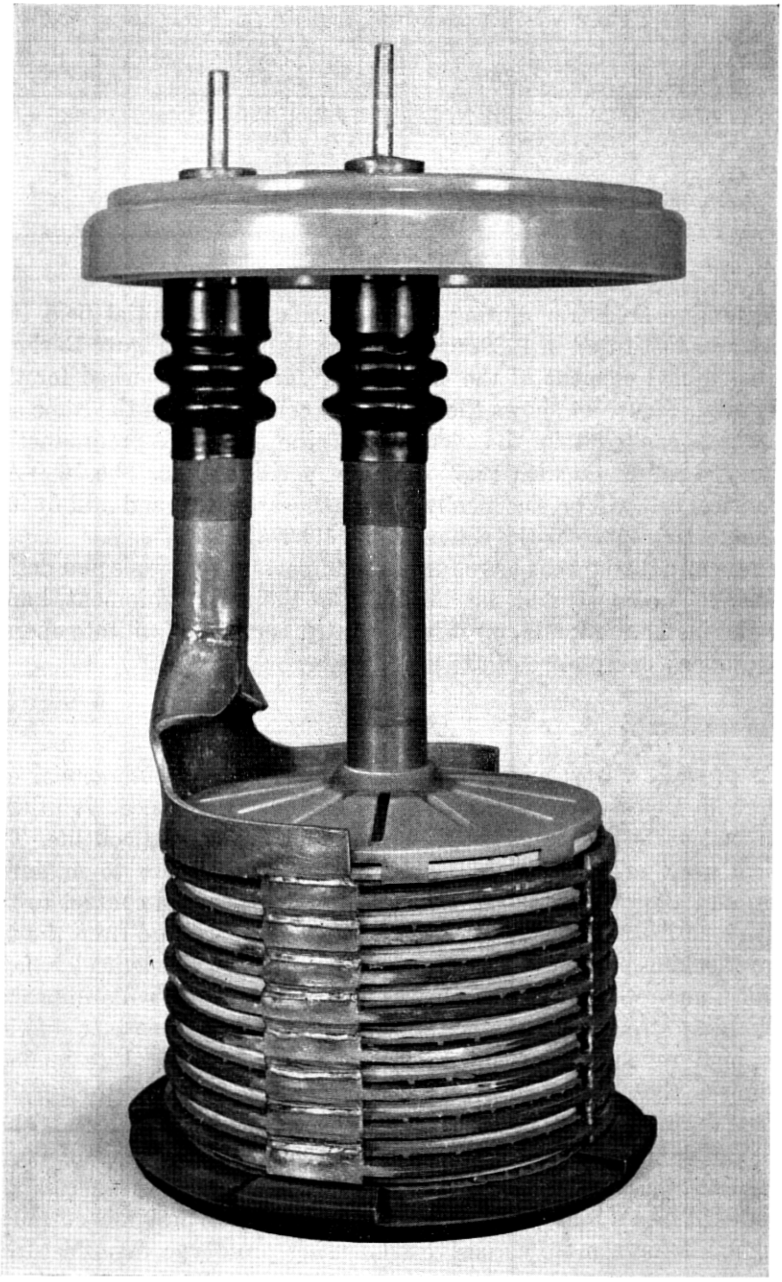

Fig. 13—Element of 420-AH field trial cell.

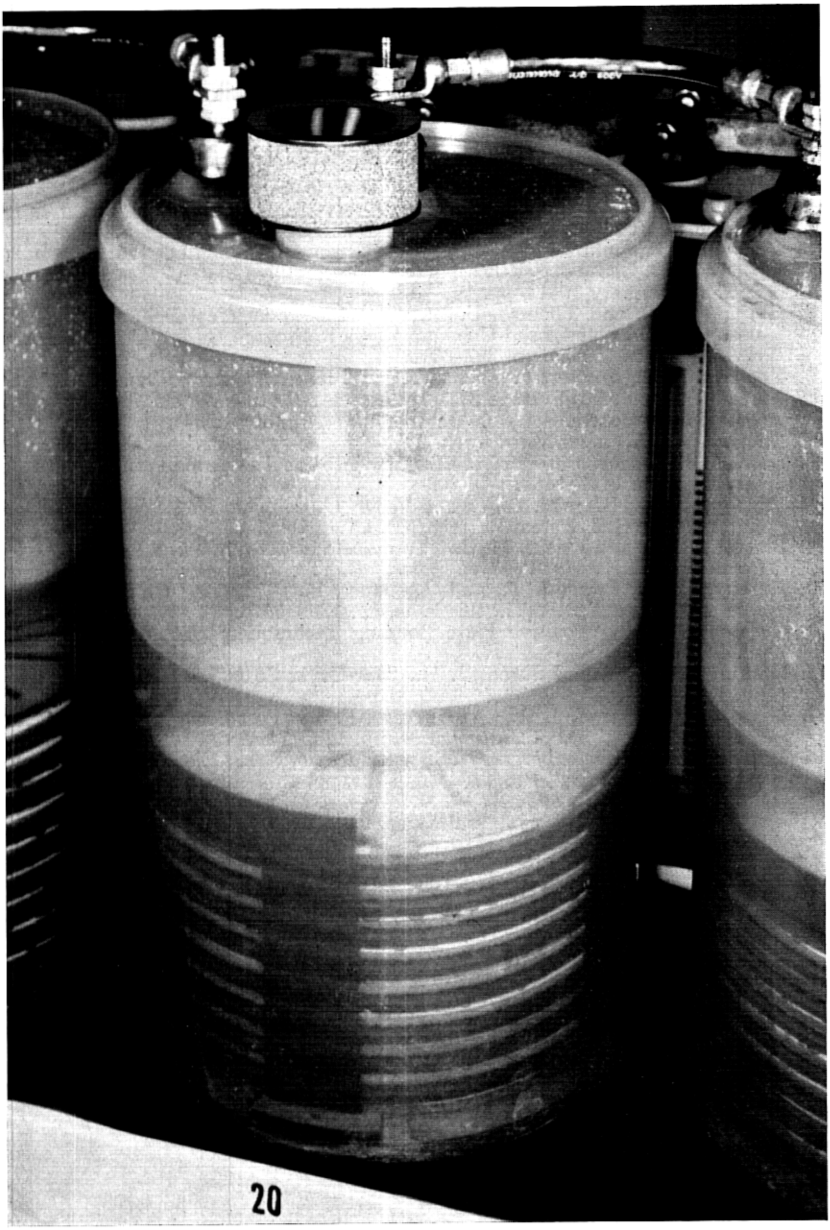

Fig. 14—Complete 420-AH field trial cell.

equipment developed by Western Electric. Accelerated tests have been developed to insure that materials, processes and designs will result in cell life, performance and reliability compatible with Bell System usage.

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