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Some Ceramic Manufacturing Developments of the Western Electric Company

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A general picture is given of the development work involved in the introduction of manufacturing processes for vitreous enameled resistances, vitreous enameled iron and copper base number plates, pressed glass lenses, extruded and pressed porcelain parts, and close tolerance ceramic insulators for use in telephone apparatus. The reasons for undertaking the manufacture of these products, some of the major problems encountered in developing suitable processes, and the work done in overcoming these difficulties including several major contributions to commercial methods of manufacturing similar parts are described.

ORIGINALLY, the ceramic parts used in the telephone and associated equipment were not manufactured by the Western Electric Company because the technical requirements and volume of consumption of such parts did not warrant the development or establishment of processes or the facilities for manufacture. The later development of such manufacturing processes for some of the ceramic parts has been necessitated largely by inability to secure an adequate supply of parts meeting the close limits required for satisfactory functioning of the apparatus, although there have usually been other influencing factors. Such developments have, in most instances, been advantageous from an economic standpoint. The experimental work has been confined to that required for the above ends and only a very limited amount of research work has been done. Some of the major projects for which it was necessary to develop new methods of processing to obtain the desired quality at a satisfactory cost are outlined.

Switchboard Lamp Cap Lenses

The first major project undertaken was the development for manufacture of switchboard lamp cap lenses of the types shown in Fig. 1. One factor necessitating this undertaking was the difficulty experienced change. The resultant compositions are illustrated by the following batch which was developed and used for clear amber glass; and the functions of the various raw materials in this composition are given below:

Glass Sand	45
Red Lead	30
Sodium Nitrate	10
Sodium Carbonate	10
Manganese Dioxide	3
Ferric Oxide	2
	100

Scrap Glass—50 parts approximately.

As is common practice, glass sand was used as the most economical means of obtaining the desired silica content. The sodium content was introduced by the use of sodium nitrate and sodium carbonate. The oxidizing action of the nitrate and manganese dioxide assisted in (1) the prevention of lead reduction; (2) the oxidation of any organic materials present; and (3) the maintenance of the iron in ferric form. The liberation of gas during the decomposition of the sodium nitrate and carbonate tended to stir the glass during melting and in addition the escape of large gas bubbles during this decomposition assisted in the removal of small bubbles of occluded gas. Some of the sodium was introduced as sodium carbonate because it was cheaper than the nitrate. Red lead was used as an economical means of obtaining the desired lead oxide content and to lessen the possibility of any difficulties from unoxidized lead particles. A percentage of glass scrap from the punching and drawing operations was used in each batch as a means of reclaiming the scrap, facilitating melting and improving the working characteristics of the glass when drawn into rods. The amber color obtained in this glass was of course dependent on the predominance of the brown color of ferric iron. If sufficiently oxidizing conditions were not maintained during melting and working, the iron would be reduced to the ferrous state resulting in a greenish color. The color intensity obtained was very sensitive to changes in the amount of heating and to atmospheric conditions in the furnace. This complicated the problem of maintaining the glass within close limits for color and translucency.

After satisfactory glasses with twice the impact strength of the previously imported glasses were developed, open pot manufacture of clear glasses was started on a limited basis.[1] It was then found desirable in order to obtain better signaling characteristics to obtain

[1] H. T. Bellamy *Patent* 1,271,652, "Method of Making Colored Glass," July 9, 1918.

the required light dispersion in certain colors of lenses without the use of sandblasted surfaces. Several methods of dispersing the light were tried including the application of a translucent layer of glass on the back of a clear lens, but as it was difficult to control economically the amount of light dispersion by these methods, it was decided to use opalescent glasses. Calcium phosphate and cryolite were found suitable as opacifiers and satisfactory compositions were developed by means of further progressive changes to suit the particular working conditions in the shop.

Several serious objections were found to the open pot method of manufacture, the most important of which were the long heating period required for new pots and their relatively short life. The manufacture of opalescent glasses increased these difficulties because of the more corrosive nature of these glasses as a result of which the maximum life of the pots was approximately twelve days. In view of this, a small 500-pound capacity gas fired melting furnace known as a day tank was designed and constructed. This tank consisted of a rectangular box shaped furnace lined with refractory blocks about twelve inches thick. With this equipment, a complete batch was melted each night and the resultant glass formed into rods during the next day. Under continuous operation, furnace life of about three months was obtained which was considered very satisfactory in view of the corrosive nature of these glasses.

Satisfactory compositions and methods of manufacture were finally developed for the production of glasses in the required colors. This development resulted in the elimination of an unsatisfactory supply situation, reduced the cost of lenses appreciably, and greatly improved the quality of lenses.

Spirally Grooved Resistance Cores

At the same time that development work on glasses was being carried on, a preliminary survey was made of the advantages of manufacturing instead of purchasing the ceramic cores used in filament resistances. As the preliminary survey indicated that definite advantage would be realized, development for manufacture was undertaken. The part, shown in Fig. 2, consists of a thick-walled tube with a spiral groove on the outer surface in which a resistance filament is placed. Tests first were made on pressing blanks from sodium silicate and powdered slate mixtures. These parts adhered to the die, were difficult to dry, and were very weak in the fired state. Further work was done with talc and sodium silicate mixtures which were stronger but still had the objectionable feature of adhering to the dies. Additional compositions were then made of talc and clay with and without sodium silicate and feldspar. It was found that most satisfactory results were obtained with a ball clay, kaolin, and talc body in the proportions of forty per cent, ten per cent and fifty per cent, and this body was therefore adopted.

Originally, attempts were made to cut the groove in the fired core with a diamond tool but this resulted in excessive chipping of the

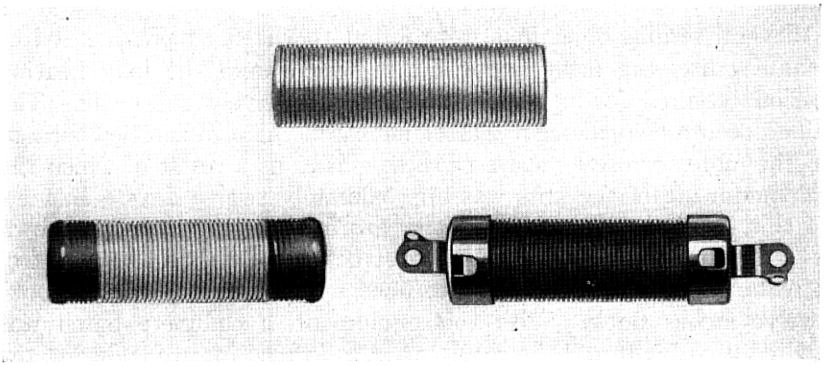

Fig. 2—Ceramic core and completed filament resistance.

groove. A chaser with alternate teeth was then tried out, with the thought that the gradual cutting action would prevent chipping. This also proved unsuccessful. The use of a circular saw, emery wheel, and a phosphor bronze disc charged with diamond dust were also considered. These methods were not completely satisfactory although better results were obtained. Rolling the thread in the core while in the leather hard state after extrusion was then tried with good results and a suitable machine was developed for performing this operation.[2]

With this machine, an extruded blank of slightly oversize diameter was placed on a revolving mandrel. An arm was provided to hold a shaving tool ahead of a disc which formed the thread. This arm was attached to a segment of a nut and the movement of the arm when the nut segment was engaged with a thread integral with the mandrel, shaved the core to exact diameter and carried the disc longitudinally across the core forming the spiral groove. An auxiliary arm carrying two knives was then engaged which cut the core to exact length and

[2] H. T. Bellamy *Patent* 1,384,587, "Manufacture of Composition Cores," July 12, 1921.

chamfered the ends. The finished core was then removed from the mandrel, dried and fired. This method of manufacture produced cores of superior quality at a greatly reduced cost.

Porcelain Protector Blocks

The next major development was that of the manufacture of protector blocks. These small porcelain blocks, used in open space cut outs and shown in Fig. 3, are illustrative of parts where it was necessary

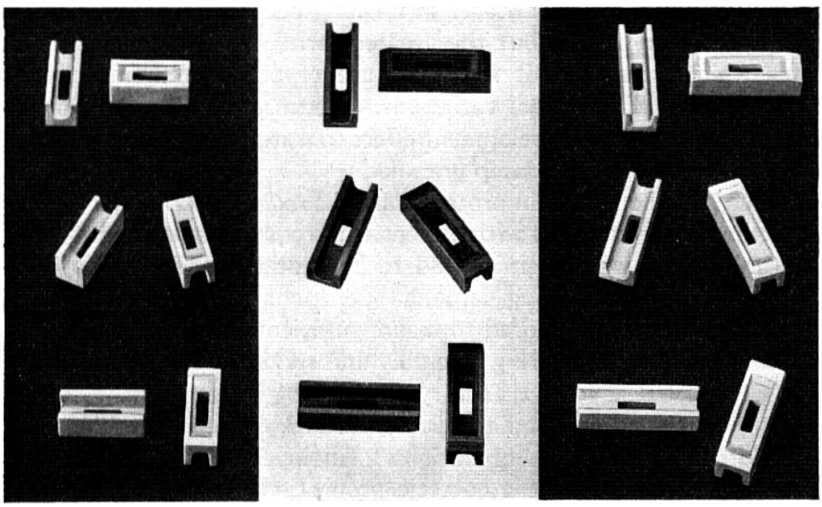

Fig. 3—Porcelain protector blocks.

to undertake manufacture for quality considerations and where such manufacture resulted in cost reduction. They were originally purchased from domestic sources which were unable to meet consistently, required limits as close as +.020-inch and −.015-inch on a .390-inch dimension. The dimensional deviations encountered necessitated sorting to insure proper functioning in the field, and it was necessary to scrap a large percentage of the purchased parts. Difficulties were also experienced in the assembly of the blocks because of manufacturing defects such as small fins and low strength.

Common commercial practice on most porcelain parts of this type at that time was to form the parts on a hand screw press, remove fins by hand, and fire the blocks in refractory containers in intermittent furnaces. The amount of hand labor involved was large and early studies of the economics of manufacture showed it would be necessary to develop new methods of manufacture before the development and plant expenditures associated with the installation of manufacturing facilities would be warranted. A survey of commercial practices indicated that mechanization of the forming operation and simplification of the finning, firing, and material preparation procedures were possible.

The two general methods of processing first considered were: (1) extrusion of a plastic column having the end cross section of the block, cutting this column to block lengths and forming complete in the plastic state; and (2) automatic pressing of damp granules. The first method offered some advantages in forming because of the thin walls of the protector blocks, but the greater shrinkage from raw to fired states which would result from the use of plastic material would involve greater dimensional variations. Because of this factor it was decided to confine the development effort to a study of the possibilities of automatic pressing of damp granules.

The uses of the porcelain protector blocks required a body as highly vitrified as was consistent with dimensional requirements, to minimize moisture absorption in service and to prevent the adherence of carborundum particles during lapping operations in assembly. High vitrification was also required to insure sufficient mechanical strength to withstand handling during assembly and service. Accurate dimensions were essential for satisfactory functioning in service.

Two general types of bodies were considered, talc-clay combinations and feldspar-clay-silica combinations. An investigation of talc-clay mixtures indicated that the eutectic proportion of the two minerals was approximately sixty-five per cent talc and thirty-five per cent clay with small variations dependent upon various clay compositions. The fusion temperature of this eutectic was approximately cone 12 or 2390° F. This combination, however, was not satisfactory since it softened over an extremely small temperature range and formed a very fluid glass in the melted state. A longer temperature range for softening and greater melted viscosity was obtained by the addition of feldspar. A eutectic composition of twelve and one-half per cent talc and eighty-seven and one-half per cent spar was found which fused at cone 6 or 2174° F. Using ten per cent to twenty per cent of this flux, a well vitrified body was obtained at cone 8 or 2237° F The firing range of this body was still much narrower than desired and any excess firing resulted in blistering. Although it was evident that commercial use of this body would require extremely close regulation of temperature, it was decided to investigate its pressing characteristics in view of the small amount of abrasive material it contained and the importance of abrasion on dies and equipment with automatic molding.

A study of the pressing behavior of the body under automatic molding speeds and conditions indicated that development work would be necessary to prevent the molded parts adhering to die surfaces. An investigation of this factor indicated that the sticking to dies was caused primarily not by adhesion between the metal and the molded clay surface but rather by the vacuum effect of a dense air-tight layer of material against the metal. This was shown by the facts that the tendency for sticking decreased with (1) a decrease in the plastic content of the body or a decrease in moisture content; (2) a decrease in the viscosity of the die lubricant which thereby tended to clog the pores of the molded surface to a less extent; and (3) an increase in the volatility of the die lubricant. Two methods of overcoming the sticking difficulties with molding compositions were therefore suggested: (1) opening up the structure of the molded part by the use of coarser material to provide capillaries for the escape of entrapped air, and (2) the use of an improved lubricating compound. Since it was not feasible to improve the lubricant sufficiently, an attempt was made to obtain much coarser talc. The talc normally available at that time was such that on sieve tests approximately five per cent to ten per cent remained on the 300-mesh screen. The availability of coarser talc was investigated and it was found that material coarser than eighteen per cent on 300-mesh was not available at an economical price. In view of the fact that the talc was very fine grained and non-plastic, it gave a very dense molded structure without contributing materially to the strength required to hold the molded part together. It therefore seemed advisable to use a clay, feldspar, and silica body and to minimize abrasion by the selection of suitable tool steels and the proper design of equipment.

In arriving at a suitable body composition of the feldspar type it was decided to use a composition which would mature at about cone 12 or 2390° F. Sufficient feldspar was used to obtain a low porosity when fired over a reasonably wide temperature range. The amount of clay used was governed by the raw strength required. Enough silica was used to obtain sharp definite outlines and to avoid warpage. The following composition was arrived at:

Flint	22.5
Feldspar	37.5
Ball Clay	20.0
Kaolin	15.0
China Clay	5.0
	100.0

Further development work was then confined to methods of processing this body to obtain satisfactory results on an automatic machine. A survey of available commercial pressing equipment indicated that machines of the type used in the manufacture of various pharmaceutical tablets or pellets offered the most promise for adaptation to molding protector blocks. The development of suitable equipment was complicated by the extremely thin walls of the parts and the necessity for rapidity of operation. In the hand molding method commonly used in the industry, a slow application of the molding force was possible at the end of the stroke and likewise a gradual withdrawal of the top die was possible after completion of the forming operation.

After some preliminary work with various types of tableting machines, we concentrated our efforts on single-plunger-type machines with double dies. One of the major problems was a satisfactory method of die lubrication since with the machine operating at twenty-eight strokes a minute, the die surfaces were exposed for oiling only an instant during each cycle. The use of an atomizer-type device with a mixture of lard oil and kerosene was finally adopted with the amount of lubricant closely controlled by oil sight cups. Exact timing of the application of the spray to dies was obtained by automatically operating air check valves. This method proved more satisfactory than wiping with saturated felt or incorporating a lubricant in the body particles before molding.

The various stages of the molding cycle are shown in Fig. 4. The cycle of operation at twenty-eight strokes per minute was as follows: as the bottom die reached the lowest position, a feed hopper was vibrated over the cavity. The withdrawal of this hopper removed excess material, after which the top punch descended forming the part. The bottom and top punches then moved upward until the bottom of the part was flush with the top of the die. A projection on the hopper then pushed the part free. Before the hopper reached a position over the cavity, any particles of clay adhering to the dies were blown off and the lubricant was sprayed over each die. The lower and upper dies were then returned to the original positions.

A large amount of work was also necessary to adjust the size and moisture characteristics of the pressing material not only to secure well formed parts and prevent sticking but also to secure fired parts meeting the desired requirements. A mixture of colored and uncolored particles was used in the study of these characteristics in order that the flow movements in the die during compression could be studied. As a result of this work, it was found that most satis-

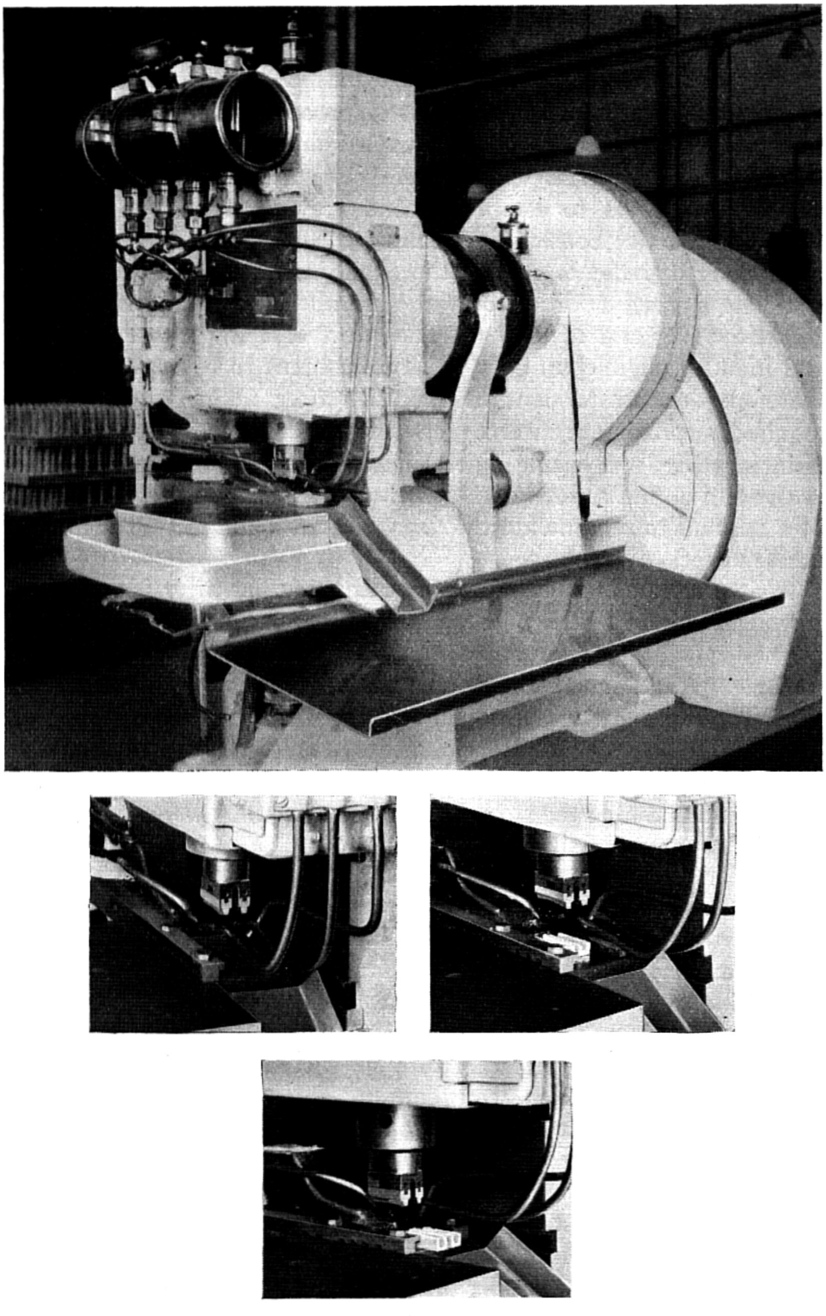

Fig. 4—Block forming press.

factory results could be obtained with 10–24-mesh material and a 12.75 per cent ± .75 per cent moisture content. This moisture content was sufficient to give a compact part and body mix still could be fed satisfactorily to the dies. Methods of processing the body mix were then worked out to hold it within these limits.

The use of material within these close size limitations involved considerable effort to establish economical methods of production. Common practice consisted of slaking the clay in water, adding the other body ingredients, mixing thoroughly with water, filter pressing, complete drying, addition of water to obtain the desired moisture content, aging and screening. The effect of aging was investigated and found negligible with the moisture content to be used and it was therefore decided to dry the material after filter pressing to the required approximate twelve per cent moisture content before the disintegrating and sizing operations. Methods of handling were evolved to obtain a maximum percentage of material between 10 and 24-mesh and to regranulate the fines without again mixing them with excess water.

Various methods of economically removing fins after forming were investigated and initially the fired parts were tumbled with small porcelain balls. This method removed fins and produced smooth surfaces. Another advantage of the method was the automatic elimination of any weak or flawed parts by breakage during the tumbling. Later, further developments in methods of firing described hereafter made it more economical to remove the fins in the raw state by vacuum brushing the parts in multiple after they were arranged on trays at the pressing machines.

Initially the parts were fired using the practice then commonly followed in the industry. With this method, the parts were placed in saggers and fired in an intermittent kiln. This method involved costly handling, heat losses due to heating and cooling the furnace at each firing, and considerable expense from sagger replacements. A small continuous kiln was therefore installed in which the parts were carried in layers on top of cars through successive preheating, firing, and cooling zones which were continuously maintained at definite temperatures, the heat from the cooling fired ware being used to heat the incoming ware.

Summarizing, the method of manufacture finally developed for porcelain blocks consisted in mixing feldspar, clay and flint with water to get an intimate mixture, filter pressing, drying to proper moisture content, sizing, automatically molding the parts, removing fins in multiple, and firing in a continuous kiln. This method resulted in a marked improvement in quality and reduced the cost of parts. The method of automatic pressing developed constituted a major contribution to existing commercial methods of manufacturing small porcelain parts.

Vitreous Enameled Copper Base Number Plates

Manufacture of parts similar to the vitreous enameled number plates used on calling dials and shown in Fig. 5 was limited to producers

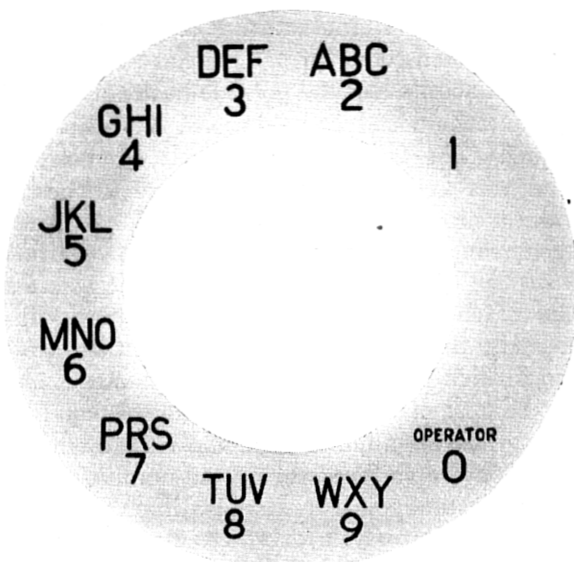

Fig. 5—Copper base number plate.

of enameled parts of the watch dial type. Because of our unusual requirements for dimensions and character location together with the need for a collar and locating pins, only one source of supply could be developed. With rapidly increasing schedules for calling dials and because of the possibility of conditions deyond the control of the supplier interfering with the continuity of supply, this situation was unsatisfactory and made it advisable to undertake manufacture to remove possibilities of any embarrassment from a supply standpoint. As sources of supply for copper enamels were also limited, various enamel compositions were investigated. It was found that the following composition would give an enamel satisfactory for color, texture, gloss, fusibility, and durability when fired on copper blanks:

Red Lead	40
Pearl Ash	6
Sodium Nitrate	9
White Arsenic Oxide	6
Flint	31
Borax	8
	100

In practice constituents of this enamel were first thoroughly melted to a homogeneous glass, giving on cooling a glass magma having high opalescence. The dead white opacity of this enamel could only be developed by slow cooling through the range necessary to precipitate the arsenic compounds. Manufacturing considerations, such as the necessity of an enclosed room for commercial smelting to avoid contamination as well as to avoid the possible health hazards involved in the smelting of arsenic-lead combinations, led us to purchase the required enamel. The fact that a suitable composition had been developed and was available for manufacture if necessary was an advantage from a supply standpoint.

Various enameling procedures were considered. In order to cover the vertical surface of the collar satisfactorily, it was essential that this surface be coated either by dipping or by spraying. It was equally important to apply the enamel coating to the flat surface of the plate by dusting on a thick coat of dry powdered enamel. This dust coat was necessary because of the thickness of enamel required on the flat portion to strengthen the number plate and also to obtain the desired quality of finish on the surface bearing the numerals and characters. From an economic standpoint, it was also imperative that only one enamel fire be used. Initially, efforts were made to dust enamel on a blank already completely coated with a thin coat of enamel slip consisting of finely divided enamel frit suspended in water by means of clay or bentonite. It was found on firing that the added refractoriness of the enamel slip containing the clay or bentonite resulted in a roughened fired surface over the dusted area. This was caused by the formation of gases in the decomposition of the clay or bentonite while the enamel was in a viscous state. It was therefore necessary to protect the flat portion of the plates by templates during spraying. As this was costly, a study was made of other means of floating the enamel frit for collar application.

In order to overcome these process difficulties, it was desirable to find a material which would (1) satisfactorily hold the heavy lead enamel particles in suspension and prevent packing, (2) not attack the enamel or impair its durability, (3) decompose before the enamel started to fuse, and (4) be inexpensive. Soluble alginates appeared to possess these properties and excellent results were obtained from their use.[3] These substances were made from kelp. Their most interesting property as a suspending medium was the ability of the alginates when added to water even in small percentages to make solutions of high viscosity. For example, water solutions of ten per cent ammonium alginate would stand stiff. Some of the advantages in our use of alginates for suspending number plate enamel were: (1) uniformity of composition resulting from the alginates being a manufactured product rather than a natural mineral; (2) the fact that dried sprayed coats of alginate suspended enamel were less subject to damage from handling; (3) a low decomposition temperature which resulted in the material being driven off before fusion of enamel, thus avoiding bubbles in the enamel; and (4) increased resistance of the finished enamel surfaces to chemical attack and their ability to withstand greater mechanical shock and distortion without damage, since any refractory materials present when the enamel was fired would not be completely fused or incorporated into the glass, leaving points more readily attacked chemically as well as lines of mechanical weakness.

Using alginate suspended enamels, suitable manufacturing processes were developed for the application and firing of enamel and the application of characters to the fired plates. A machine was devised for the application of the sifted coating, and rotary continuous furnaces were installed for the firing operations.

Originally the decalcomania method was used for character application. In this process, the enameled parts were first coated with a thin coat of sizing and, after partial drying, they were placed in a locating fixture mounted on a small arbor press and pressure was applied to a properly located transfer by means of a soft rubber pad. The paper backing of the transfer was then removed by soaking in water and, to insure contact, the characters were repressed with a silk covered pad. The sizing was then baked off before firing to remove organic materials and eliminate shadows around the characters. This method was costly and even well trained, careful operators did not produce satisfactory plates.

To eliminate these defects, an offset printing and dusting method was developed in which an electrotype printing plate was covered with printer's ink and an impression was transferred to the number plate by means of a rubber transfer pad. Powdered vitrifiable colors were then dusted over the entire surface of the plate and the unprinted areas of the part brushed clean with a camel's hair brush. In printing two color plates, the black letters were printed and dusted first, after

[3] L. I. Shaw *Patent* 1,806,183, "Suspension," May 19, 1931.

which the red numerals were printed and dusted. By using a special black powder which would give an intense black in combination with a thin film of red powder, one firing for both colors was possible. This method required close control of temperature and humidity of the air in the room which was therefore air conditioned.

Even under good conditions considerable difficulty was experienced at times with the adherence of the powder to unprinted areas. In addition, the application of the powder and the brushing operation required the installation of a special well exhausted unit and involved some problems in the recovery of the ceramic dust which were quite expensive. Efforts were therefore made to incorporate the glass powder directly in the printing vehicle. The development of a

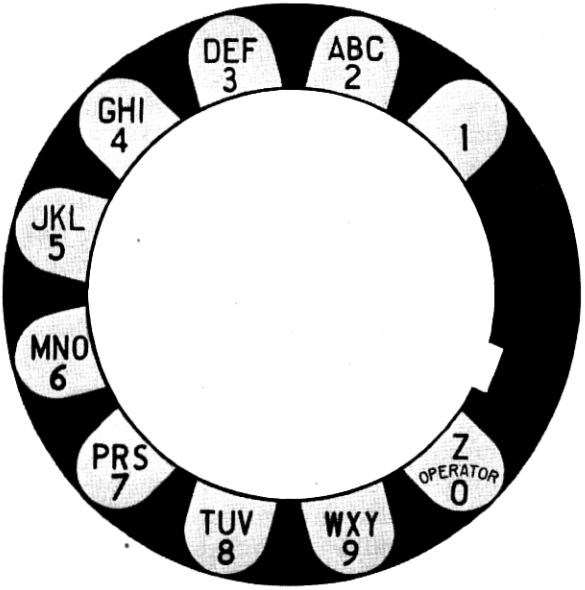

Fig. 6—Iron base number plate.

ceramic printing ink covered tests on various printing vehicles to determine what vehicle or mixture of vehicles would be most suitable. Difficulty was encountered in incorporating a sufficient amount of inert, finely pulverized, intensely colored glasses into a vehicle and still retaining the properties essential for offset printing by transferring an impression from an electrotype plate to a vitreous enamel. This problem was finally solved by the use of a relatively large percentage of uncalcined ceramic material in combination with light and heavy ink varnishes.[4] Motor driven presses using this ink were also developed to facilitate the printing operations.[5]

The manufacture of these parts was undertaken primarily to eliminate an undesirable supply situation but Western Electric manufacture resulted in improvements in quality of enameling, quality of printing, and in mechanical strength. This latter characteristic was important since it reduced assembly losses from cracked plates.

While vitreous enameled copper base number plates have been replaced by other types, the developments outlined were the basis of subsequent enameling developments.

Vitreous Enameled Iron Base Number Plates

The low level of illumination at some pay stations led to the design by the Bell Telephone Laboratories of a large iron base number plate, shown in Fig. 6, to be mounted flush with the finger wheel of the dial. Since the demand for these plates was relatively small, they were originally made by the usual process followed in the industry in enameling similar articles. This process consisted of applying and firing one ground coat for adherence and then applying and firing two sprayed cover coats to obtain the whiteness and opacity desired; all being felspar enamels. The whiteness was not as good as that obtained on the copper base plates with lead enamels and in addition considerable difficulty was experienced in the field due to the fading of the characters as a result of chemical action on plates exposed to corrosive gases such as sulphurous fumes in certain locations. The process was also costly.

Since maximum whiteness and opacity was obtainable in the lead-arsenic type of enamels previously described when applied by dusting on dry, it was desirable that the coating be applied in this manner. In order to avoid several enamel applications and firings, it was also desirable that other portions of the plate be protected by some corrosion resistant coating other than vitreous enamel which would necessarily have to retain such corrosion resisting properties after exposure to a temperature of 1500° F. for six minutes and also be capable of being enameled with satisfactory results. Numerous coatings were tried and it was found that a Western Electric black oxide finish on iron would satisfactorily meet all requirements.[6] Using this finish, it was possible to fuse the enamel directly on the upper surface of plates, to retain corrosion resistant qualities on all other exposed surfaces, and to reduce the number of process operations. A number plate of greatly improved appearance and durability also resulted. In addition, the curved

[4] L. McLaughlin *Patent* 2,030,999, "Ink," February 18, 1936.
[5] L. McLaughlin *Patent* 1,951,430, "Printing Apparatus," March 20, 1934.
[6] W. J. Scott *Patent* 1,962,751, "Ceramic Coated Articles," June 12, 1934.

surface obtained in dusting a base plate having a groove around the edge prevented the entrapment of air between the plate and the printing pad during the printing operation, thereby resulting in a simplification of that process.[7]

As a result of our development of enameling over the black oxide finish it would have been possible to replace the previously described copper-base number plate by one employing a sifted coat of enamel over such finish on a steel blank. However, the application of the black oxide finish on enameling iron was so costly that manufacture of number plates by this process was not competitive. We therefore continued our developments and found that it was possible to enamel directly over an electroplated copper-nickel finish consisting of a minimum of 25 m.s.i. each of copper and nickel on a mild steel blank and get a smooth enamel coat having very good adherence.[8] As this finish had the necessary rust resistance and the blank was relatively flat, the enamel could be applied in a single sifted coat on the face only to produce a satisfactory number plate. Also with the steel base it was not necessary to have a thick coating of enamel for strength as was the case with the copper base number plate. In fact, due to the good adherence of the enamel coat, if the thickness of enamel after firing was less than 0.010 inch the plate could be flexed considerably without chipping the finish. On the other hand, it was necessary to have a minimum of 0.007 inch of enamel to hide sufficiently the gray color of the nickel surface. Additional refinements of the enameling process were effected by improvements in the uniformity of enamel distribution and in the printing of characters; and the process was generally automatized. These developments produced a number plate of superior quality and appearance at a reduced cost. As all final details for commercial manufacture have not been completed further details of this process will not be given here.

Vitreous Enameled Resistances

With the increased use of panel-type machine switching, the demand for vitreous enameled resistances for controlling the current for operating relays and switches increased materially and manufacture of these parts was undertaken. These resistances were required to dissipate a considerable amount of heat in service and to reach a high operating temperature without being damaged. The units therefore consisted of a suitable resistance wire wound on a ceramic core and covered with a vitreous enamel. Some of the types now being manufactured at Hawthorne are shown in Fig. 7.

[7] W. J. Scott *Patent* 2,020,476, "Ceramic Articles," November 12, 1935.
[8] S. R. Mason and W. J. Scott *Patent* 2,020,477, "Ceramic Article," November 12, 1935.

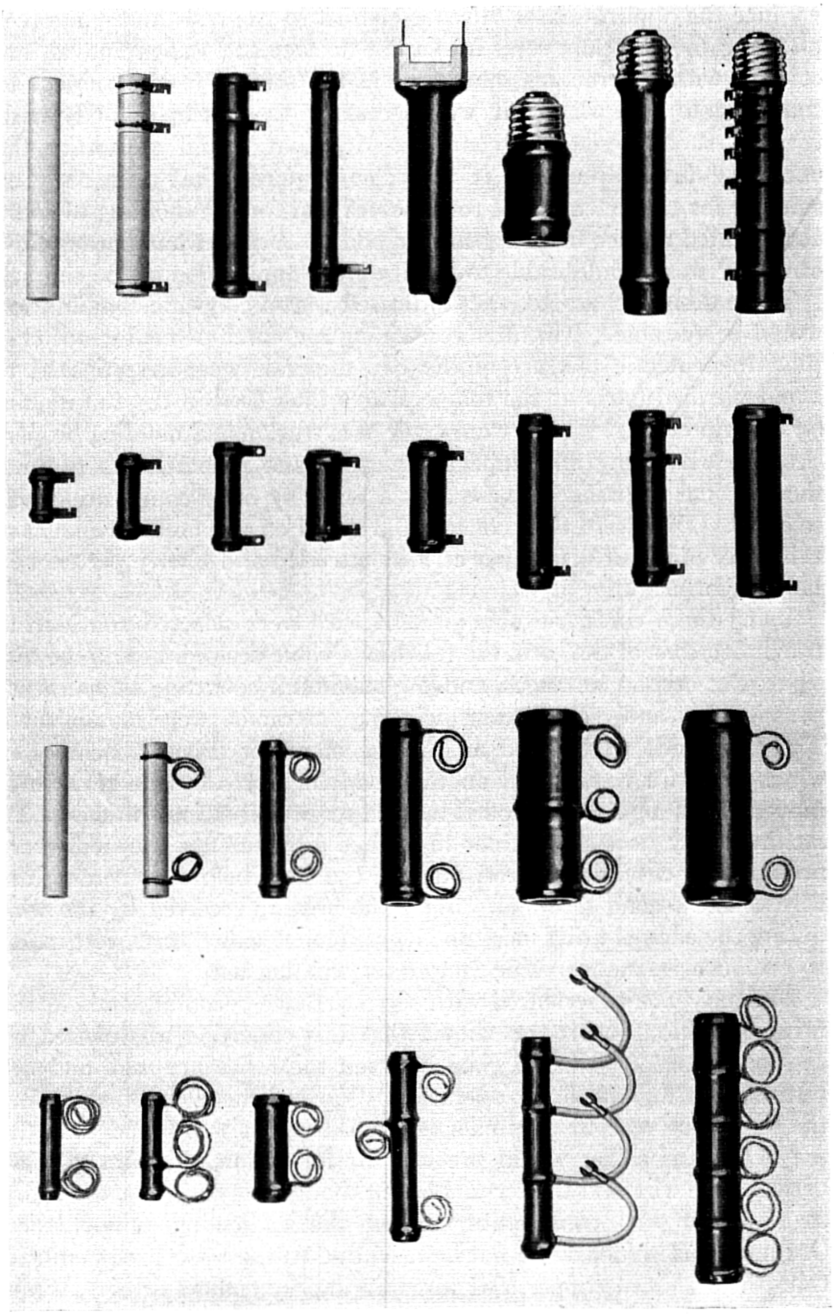

Fig. 7—Ceramic cores and vitreous enameled resistances.

Since the application of vitreous enamel to the resistances involved plunging the porcelain cores into a hot furnace and their removal into cold air without cracking, and since in use they were also subject to considerable heat shock, it was necessary to develop a body with thermal shock resistance characteristics that would still have the necessary fired strength. It was also required that this body be suitable for the extrusion of round cores and for the molding of more complicated shapes from a granular body. A somewhat porous fired structure was also desirable to facilitate the application of the enamel.

These desired characteristics indicated that a clay-talc combination would be suitable. Mixtures containing a greater percentage of clay than the eutectic mixture of the two minerals were investigated to avoid vitrified parts at the temperatures then used in the tunnel kiln for other products. Tests were made of extrusion and molding properties, fired, breaking and impact strengths, and resistance to thermal shocks. On the basis of these tests a talc-clay body composition was selected. Dies were then constructed based on the fired shrinkage of this body of about fifteen per cent in extruded and twelve per cent in molded forms.

Using these cores, suitable sizes of wire were selected considering the dimensions of the core, the resistance value desired, heat to be dissipated at certain wattages, and the maximum operating temperature permissible, and satisfactory winding methods were established. These methods were based on the use of motor driven machines in which the wire was spaced on the revolving cores by the transverse movement of a guide controlled by lead screws of various pitches. To facilitate any necessary minor resistance adjustments, methods were provided for checking the resistance of the units before connecting the wire to the second terminal. Since the heating received by the wire during the enamel firing increased its resistance value, tests were made to establish resistance value factors for winding use.

Difficulty was experienced with the resistance becoming open in the firing operation and it was shown that this condition was caused by the formation of a film of glass between the resistance wire and the terminal during the firing operation. Various methods of attaching the resistance wire to terminals were tried and it was found that the use of lead as solder would prevent the formation of a film of glass between the wire and the terminal even though the fusion temperature of the lead was considerably below the enameling temperature. Ordinary soft solder could not be used due to the tin content embrittling the standard copper lead wires during the enamel firing. While silver solder could be used it was costly both for material and in application.

In developing an enamel to be used for resistances, it was desirable that the melting temperature be as low as possible consistent with good durability in order to maintain at a minimum the thermal shocks received by the porcelain cores and any changes in the resistance of the wire during firing. A very high viscosity during fusion was also desirable in order to avoid running of the enamel during firing, an undesirable feature which would result in exposed wires and unsightly lumps unless the enamel was applied in numerous thin coats. Conversely to these requirements, it was necessary that the enamel coating be glassy in appearance, smooth, free from blisters and pin holes, and capable of being fired in a relatively short time.

These factors indicated the desirability of investigating lead-boron-silica mixtures and the elimination of any raw clay or similar refractory substance in the enamel slip. The enamel finally developed was as follows:

Red Lead	48.0
Boric Acid	24.0
Flint	10.0
Soda Ash	3.7
Cryolite	6.0
Tin Oxide	1.6
Manganese Dioxide	0.5
Cobalt Oxide	0.6
Iron Oxide	4.0
Zinc Oxide	1.6
	100.0
White Lead	10.0
Light Calcined Magnesia	1.3

All of the materials other than the white lead and light calcined magnesia of the above composition were fritted or melted to a glass and then quenched in water. The fritting of these materials was done to insure complete formation of stable compounds and to permit more rapid firing of the enamel coating on resistances to a smooth homogenous glass. The proportions of sodium, lead, boron and silica were selected to obtain a stable coating with the desired viscosity characteristics at as low temperature as possible. Sufficient opacity of the coating was obtained through the use of cryolite and tin oxide. The cryolite also functioned as a flux. A pleasing dark color was obtained economically with the iron, cobalt and manganese contents. The zinc oxide functioned as an additional flux and also aided considerably in the formation of a smooth coating. Slight variations in the sodium content of this enamel affected its viscosity markedly and also affected its expansion characteristics.

After fritting, the resultant glass was sized and suspended in a water suspension of white lead and light calcined magnesia in a tank provided with mechanical agitation. This method of suspension aided in increasing the fired viscosity without the formation of blisters and pin holes. Smooth glassy resistances were obtained with this enamel in a ten minute firing at 1150° F. without appreciable bubbling or flowing of the coating. This eliminated the necessity of three or four thin fired coats and resultant greater variations in resistance values after firing.

Close Tolerance Ceramic Barriers and Insulators

In the design of the handset type of telephone transmitter, it was found desirable to use a thin washer type insulator, shown in the lower portion of Fig. 8, as a barrier to control the path of the current between

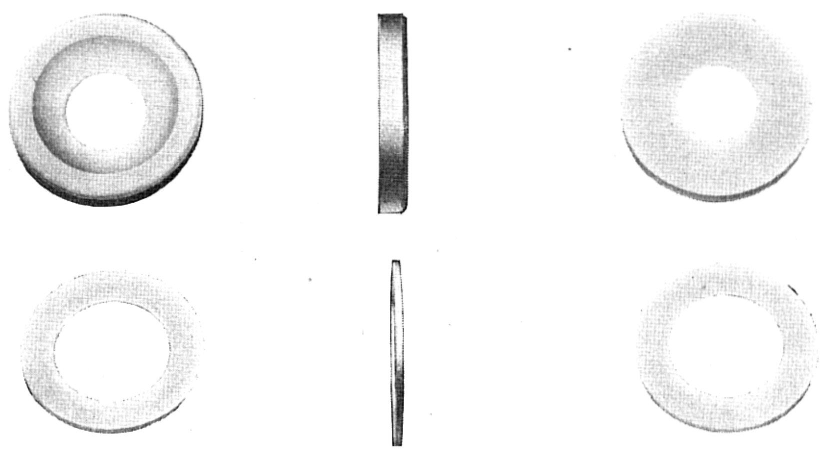

Fig. 8—Close tolerance insulators.

electrodes. This necessitated very close dimensional tolerances, unusual freedom from surface and edge defects, and reasonable strength to withstand the clamping force used in assembly.

Various materials such as fiber, lava and metal coated with vitreous enamel, were tried and lava gave the most promising results. In view of the cost of lava parts, experiments were made using the usual process of dry pressing a porcelain body in which the clay content furnished the raw strength. The difficulties inherent with this process were the fragility of the raw part and the variable dimensions resulting from uneven drying and firing shrinkages. Because of the fragility of the parts, it was necessary to mold them 0.050 inch thick and then lap the fired parts to the desired thickness of 0.030 inch. This operation was costly and losses from breakage were high. The narrow dimensional limits of $\pm$.002 inch on thickness were also hard to maintain because of the difficulty of keeping the lapping surfaces parallel. In view of this, it was decided to machine the parts from natural talc rod or lava.

The mineral talc or lava, being soft, was easy to machine and the firing shrinkage was only one per cent as compared to about ten per cent with dry pressed porcelain. While less difficulty with warpage and dimensional variations was experienced, the machined surfaces, while reasonably smooth and accurate, were not equal in quality to surfaces obtainable with molded parts. The chief difficulty with the process was in obtaining a satisfactory raw material free from flaws and fissures. The first work was done with domestic lava which was somewhat granular in structure but large rejections resulted from pitted surfaces and chipped edges. A survey of domestic lavas showed that only a small percentage was sufficiently dense. Chinese white lava was found to be homogeneous and fine grained but of uneven shrinkage. Best results were obtained with Italian green lava and this material was used in commercial production. Due to breakage because of fissures, the number of good insulators per foot of rod was very low and the manufacturing cost was therefore excessive.

In view of this, various domestic manufacturers of glass, porcelain, lava and other types of ceramic parts were canvassed but no source of supply that could meet the required quality limits could be located. It was therefore decided to make a thorough investigation of new molding compositions for the job. As a first step in this study, it was necessary to do away with drying shrinkage which required a binder which would give sufficient strength in the raw state to withstand the various finning and handling operations prior to firing. It was also desirable that such a binder should not affect the fired structure of the parts. Various organic substances such as pitches, phenolic resins, asphalts, paraffins, and waxes were tried in both hot and cold molded bodies. It was found that a large percentage of these binders could be incorporated into a body without deformation during firing.[9] As a mixture of paraffin and carnauba wax was found satisfactory for cold molding and in addition possessed sufficient hardness to furnish the necessary molded strength, this combination of materials was chosen for the binder.[10]

[9] W. J. Scott *Patent* 1,847,102, "Ceramic Material," March 1, 1932. W. J. Scott *Patent* 1,977,698, "Ceramic Material and Method of Making the Same," October 23, 1934.

[10] L. I. Shaw and W. J. Scott *Patent* 1,847,197, "Ceramic Material and Method of Making the Same," March 1, 1932.

Another major factor in the development of a suitable molding compound was the abrasive effect of the molding body on the die parts. Because of the close tolerances required, this factor was important in order to avoid excessive tool expense. Talc was therefore chosen as the chief body constitutent to obtain a long die life. The balance of the body was made up of twenty-five per cent clay which gave the desired density in both molded and fired states. With the talc-wax compound, a long die life was obtained even with the close tolerances required. As a result of the use of a combination of waxes as a binder this composition had a low uniform shrinkage of approximately four per cent as compared to about ten per cent with most dry pressed porcelains. In addition, variable shrinkage and warpage resulting from drying strains were eliminated.

In molding this body, the lubrication of die surfaces was found to be critical because of the extreme thinness of the part. It was impracticable to apply a sufficiently exact amount of a liquid lubricant to prevent the parts from either adhering to the dies or being weakened from the absorption of the liquid. This problem was overcome by tumbling the granulated molding material with a fraction of a per cent of zinc stearate.[11] The stearate coated grains of material were then molded without any additional die lubricant.

Using the above composition, the process developed was as follows: The talc and clay were thoroughly milled in a carbon tetrachloride solution of the waxes. After drying, this mixture was disintegrated and sized, after which the particles of compound were coated with zinc stearate. The parts were then molded four at a time in a commercial self-contained hydraulic press within an accuracy of ± 3 per cent of the total thickness and ± 1 per cent of the inside diameter. After molding, any fins were removed and the parts trimmed within ± 1.5 per cent of the total thickness in a finning machine which was an adaptation of a commercial automatic indexing head drill press. In this machine, the parts were fed to a rotating end cutter by a revolving indexing head and were held under this cutter by a vacuum applied to the underside of the parts. Tungsten carbide cutters were used to obtain long tool life. After finning, the parts were fired in small trays in a continuous kiln. The parts were then individually gauged for thickness, roundness and inside diameter and individually inspected for cracks, flaws, and burrs. They were then examined under a 10 to 1 glass for smoothness and regularity of inner edge before being used in the assembly of the transmitter.

[11] W. J. Scott *Patent* 1,847,196, "Ceramic Article and Method of Making the Same," March 1, 1932.

This development permitted the manufacture of ceramic insulators within limits not feasible with other methods of manufacture at that time except by machining from mineral talc and to closer dimensional tolerances than ever before attained in molded ceramic parts. The cost of the parts was reduced to a fraction of that of machined parts and their quality was greatly improved. Since that time the process has been used in the manufacture of other close tolerance ceramic parts for telephone use such as the insulator shown in the upper part of Fig. 8.

Although the outline of miscellaneous manufacturing developments given herein does not include all of the engineering development effort on glass, porcelain and vitreous enamel problems it gives a general picture of the type and scope of past engineering work in the production of ceramic articles for telephone apparatus. The miscellaneous ceramic parts used in telephone apparatus were described in an earlier publication.[12]

[12] A. G. Johnson and L. I. Shaw, "Ceramics in the Telephone," *Industrial and Engineering Chemistry*, Vol. 27, pp. 1326–1332, November, 1935.