

June 8, 1937.

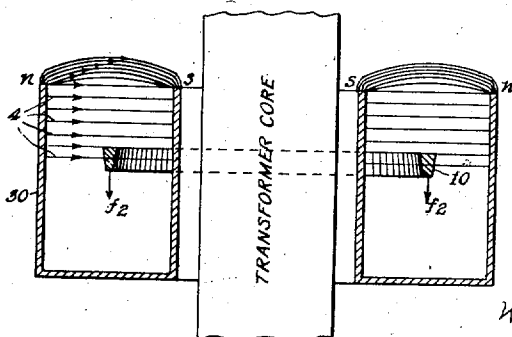
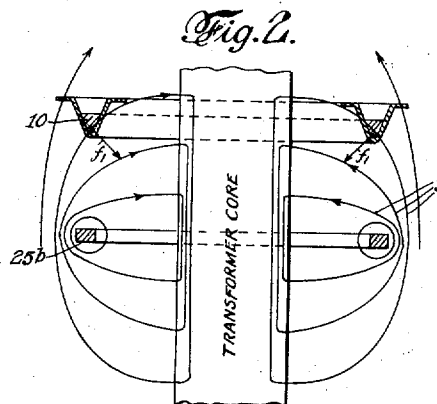
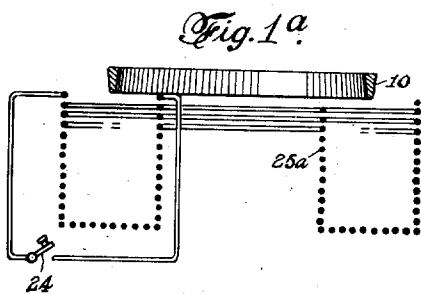
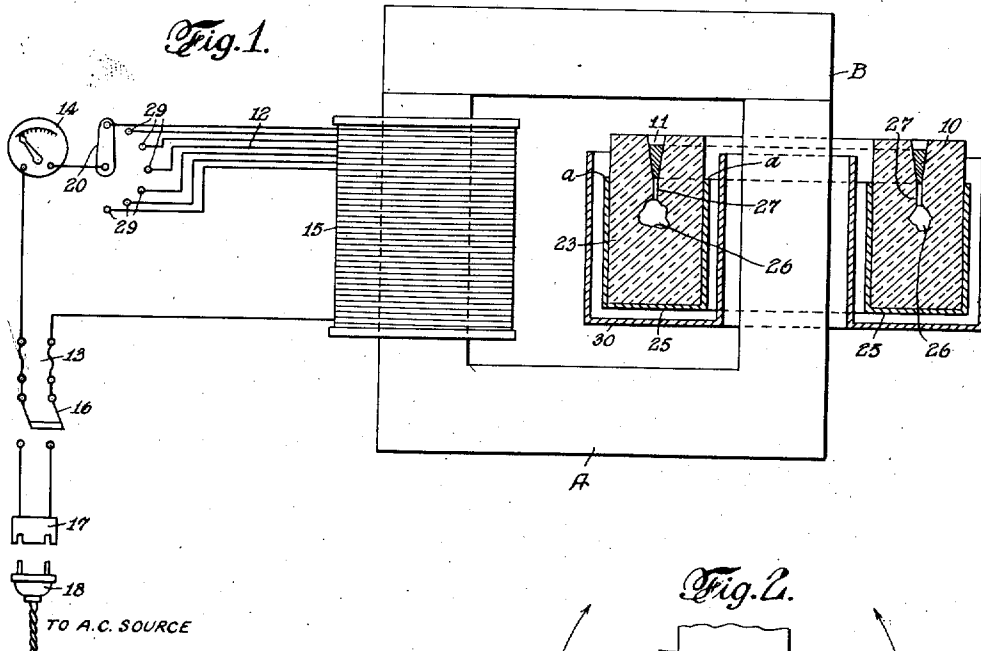
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2,083,022

METHOD OF CASTING METALS BY ELECTROMAGNETIC FORCES AND APPARATUS THEREFOR

Filed Sept. 29, 1933

4 Sheets-Sheet 1



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4 Sheets-Sheet 2

Fig. 4.

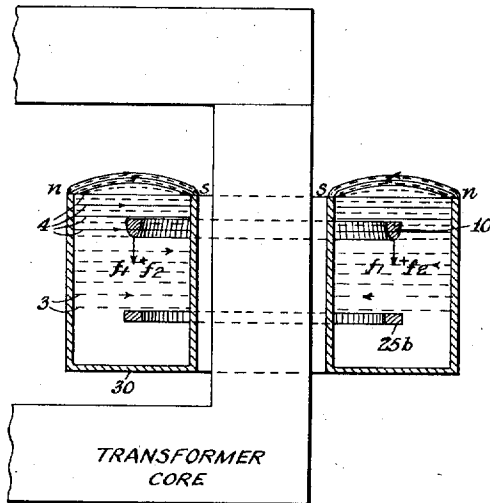


Fig. 4^a.

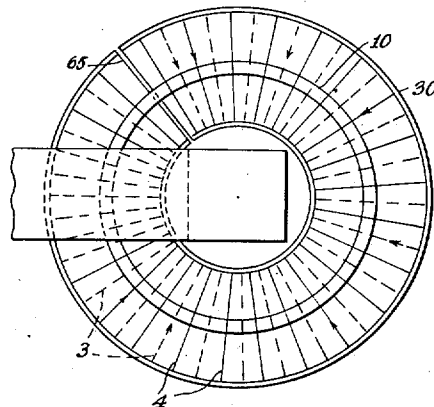
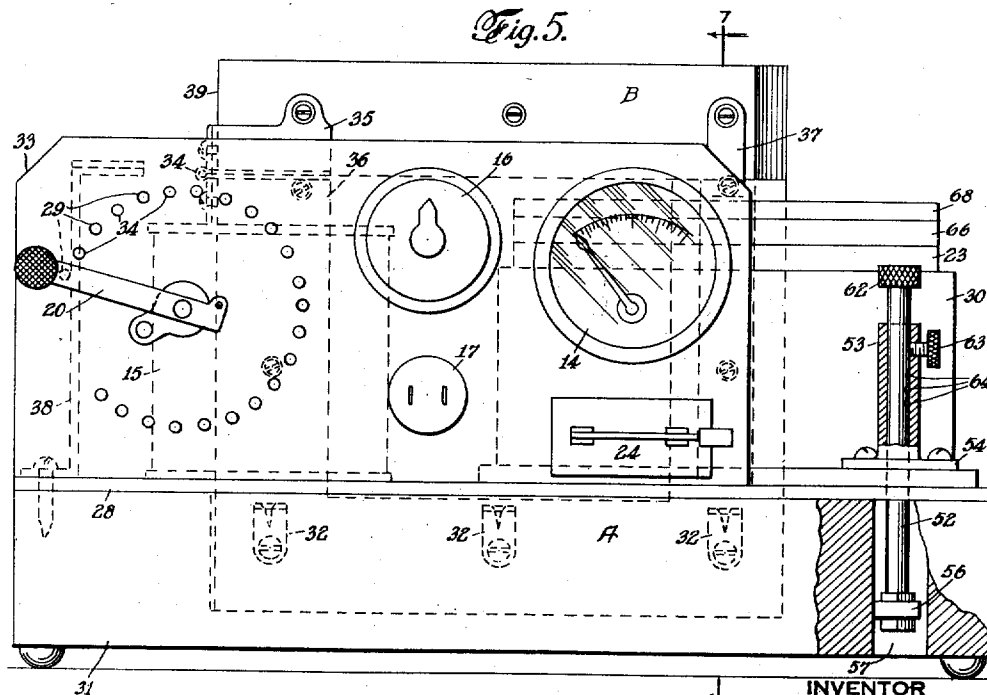


Fig. 5.



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Fig. 6.

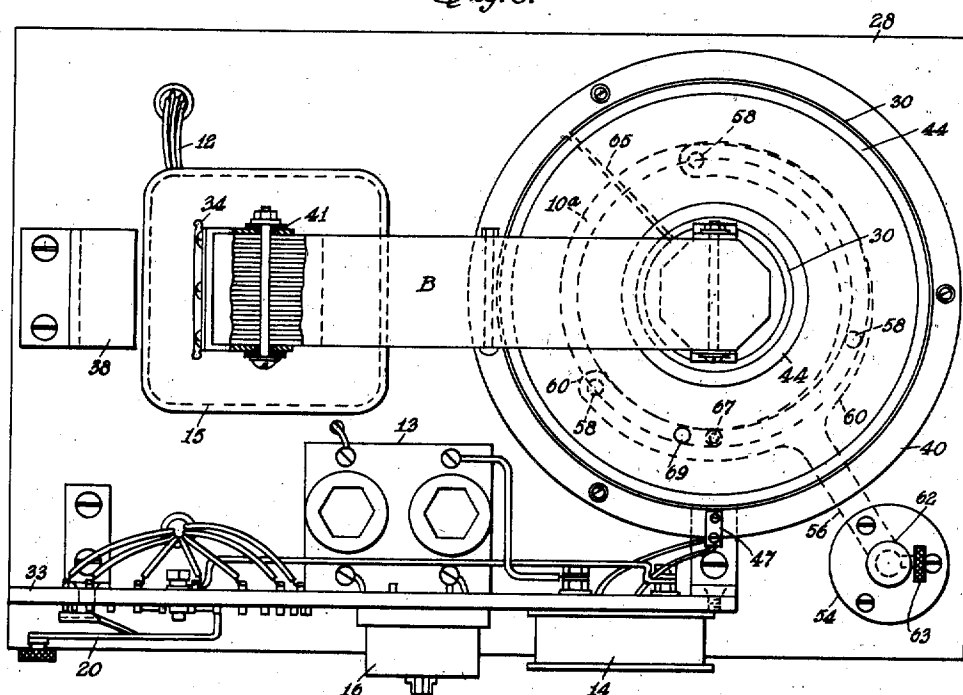


Fig. 9.

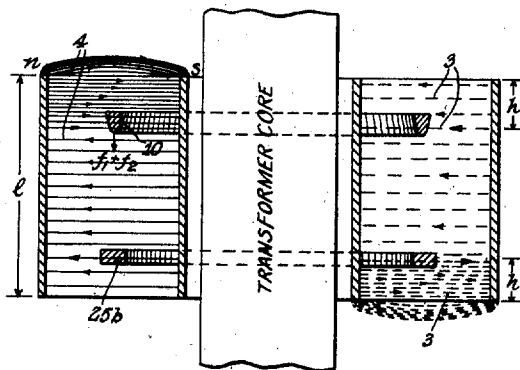
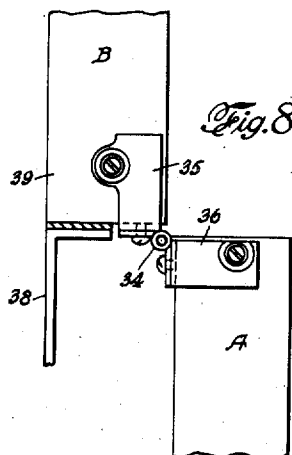


Fig. 8.



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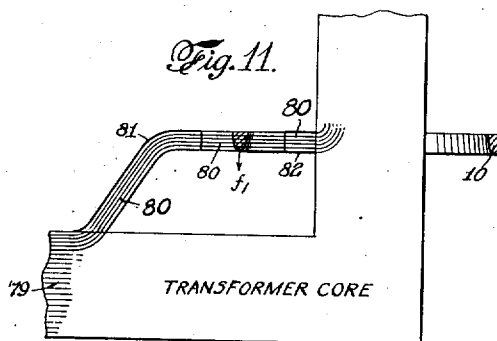
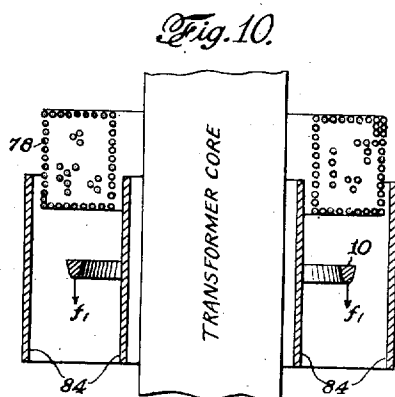
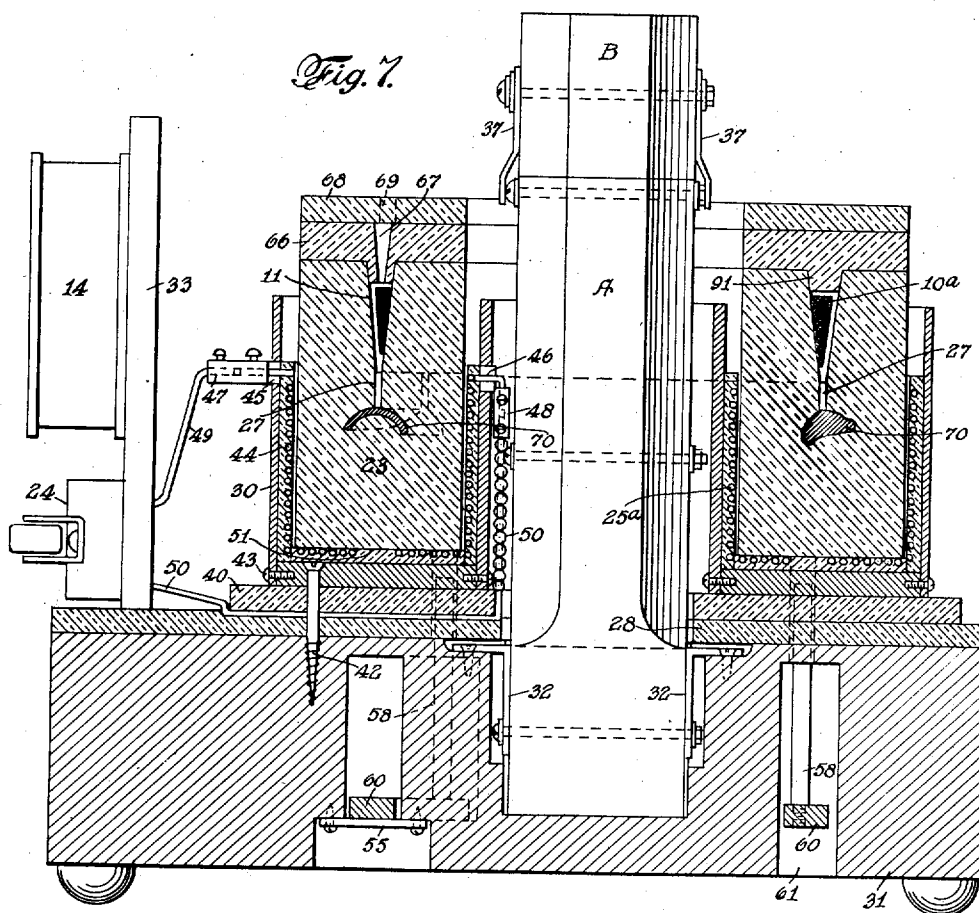
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4 Sheets-Sheet 4



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2,083,022

METHOD OF CASTING METALS BY ELECTROMAGNETIC FORCES AND APPARATUS THEREFOR

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Application September 29, 1933, Serial No. 691,479

36 Claims. (Cl. 22-57)

This application is a continuation in part of application Serial No. 440,368, filed March 31, 1930, which is itself a continuation of application Serial No. 289,812, filed July 2, 1928.

5 The present invention relates to a novel method of casting metals and apparatus therefor, and is herein particularly described in connection with the production of comparatively small castings having particular need for accuracy of configuration, such as are used in dentistry. Larger castings, however, may be produced according to the invention.

10 The fundamental objects of the invention is to provide for an improved method of casting for use in those cases requiring a casting pressure greater than that which can be practically obtained by gravity alone, as in dentistry.

15 In accordance with the invention, the pressure required to cause the casting of metal into a mold is internally produced in the body of casting metal, electromagnetic forces of appropriate direction being employed for that purpose. That is, internal casting forces having a single or substantially single direction of action are caused to be electromagnetically induced in the metal to be cast, which forces cause it to be introduced into the mold under pressure produced in opposition to the resistance to its entry therein and to forcibly impinge on the surface of the mold under the influence of that pressure. One requirement for producing these forces is that an electric current be passed through the body of casting metal, and this current may be conveniently utilized to melt said body. Either direct or alternating current may be employed, but the use of alternating current is preferred in view of the greater advantages which this current makes possible. As I have found, considerable reduction in casting pressure is permitted when alternating current is employed.

20 The above method of casting is not limited to the field of dentistry, but is capable of use wherever from a practical standpoint gravity cannot be satisfactorily used to effect the casting of metal into a mold.

25 As will hereinafter be shown, under certain conditions the unidirectional forces introduced into the body of casting metal cause it to undergo a treatment which is extremely effective in eliminating non-conductive impurities from its interior, an artificial pressure gradient being created resulting in a forced separation of such impurities in a direction opposite to which the casting forces are applied. Since most common

impurities in metal are non-conductive, it is apparent that castings produced from said body while this treatment is taking place will have their internal structure much improved. While this impurity elimination may be caused to occur with either direct or alternating current, it may be carried out with utmost efficiency when alternating current is employed. That is, the treating forces are then cyclic forces and, because of their parallelism, create such internal agitation in the body of casting metal that travel of impurities from its interior is considerably facilitated. If the fluidity of said body is not actually increased as a result of this agitation, at least an effect similar to a pronounced increase thereof is produced. Hereinafter, the effect produced by the agitation stated will be referred to for convenience as an actual increase of fluidity.

30 It is the preferred practice of the invention to cause the above treatment to be carried out. Also, electromagnetic forces of both cyclic character and downward direction are preferably employed. As will hereinafter be more clearly understood, if the treatment is caused to take place employing these forces, they then function to assist or supplement the natural tendency of the metal to free itself of impurities, both an effect of increased fluidity and an actual increase in buoyancy being obtained. Besides, the agitation peculiar to the treatment is believed to be most effective when the cyclic forces are caused to be downwardly directed.

35 The above treatment is claimed per se in my copending application Serial No. 93,429, filed July 30, 1936, for reissue of my Patent No. 2,013,653, issued September 10, 1935. It should not be regarded as being essential to the method of casting to which the present invention relates, but merely as an advantage which may be derived from the practice of that method. Whether or not it is caused to be carried out, distinct advantages are provided by the invention peculiar to casting metal electromagnetically into a mold. When alternating current is employed, the resulting agitation in the body of casting metal may or may not be the agitation called for by the treatment, but most probably in either case creates a condition in said body of extreme sensitivity to displacement into the mold by the internal pressure created. To this is attributed the aforementioned considerable reduction in casting pressure permitted. Moreover, a certain degree of agitation is mechanically communicated to the metal in the mold during the casting

operation, which causes every corner space of the mold to be filled. The finished casting thus conforms accurately to the original pattern, this advantage being of particular importance in dentistry in view of the intricate nature of the structures which it requires. Further advantages peculiar to the casting operation will become apparent hereinafter.

When melting metal by current in small amounts in a trough, there is a limit to the magnitude of current which may be employed, owing to the well-known "pinch-effect" as a result of which a complete and permanent break in the metal where it reaches its melting point will occur if the current density is too high. It is an object of the invention to considerably increase the range of current values permissible in such melting operations. This object of the invention is attained by employing electromagnetic forces of downward action in the trough, the pinch-effect being so modified in character by these forces that the tendency of a permanent break taking place in the metal is considerably reduced.

Another object of the invention is to provide a trough for melting small masses of metal by current therein, so constructed that maximum melting current values are made possible.

Still another object of the invention is to provide apparatus of simple construction for carrying out the aforementioned method of casting by electromagnetic forces, including a trough for casting the metal therefrom so constructed that maximum casting pressure is obtained.

A still further object of the invention is to provide apparatus for the production of dental castings, by which the usual preliminary operations of moisture and wax expulsion and metal melting may be performed electrically prior to electromagnetically forcing the metal into the mold, all of these operations being performed in a single positioning of the mold in the apparatus.

These and other objects and features of the invention will more fully appear with the aid of the following description taken in conjunction with the accompanying drawings, in which Fig. 1 is a schematic illustration of a dental casting device embodying the invention, showing the wiring connections; Fig. 1a illustrates another arrangement of bottom heating secondary; Fig. 2 is a schematic view illustrating the distribution of the flux produced by the bottom heating secondary when the magnetic walls are omitted and corresponding production of forces f_1 of feeble intensity in the top casting secondary; Fig. 3 is a schematic view illustrating the distribution of the flux produced by the top casting secondary in cooperation with the magnetic walls and corresponding production of strong downward forces f_2 in the top casting secondary; Figs. 4 and 4a are schematic views illustrating the distribution of the flux produced by both the top casting secondary and the bottom heating secondary in cooperation with the magnetic walls and corresponding production of strong downward forces $f_1 + f_2$ in the top casting secondary; Fig. 5 is a front view of the complete device; Fig. 6 is a plan view thereof; Fig. 7 is an enlarged sectional view taken on the plane indicated by the line and arrows 7-7 in Fig. 5; Fig. 8 is a fragmentary view illustrating the upper transformer core part seated in a vertical position; and Figs. 9, 10, and 11 are schematic illustrations of other apparatus embodying the invention.

Present methods of producing castings as commonly employed in dentistry necessitate three distinct operations. First, the investment plaster mold, containing the wax pattern or patterns, is heated, usually on a gas stove, primarily to expel the moisture and the wax therefrom and to oxidize all of the carbon deposit resulting from the evaporation of the wax, but also to produce a sufficiently high temperature in said mold prior to the casting of the gold therein. The driving out of the least traces of carbon is considered essential for the production of the castings, so that the final temperature in this second operation is necessarily high throughout the complete extent of the mold. Second, the gold is placed on the mold and melted thereon, usually by a gas flame. Third, the molten gold is cast into the cavities formed by the expelled patterns by centrifugal force or other means such as extraneous air pressure. It is a well-known fact that castings produced by these methods are never free of air or gas pockets, a large number of them failing completely in the exacting requirements of dental structures. Among other difficulties which arise, may be cited the tendency of breakage of delicate portions of the mold by sudden inrush of metal therein due to the comparatively high casting pressures required, and the tendency of the mold to crack or disintegrate by the somewhat abrupt changes in temperature due to the carrying of the mold from one operation to another. The metal must be heated to a temperature appreciably higher than the melting point, not only to render it sufficiently fluid for the casting operation, but also to compensate for the loss of heat from the time the metal is melted to the time it is cast. This high temperature is dependent upon the judgment of the operator and often burns out the copper generally present in dental molds.

The present invention eliminates these difficulties. In view of the reduced casting pressure which it makes possible, the tendency of breakage of mold cavity walls is avoided. The mold is heated by electric current to expel the moisture and the wax therefrom. It is also possible by this means to drive off the carbon residue, but this apparently is not as essential as heretofore because of the improved manner the metal is cast into the mold. The tendency of the plaster mold to disintegrate due to prolonged heating at high temperature is, therefore, greatly minimized. The metal is melted also electrically, no reduction nor abrupt changes of temperature taking place from the time the mold is positioned in the apparatus to the time the metal is cast electromagnetically therein.

Fig. 1 represents a transformer having a rectangular core made in two separate parts, namely, a lower part A and an upper part B, the latter of which is removable from the former. Each of the parts should, of course, be built up in the usual manner of suitable plates of iron or steel, to minimize eddy current loss. The primary of the transformer is wound about one leg of the part A, and has a number of taps 12 leading to terminals 20 with which a switch arm 20 cooperates. As shown, the primary and tap switch are connected in a circuit including an ammeter 14, a fuse block 13, a switch 16, and a base receptacle 17, the latter being adapted to be engaged by a plug 18 leading to a suitable source of alternating current (not shown). As a secondary the transformer comprises a ring 19, positioned about the other leg of the core part A

and of the substance to produce the required castings. This ring is held in an open trough 11 formed in the upper portion of an annular body 23, made of a suitable refractory material capable of being molded, such as dental investment plaster. Embracing the refractory body 23 is an additional secondary 25 shaped as an annular channel made up of bottom and side elements of thin metal plate. Preferably, the side elements terminate, at their upper edges *a*, in horizontal alignment with the bottom of the trough 11, but should not extend above this level. Separated a short distance from the secondary 25 and also following the shape of the refractory body 23, another channel 30, likewise comprising concentric tubes joined to a bottom portion. These walls 30 are made of a magnetic material and are of substantial thickness, the side walls extending above the secondary 25 with their upper edges in substantial alignment with the top of the metal ring 10 or preferably slightly below said top. The magnetic walls 30 are formed with a radial slot 35, as shown in Fig. 4^a, to prevent them from acting as a closed single-turn secondary.

The cavities 26, located within the refractory body 23 and communicating with the trough 11 by means of the ducts 27, are the hollow spaces formed by expulsion of wax patterns therefrom. These patterns, as well as the moisture in said body 23, are driven off as a result of the heat created by the current in the secondary 25 (and by the current in the secondary 10, if the latter is placed in the trough 11 at the start); the secondary 10 is melted as a result of the heat created principally by the current therein; and, as will be hereinafter more particularly described, the magnetic walls 30 cooperate with the currents in both top and bottom secondaries 10 and 25 in electromagnetically inducing downward effective forces within the secondary 10, which forces cause a portion of the molten metal 10 to flow through the ducts 27 into the cavities 26 to form the required castings. Said forces also act to considerably reduce the tendency of a permanent break taking place in the melting metal 10. In order to melt the ring 10, the switch arm 20 should be actuated to progressively decrease the number of primary turns, this being made necessary by the increase in the resistance of said ring with increasing temperature. However, the primary taps 12 are employed primarily to cause the temperature of the plaster investment 23 to be gradually raised from the ambient temperature. The taps 12 also permit accurately controlling the temperature of the metal after it has entered the cavities 26. The ring of metal remaining in the trough 11 may be used for further casting operations, more metal being added in said trough when required.

As shown in Fig. 1^a, the bottom secondary may also be formed by a single length of wire 25^a wound in a plurality of turns in such a way that it follows the contour of the mold 23 (not shown in Fig. 1^a). In this form, the ends of the bottom secondary may be connected through suitable leads to a controlling switch 24.

One of my methods of electromagnetically inducing parallel forces in metal, causing the latter to flow into a mold, utilizes the principle underlying the generation of the force exerted on a current-carrying conductor when disposed in a magnetic field other than that produced by the current therein and having a direction transverse to the path of said current, such a force, in

accordance with the well-established rule governing motion produced electromagnetically, being in the direction in which motion causes an increase in magnetic energy (in the case under consideration, either an increase or a decrease in the flux, peculiar to said field, as links the circuit of the conductor, depending on certain conditions including the relative directions of current and field). Thus, the body of casting metal, through which a current is passed, is subjected to the action of a magnetic flux, which is produced otherwise than by said current, and which is caused to be properly directed through said body, transversely to the current path therein. Said current and flux may be either both direct or both alternating, and, when alternating, must be of the same frequency and of the proper phase relation. No force is actually produced on the metal at its surface, but the force acting on the metal as a whole is distributed throughout its mass, i. e., should be considered as made up of an infinite number of infinitesimal forces acting on its current-carrying elements.

In the aforesaid method of producing electromagnetic casting forces, it is to be particularly noted that the flux produced by the current passed through the metal also acts to produce internal forces in the metal. Normally the latter forces (the forces producing "pinch-effect" and possibly others) are variously directed; and, while they are not especially objectionable from the standpoint of the casting of the metal, the treatment to be hereinafter more particularly described demands that they be eliminated or substantially eliminated, either by altering their character or by neutralizing their action in the metal. Actually the only forces in the metal are those produced by the resultant flux therein, but for convenience in description the production of the forces by the flux produced otherwise than by the current passed through the metal is herein treated independently of the production of the forces by the flux produced by said current. That is, the aforesaid method of producing electromagnetic casting forces is treated in a manner presupposing the existence of both fluxes, this being permissible in view of the fact that the actual forces present in the metal may also be considered as the resultants of the respective forces produced by the two fluxes. The forces hereinafter indicated by f_1 refer to those forces solely produced by the flux produced otherwise than by the current passed through the metal. The effective forces f_1 resulting from the use of alternating current are greatest, for given effective values of current and flux, when the flux is in phase with the current.

In each of the embodiments of the invention illustrated and described herein, alternating current is induced by transformer action in the body of casting metal acting as a closed single-turn secondary, which current is utilized to melt the metal ring. Now, in carrying out the aforesaid method of producing electromagnetic casting forces for the production of dental structures, use is preferably made of the alternating leakage flux of an extra secondary located below the ring of casting metal, so that the heat generated by this extra secondary may be conveniently utilized to drive off the moisture and the wax from the mold. However, the extra secondary is not alone capable of causing the upper metal to flow into the mold cavities, but its use necessitates that its leakage flux be increased in magnitude. On the other hand, another method, to be hereinafter

more particularly described, is also utilized for producing the required casting forces in the top secondary, which results in modifying the leakage flux of the bottom secondary to advantage. To facilitate an understanding of the subject, different portions of the apparatus have been illustrated diagrammatically in Figs. 2 and 3, which portions are combined as shown in Fig. 4 and operate conjointly.

The extra secondary, shown in Fig. 2 as comprising a ring 25b, provides a high temperature by reason of the current induced therein by transformer action and is therefore composed of a metallic substance having a high melting point and the property of resisting corrosion at the temperature which it attains when the casting metal 10 has been raised to its melting temperature. It may be made of a conducting substance, such as copper, electroplated with a suitable refractory and corrosion-resistant metal. The lines 3 in Fig. 2 illustrate the normal distribution of its leakage flux, which, as observed, reacts on the current in the metal 10 to produce effective forces f_1 therein. That is, the flux 3, which has the same frequency as the current in the metal 10 and is in phase or substantially in phase therewith, is of such a direction relative to the direction of the current, and the circuit of the metal 10 as a whole bears such a relation geometrically with respect to the flux 3, that each mass element of the metal 10 is acted upon by an effective force f_1 having a direction in which motion of the element causes an increase of flux lines 3 linking its circuit. In the specific arrangement of parts shown in Fig. 2, these forces f_1 , because of the fact that the flux 3 is not uniformly directed through the metal 10, do not act unidirectionally from point to point (in a given radial plane through the metal 10) and, while tending to draw the molten metal downwardly, are not in themselves sufficient to exert a marked influence on the casting operation. Further, the metal secondary 10, in Fig. 2, produces a leakage flux (not shown) which, in view of its distribution, results in the production of forces (not shown) of entirely different character than the forces f_1 . These additional forces, which comprise the forces producing "pinch-effect", converge toward an interior point in the secondary 10 and, in view of the fact that the flux produced by the secondary 10 is appreciably stronger, in the secondary 10, than the flux 3, necessarily dominate the forces f_1 . While the total resultant force (in a given radial plane through the secondary 10) acts in the general direction of the forces f_1 (in said plane), yet the resultant internal forces on the current-carrying elements of the secondary 10 are considerably different from the forces f_1 . That is, the resultant internal forces are still variously directed, the flux 3 having substantially no other effect on the forces normally produced than to slightly shift their point of convergence. In the specific arrangement of parts shown in Fig. 2, therefore, the production of the forces f_1 in the metal 10 results neither in sufficient pressure for the casting operation nor in the treatment which it is the preferred practice of the invention to combine with that operation. As will hereinafter appear, the bottom secondary will be made to produce forces f_1 suitable for both treating and casting the metal 10 in accordance with that practice.

Another of my methods of producing electromagnetic casting forces in metal is particularly

advantageous in that simple apparatus may be used to create the pressure required to force the molten metal into the mold. It utilizes the principle underlying the generation of the force exerted on a current-carrying conductor when a magnetic body or magnetic bodies are placed in the field produced by the current therein, the direction of the force, according to the rule already stated, being again that in which motion causes an increase in magnetic energy (here, an increase of flux produced by the current flowing in the conductor). The effect of field on current is utilized in this second method as in the first, the essential difference between the two methods being that in the first the field is one produced independently of the current, and in the second it is the particular field produced by the current, but modified in character by the action of the magnetic body or bodies. Thus, the body of casting metal, through which a current is passed, is subjected to the action of a magnetic body or magnetic bodies, which are placed in the vicinity of said metal body and partially enclose it, so that the flux produced by said current is caused to be both directed through said metal body and increased in intensity. As in the first method, either direct or alternating current may be passed through the metal; and, again, the total force acting on the metal should be understood as a system of internal forces acting on the current-carrying elements. The forces herein designated by f_2 refer to those forces solely produced by the flux peculiar to the current passed through the metal, when said flux is modified in the manner stated.

Referring to Fig. 3, which is illustrative of an apparatus for carrying out with alternating current the aforesaid second method of producing electromagnetic casting forces, the magnetic walls 30 are shown enclosing the casting secondary 10, the lines 4 illustrating the path which the alternating leakage flux of the secondary 10 follows outside the iron. As observed, the flux lines 4 pass horizontally, above their respective current elements, from one vertical wall to the other, it being understood that they then follow the low-reluctance path provided by the walls 30. There is a downward tendency of motion of the ring 10, as indicated by f_2 , since such motion results in increasing the number of flux lines 4 with a resulting increase in magnetic energy. That is, the current-carrying elements of the metal 10 are acted upon by unidirectional effective forces f_2 , which may be conveniently considered as being produced by the action of the flux 4, within the metal 10, on the elements. These forces f_2 decrease in magnitude toward the bottom of the metal 10 because of decreasing flux density, within said metal, with increasing distance from its upper surface, both the flux density and the forces f_2 being zero at the bottom. But the downward tendency of motion is nevertheless strong because of the increased intensity of the leakage flux of the metal secondary 10 established by the action of the magnetic walls 30.

In Fig. 4 I have illustrated the combined action of forces f_1 and f_2 produced within the metal ring 10. Here, the magnetic walls 30 enclose both the body of casting metal 10 and the extra secondary 25b. The full lines 4 again indicate the flux lines established by the ring 10 in cooperation with the walls 30, while the dotted lines 3 represent the flux lines established by the bottom secondary 25b in cooperation with said walls. Both

the flux lines 3 and 4 link their respective secondaries through the magnetic walls and pass, as shown, above their respective current elements substantially horizontally from vertical wall to vertical wall. It is clearly seen that the effective forces f_1 , now produced as a result of the horizontal flux 3 which is caused to be directed through the metal 10, are unidirectional and act vertically downward, adding to the forces f_2 already discussed. Furthermore the forces f_1 are greatly increased in magnitude by the iron walls, which cause a much greater density of flux lines 3 to be led to the metal ring 10. Due to the iron walls, the flux 3 is shifted somewhat out of phase with the current in the metal 10, but the effective values of the forces f_1 nevertheless act downwards and are increased in magnitude.

As illustrated in Fig. 4*, the magnetic walls 30 provide a radial path for the flux lines 3 and 4 from vertical wall to vertical wall, and said flux lines are symmetrically distributed throughout the periphery of the parts. Consequently, for a uniform cross-section of the ring 10, the casting forces f_1 and f_2 are uniformly distributed along the periphery of the metal. Without the use of the magnetic walls 30, the forces f_1 would not be so distributed owing to the transformer core parts.

To obtain a maximum electromagnetic effect, the ring of casting metal should not only be located concentrically between the walls 30, but preferably at the geometrical mean between said walls; i. e., the theoretical value for the diameter of the ring 10 is

$$\sqrt{d_1 d_2}$$

where d_1 and d_2 are the outer and inner diameters of the inner and outer vertical magnetic walls, respectively.

From previous description it is clear that, in order to cast a metal by electromagnetic forces, it is necessary that, regardless of the particular method employed in producing such forces, an electric current be passed through the metal and a flux be uniformly or substantially uniformly directed through the metal transversely to the path of the current. The forces introduced in the metal in this manner will be unidirectional or substantially unidirectional, which is obviously a requirement for casting the metal in accordance with the invention. By the term "unidirectional" is of course meant single direction with respect to the path of the current. In other words, the invention requires that unidirectional or substantially unidirectional forces be produced in each consecutive plane transverse to the path of the current, which condition will prevail if the cross-flux employed for their production is likewise of single direction or substantially of single direction in each consecutive plane transverse to the path of the current (see Fig. 4*). The invention does not require that forces f_2 be employed; and neither is it positively required for actually forcing the metal into the mold that the variously directed forces normally produced by passage of current through the metal be eliminated, substantial elimination of these forces being necessary only when it is desired to also effect the treatment to be hereinafter more particularly described. In other words, when it is merely desired to cast the metal in accordance with the invention, only the useful forces intentionally produced for this purpose need have a general

direction of action so as to provide the pressure necessary to cause the metal to flow into the mold, it being possible to cast by forces f_1 alone, provided of course these are of sufficient intensity.

When direct current is used, the electromagnetic forces (f_1 or f_2) produced in the metal are obviously steady forces. On the other hand, the electromagnetic forces (f_1 or f_2) resulting from the use of alternating current are cyclic forces varying with time at a frequency twice that of the current, but having definitely directed effective values in the metal. As will be hereinafter shown, these cyclic forces, except under certain conditions at isolated points of the metal, are truly alternating forces, reversing in direction when passing through zero points of their waves. That is, they generally act through recurrent portions of their waves in a direction opposite to that of their preponderant action. For convenience in description, they are nevertheless at times referred to or inferentially identifiable herein as unidirectional forces, implying, even when their particular direction is specified, as when referring to them as downward forces, that their effective values have a single direction of action in the metal.

My improved method of making castings preferably comprehends a substantial elimination of impurities from the body of casting metal. Such impurity elimination is obtained by treatment inherently effected as a result of the unidirectional electromagnetic forces employed for casting said body, when these are the only electromagnetic forces produced in said body or when they are substantially the only electromagnetic forces having any effect in said body (i. e., in a very large measure the dominating forces substantially neutralizing all others). This treatment will now be explained in connection with casting forces of downward action, which forces for convenience will be considered as being the only electromagnetic forces present in the body of casting metal.

The pressure in the body of casting metal may be considered as made up of the normal pressure resulting from the action of gravity therein and the induced pressure resulting from the action of the casting forces electromagnetically induced on the conducting elements. When steady forces as result from the use of direct current are caused to be present, the induced pressure is obviously constant at any instant. Under the assumption of downward action of such forces, the induced pressure at a given point is equal to the sum of those forces situated directly above the point, the induced pressure therefore increasing with increasing depth in the metal, it having a maximum value at the bottom of the metal and the value zero at its upper surface. On the other hand, the induced pressure varies with time when alternating current is employed. As has already been stated and the later description will show, the cyclic forces then present in the metal generally reverse in direction when passing through zero points of their waves. Further, they are not in phase with one another, as will also be shown. Under the assumption of downward effective action of such forces, the instantaneous induced pressure at a given point is equal to the sum of those instantaneous forces both directly above and below the point which act in opposite directions toward the point. Nevertheless, the induced pressure resulting from the use of alternating current may be consid-

ered to have a definite effective value at any point; and, with the cyclic forces acting predominantly downward, this effective pressure necessarily increases from the upper to the lower limits of the metal. Like the steady pressure obtained with direct current, it obviously is maximum at the bottom of the metal and zero at its upper surface. Whether direct or alternating current is employed, therefore, the casting forces inherently establish a gradient of pressure gradient produced by gravity alone, artificial pressure gradient adds to the normal pressure gradient produced by gravity alone, thereby increasing the buoyant effort of the molten metal on non-conductive bodies immersed therein. As a consequence of this increased buoyancy, air upon passing from the mold into the body of casting metal is caused to travel rapidly upwards to the atmosphere, said body being substantially freed of all gas normally tending to form pockets or blowholes therein. In fact, any impurity which is non-conductive or less conductive than the metal, is forced to rise to the upper surface, either floating there if it is a solid or escaping into the atmosphere if it is a gas. Slag or formed oxides are therefore separated and forced to remain at the upper surface. The oxide or oxides as may be formed are usually less in specific gravity than the metal, so that both the normal pressure gradient and the induced pressure gradient act to free the body of casting metal of these impurities. However, the buoyancy may be so increased as to cause all non-conductive or comparatively non-conductive impurities, whether less or greater in specific gravity than the metal, to rise to its upper surface.

The above treatment favors the use of alternating current because of the added effect of increased fluidity caused by the internal agitation which is produced. It is known that a conducting liquid mass is agitated by passage of an alternating current of sufficient strength there-through. However, the character of the agitation which is produced in molten metal by that treatment, has an improved effect with reference to the increased fluidity which is produced, because of its parallelism and uniformity of action throughout the metal mass. That is, the cyclic forces parallelly produced in the metal are the motive forces producing the agitation, and they accordingly cause parallel or substantially parallel relative displacements of all adjacent interior elements of the metal. Thus, when cyclic forces of downward effective action are employed, an up and down relative motion of adjacent elements takes place without interruption throughout the body of metal under treatment. The adherence between elements is therefore effectively eliminated, so that the viscosity of the molten metal is in all probability substantially neutralized. Like the increased buoyancy, the increased fluidity of the molten metal is an important result of the treatment, air and other impurities being permitted to pass freely and rapidly to its upper surface. It may be said that the increased buoyancy, in cooperation with the slippage of impurities relatively to adjacent mass elements caused by the agitation, force the impurities to rise immediately, this action being continuously repeated during their upward travel in the metal.

Generally stated, the motive forces agitating a liquid mass carrying an alternating current, besides being cyclic forces, have different wave forms and are out of phase with one another at

various points of the mass, which is probably the principal factor causing the agitation. Ordinarily, the motive forces are so directed and so differ in both wave form and phase at different points of the mass that no uniform agitation can possibly result. While the fluidity may be increased, yet the impurities in their travel from the interior are more or less impeded by the displacements of the mass elements. The freedom with which impurities may escape as a result of the agitation produced in accordance with the preferred practice of this invention, is essentially due to its parallelism and uniformity of action throughout the molten mass, the displacements of the mass elements being caused to take place parallelly to the direction of travel of the impurities. The parallelism and uniformity of action of the agitation is due in great part to the fact that the motive forces all act parallelly to one another, but, when either forces f_1 alone or both forces f_1 and f_2 are employed, is believed to be also due to the distinct manner in which the motive forces differ as to wave form and phase from point to point in the mass. These phase and wave form variations and the alternating-current phenomena associated therewith will now be described in detail in connection with forces of downward effective action.

When forces f_2 are produced in metal, the "skin-effect", or the tendency of an alternating current to distribute itself non-uniformly over the cross-section of a conductor, takes place in an entirely different manner than under normal conditions of current passage. Referring to Fig. 3, the walls 30 act to change the direction of the magnetic field, established by the current flowing in the metal 10, both outside and inside said metal. That is, interior flux lines 4 are caused to travel directly through the metal 10 parallelly to the exterior lines 4. The lower elements of the metal are linked by a greater number of flux lines 4 than the upper elements, so that the lower elements have greater self-inductances than the upper elements. The self-induced back electromotive forces or opposing voltages of self-induction are greater in the lower elements than in the upper elements; and, instead of the current being forced outwardly in all directions toward the complete extent of the outer surface or "skin" of the conductor, as normally takes place, it is so distributed that the current density is greatest only at the upper surface of the metal. That is, the current density continuously increases with decreasing depth, it being minimum at the bottom of the metal and maximum at the top. This modified skin-effect or increase of current density with decreasing depth becomes more pronounced the higher the level to which the metal 10 is raised within the magnetic walls 30.

Because of increasing self-inductance with increasing depth, the currents in the lower elements lag behind the currents in the upper elements, thus causing the densities of magnetic flux 4 produced at various depths to be not only out of phase with one another, but also out of phase with the currents with which they act to produce the cyclic forces f_2 . Therefore, the forces f_2 reverse in direction when passing through zero points of their waves, i. e., while acting predominantly downward, nevertheless act in the opposite direction through recurrent portions of their waves. They are out of phase with one another at points of different depth, those

acting on the lower elements lagging behind those on the upper elements, the lag increasing continuously with increasing depth. And their wave form changes continuously with changing depth, their upwardly acting portions increasing in both amplitude and period of action from the lower limit of the metal to its upper limit. It is thus seen that the induced pressure at a given point in the metal, or the summation of the forces f_2 directed toward that point, is out of phase with and has a wave form different from the induced pressure at any other point of different depth. That is, the induced pressure in the metal 10 in Fig. 3, like the forces f_2 which produce it, experiences gradual changes in both phase and wave form throughout the vertical distance between the upper and lower limits of said metal. It is these phase and wave form variations which, it is believed, at least in part cause the agitation and in part cause its parallelism and uniformity of action throughout the treated metal and the resulting improved effect of increased fluidity of such metal.

A skin-effect similar to but entirely independent of that which has been described also results from the introduction of cyclic forces f_1 in metal, and in this instance is caused by transformer action between the external circuit employed for producing such forces and the individual circuits of the conducting elements composing the metal. Thus in Fig. 4, it is seen that some of the flux 3 established by the bottom circuit 25b passes directly through the metal 10. The lower elements of the metal 10 are linked by a greater number of flux lines 3 than the upper elements, so that the lower elements have greater mutual inductances with respect to the circuit 25b than the upper elements. The mutually-induced electromotive forces or voltages of mutual induction are therefore greater in the lower elements than in the upper elements. The induced currents caused to be established by this transformer action are affected in strength by self-inductance of the various elements, more so in the lower elements than in the upper elements because of increasing self-inductance with increasing depth. Also, the induced currents in the lower elements are caused to lag behind the induced currents in the upper elements. Nevertheless, the induced currents in the lower elements are stronger than the induced currents in the upper elements, and the induced currents in all elements act preponderantly to oppose the current induced by the primary 15 (Fig. 1). The density of resultant current is thus caused to increase from the bottom of the metal to the top, the increase of current density with decreasing depth in Fig. 4 including both skin-effect inherent in the production of the forces f_1 and skin-effect inherent in the production of the forces f_2 . That corresponding to the forces f_1 also becomes more pronounced the higher the level to which the metal 10 is raised within the walls 30.

The flux 3 in the above discussion should be considered as the resultant flux produced by the current in the bottom circuit 25b and the induced currents in the metal elements acting as secondaries. The forces f_1 should be considered as being produced by the action of this resultant flux on the resultant current in the metal 10.

It should be observed that the skin-effect derived from the production of cyclic forces f_1 in metal is not in any way dependent upon the simultaneous production of cyclic forces f_2 . That

is, there is always a distinct tendency for the current to be forced toward the top when cyclic forces f_1 of downward effective action are produced, because of the transformer action stated. However, in the absence of forces f_2 , this current variation depends on the condition that the forces f_1 are the only forces produced having substantial effect in the metal, and is not as uniformly effected as when forces f_2 are also present.

Generally stated, cyclic forces f_1 produced in metal, because of their parallelism, produce or contribute to an agitation which, like that produced by forces f_2 alone, is believed to be very effective in providing increased fluidity of the metal (conditional to the forces f_1 being the dominating forces in the absence of forces f_2). However, the agitation is most effective, it is believed, when forces f_2 are also produced. Referring to Fig. 4, because of the continuous change in self-inductance with changing depth, the forces f_1 themselves undergo phase and wave form variations identical in character to those of the forces f_2 , also produced. The agitation is more intense because of the production of both forces f_1 and f_2 , but is characterized by the same uniformity and parallelism of action as takes place in Fig. 3 as a result of the production of forces f_2 alone. Whether or not forces f_2 are simultaneously produced, forces f_1 produced in metal reverse in direction when passing through zero points of their waves, except possibly at such points where the density of flux may be caused to be in phase with the current.

It is of course understood that the agitation in Fig. 4 is actually produced by the resultants of the forces f_1 and f_2 , which resultants also undergo continuous changes in both phase and wave form with changing depth, even though their components f_1 and f_2 are not in phase. The effect of increased buoyancy in Fig. 4 is likewise produced by the resultants of the forces f_1 and f_2 .

When carrying out the invention with the use of alternating current, there is also the possibility of eddy currents being formed in the body of casting metal as a result of the varying flux therein. With the magnetic channel 30 completely enclosing the metal ring 10 (except for the slight fraction thereof corresponding to the radial slot 65), no eddy currents are established because no path is provided for their flow. However, should the channel 30 be caused to extend along a portion only of the metal ring 10, eddy currents are then formed in that portion, circulating in closed paths linked by the interior lines of flux. These circulatory currents are by necessity established whenever the metal mass under action by the casting forces is of a character presenting other than an endless path for the load current. They may be established regardless of the manner in which the casting forces are produced, and their formation when treatment is employed occasions more pronounced current density variation with changing depth in the metal, as well as increased agitation. Thus, for a rectilinear body of metal and cyclic forces (f_1 or f_2) therein of downward effective action, the eddy currents correspondingly established flow in vertical planes, following the top surface of the metal along its upper elements and returning in the opposite direction along its lower elements. They are out of phase with one another, but act preponderantly to assist the load current in the upper elements and to oppose it in the lower elements. The density of total current is thus caused to increase from the bot-

tom to the top of the metal, this increase in current density including either or both of the aforescribed skin-effect increases depending on the forces introduced in the metal. The eddy currents also produce flux, and the electromagnetic forces are produced by the action of the resultant flux on the resultant current. More pronounced phase and wave form variations of the forces are caused to take place resulting in increased agitation, the phase and wave form variations when forces f_2 are present taking place in the manner previously described. The eddy currents cause oppositely directed inward forces to be produced at the end portions of the metal, which forces, however, are substantially neutralized by the casting forces also present.

It may be generally stated that the current density established in metal by the treatment when it is caused to be carried out by cyclic forces, increases in a direction opposite to that of the effective action of such forces. For convenience in description, skin-effect will be hereinafter used to broadly signify this current density variation, regardless of the phenomena with which it may be associated.

Another important effect of the treatment when alternating current is employed, is the temperature gradient accompanying the skin-effect. The chief advantage of this temperature gradient resides in the fact that, when treatment is continued during the cooling stage, solidification takes place progressively in the same direction in which impurities are separated. One reason for the presence of blowholes in metals resides in their pronounced tendency of dissolving or occluding gases while molten, with the result that, when approaching solidification, considerable quantities of gas are suddenly evolved. In the case of aluminum, for example, this phenomenon is quite noticeable. The gases being set free close to the point of solidification, they are in large part normally entrapped in the form of gas pockets. Now, when cyclic forces of downward effective action are produced in metal, as in Figs. 3 and 4, a pronounced increase of temperature is effected from the bottom to the top of the metal, this temperature variation being nevertheless characterized by an even or substantially even temperature at all points of equal depth. By continuing the treatment while the metal is cooling from its molten state, the metal is therefore caused to solidify progressively from the bottom upwards. As a result, the gases, immediately upon taking form at each solidifying layer, are permitted to pass freely upward to the atmosphere. In fact, the evolution of gases takes place slightly above the layer which has solidified, so that progressive solidification has the effect of crowding the gases out as they are formed.

In order that the treatment which has been described may be caused to take place in the body of casting metal, it is essential that there be effected an elimination or substantial elimination of all forces normally produced by passage of current, which have directions different from that of the casting forces. For example, when passing a current, either direct or alternating, through a conductor, internal forces are ordinarily produced within the conductor, the directions of which converge radially inward toward an interior point. These converging forces must be eliminated when treatment is employed. Their production may be conceived as resulting from the action of the circularly directed field within the conductor on the current-carrying

elements. The pressure which they cause is greatest at the interior point toward which they converge and decreases in all directions from this point toward the outer surface of the conductor. When acting alone in molten metal, the converging forces therefore tend to eliminate whatever beneficial effect is derived from the natural buoyancy of the metal, and may neutralize it altogether if the current density is large enough. They are the motive forces agitating the metal when produced by alternating current, a pronounced stirring of the metal being produced, which acts to retard upward travel of impurities. Their complete elimination from the body of casting metal may be effected by subjecting said body throughout its mass to the action of forces f_2 . Referring to either Fig. 3 or 4, the magnetic channel 30 acts to modify the path of the very flux normally acting to produce the converging forces, i. e., causes this flux to pass, as shown by the lowermost line 4, directly through the metal 10 from one vertical wall to the other. Internal forces are produced, but they no longer converge. Stated in other words, the forces f_2 are the original converging forces, but shifted in direction to act downward, as well as increased in magnitude because of the greater strength of the field established.

When forces f_2 are not produced in the body of casting metal, the converging forces above referred to may nevertheless be substantially eliminated by the use of forces f_1 , provided that the proper relative strengths of current and field are employed for producing the forces f_1 . It should be observed that, for properly strengthening and directing the field required for producing the forces f_1 , the use of a magnetic body or magnetic bodies is generally necessitated, which body or bodies may or may not act to so modify the field peculiar to the current in the metal as to cause the converging forces to be transformed into useful forces f_2 . In Fig. 4, the latter field is modified in that manner. In either case, however, the two fields combine to produce a resultant field, and the actual forces present in the metal are those produced by this resultant field. It therefore follows that, when the field peculiar to the current in the metal is not modified with a resulting transformation of the converging forces into forces f_2 , formation of the converging forces will nevertheless be prevented by causing the field employed in producing the forces f_1 to be of sufficient strength to overcome the field peculiar to the current in the metal. In this connection it is to be particularly noted that, when the field peculiar to the current in the metal is not modified with a resulting transformation of the converging forces into forces f_2 , substantial neutralization of that field by the superior strength of the field employed in producing the forces f_1 is an essential requirement for proper treatment of the metal in accordance with the preferred practice of this invention. In Fig. 2, the converging forces are only slightly affected by the flux 3 and are not eliminated, the forces f_1 in this figure being therefore prevented from effecting the treatment.

A phenomenon has been observed in low-frequency induction furnaces of the horizontal ring type, according to which the molten metal in the annular trough is acted upon by outwardly directed radial forces of such strength that, in certain cases, the bottom of the trough can be seen. In principle, this phenomenon is the same as that of a current-carrying circuit tending to

enclose the largest possible area. Referring to either Fig. 3 or 4, that it is entirely absent in the ring of metal 10 by its position within the iron channel 30, can be understood by observing that an outward horizontal motion of that ring produces no additional flux, i. e., no increase in magnetic energy. This elimination of outward forces also applies to any portion of the ring 10, alone positioned within magnetic walls 30 of corresponding arcuate length, substantially no other forces being present in the portion thus positioned than the unidirectional useful forces produced in accordance with this invention.

It is understood that the aforescribed elimination of the forces normally produced by passage of current applies only when it is desired to effect the treatment in conjunction with the casting operation. While it is true that the effect of the forces normally produced by passage of current is more or less reduced as a result of the unidirectional casting forces employed, yet an elimination or substantial elimination of the forces normally produced by passage of current is not a true condition to be satisfied in so far as the actual step of casting the metal into the mold is concerned. This may be readily understood when it is taken into account that all forces present in the metal resolve into a single resultant force as the result of the unidirectional forces introduced, which resultant may be conveniently considered as producing the pressure required to force the metal into the mold. Strong casting pressure may be produced by the use of forces f_1 without effecting a neutralization of the forces normally produced by passage of current. And it is also possible to effect the casting operation by the use of forces f_2 without a complete transformation of the forces normally produced by passage of current into forces f_2 .

Best results are obtained by the treatment when the unidirectional electromagnetic forces employed are caused to be vertically downwardly directed, as in Figs. 3 and 4. Only under this condition can increased buoyancy be obtained, which likewise applies to temperature gradient causing progressive solidification from the bottom upwards. Moreover, it is believed that the agitation is then most effective in increasing fluidity. When the unidirectional forces are inclined, their lateral or horizontal components have a tendency to cause a stirring or circulation of the molten metal. On the other hand, when the unidirectional forces act vertically downwards, they add directly to the weight of the mass elements, thereby causing more linear and parallel displacements of the mass elements.

The induced buoyancy peculiar to the production of forces f_1 has a real value (i. e., a value other than zero) at any point of the metal. On the other hand, the induced buoyancy peculiar to the production of forces f_2 is theoretically zero at the bottom of the metal, but increases continuously to a maximum value at the upper surface. When alternating current is employed, both the induced buoyancy derived from forces f_1 and the induced buoyancy derived from forces f_2 tend to be forced toward the top of the metal by the skin-effect.

In both Figs. 3 and 4, the various effects of the treatment are somewhat stronger at the inner side portions of the metal 10 than at the outer side portions, which is due to increasing flux density (see Fig. 4a) and increasing current (because of decreasing resistance), with decreasing diameter

of the conducting elements. While the variation in strength which the forces (f_1 or f_2) experience in radial directions is but slight, the changes in phase and wave form which they also experience in these directions are even slighter. The various effects of the treatment are obviously more pronounced in Fig. 4 than in Fig. 3.

Referring to Fig. 1, it now becomes apparent that the metal 10 upon being melted by the current therein enters the cavities 26 free of air and other impurities, perfect castings being obtained without the application of external forces on the metal. In producing dental castings according to prior practice, the air that is actually expelled from the mold during the casting operation, must escape through the porous walls, particularly if extraneous pressure is employed to forcibly introduce the metal, any air particles entrapped by the metal filling the mold being by necessity caused to remain therein. The air displaced from the cavities 26 likewise finds an exit path through the porous walls, but, in view of the increased fluidity of the metal 10, is nevertheless also permitted to pass freely through said metal to the atmosphere. This, together with the agitation mechanically communicated to the metal filling the cavities 26, causes complete expulsion of the air originally present in said cavities. Moreover, because of the increased fluidity of the metal 10, the latter need not be heated, for proper flow into said cavities, to the elevated temperatures which present methods of casting employed in dentistry require, but will produce accurate castings when at a temperature close to the melting point and with casting pressures much below those at present employed. A further advantage lies in the fact that it is possible to employ very small diameters for the ducts 27.

It is to be particularly noted that, except for elimination of impurities, none of the above advantages actually depends upon effecting the treatment in the body of casting metal. With or without the treatment the establishment of cyclic forces in said body will cause it to undergo an agitation effective in producing such advantages as reduced casting pressure, reduced casting temperature, complete filling of the mold, etc. While the agitation peculiar to the treatment may enhance these advantages, yet they are in large measure provided by the invention even in the absence of the treatment. It may be said that the advantages peculiar to the casting operation per se are essentially dependent on the establishment of internal agitation by electric current.

Again referring to Fig. 1, by proper control of the current indicated by the ammeter 14, the structures formed in the cavities 26 may be cooled at predetermined rates, the heat produced by the two secondaries 10 and 25 maintaining a substantially uniform temperature throughout their masses at any instant so that defects due to uneven cooling are eliminated. Moreover, by such current control, treatment of the metal remaining in the trough 11 after a casting operation may be continued while it is cooling from its molten state into a state of solidification, so that it is in an ideal condition to produce perfect castings for the succeeding casting operation. When adding more metal in the trough 11, any oxides or impurities below the added metal are caused to rise to the upper surface of the total mass of metal when melted.

The total effective force f_1 acting on the metal 10 in Fig. 4 and the total effective force f_2

acting on the metal 10 in Figs. 3 and 4 are approximately given by the following formulae:

$$f_1 = \frac{8\pi I_t I_b}{d_a \log_e \frac{d_2}{d_1}}$$

per unit length of the metal 10;

$$f_2 = \frac{4\pi I_b^2}{d_a \log_e \frac{d_2}{d_1}}$$

per unit length of the metal 10; where

I_t —the current in the top secondary;

15 I_b —the current in the bottom secondary;

d_a —the mean diameter of the ring 10;

d_1 —the outer diameter of the inner vertical magnetic wall;

20 d_2 —the inner diameter of the outer vertical magnetic wall.

The above equations apply only to annular walls 30 in the form of a channel, as in Figs. 3 and 4. They disclose that both type f_1 and type f_2 of casting forces are independent of the height of the channel and of the location of the ring of casting metal 10 in the channel, the equation for f_1 further disclosing that this type is also independent of the distance between the two secondaries. With a properly constructed channel comparatively large structures, such as dental plates, may thus be cast, the dimensional height of the castings being in no way limited.

Referring to Fig. 1, the ring 10 is preferably positioned substantially in line with the upper circumferential extremities of the magnetic walls 30. Such placement of the ring 10 produces maximum casting forces, f_1 and f_2 , because of the magnetizing effect of the induced poles n and s (alternating in polarity), which tend to group at the said extremities (see Figs. 3 and 4). The effect of the induced poles is not taken into account in the above equations.

The bottom secondary is used primarily to add heat to the mold 23, and a feature of the invention comprises the shaping of this secondary as shown in Figs. 1 or 1a. By enclosing the major portions of the walls of the mold 23, the latter and the cavities 26 therein are maintained at high and substantially uniform temperatures. Even cooling of the castings, regardless of their size, may thus be effected. With the bottom of the metal ring 10 in substantial alignment with the upper circumferential edges a of the bottom secondary and with the metal ring 10 in substantial alignment with the upper circumferential edges of the walls 30, both forces f_1 and f_2 are produced with the least possible amount of leakage flux established by the two secondaries, so that maximum power factor of the transformer is obtained.

When passing a melting current through a small amount of metal held in a trough, the metal usually starts to melt at its point of weakest cross-section and highest current density. If a certain current limit is exceeded, a complete and permanent break occurs in the metal at this point owing to "pinch-effect," circuit connections through the metal being interrupted by the break and complete melting of the metal therefore prevented. According to the invention, this limit of current is considerably increased when electromagnetic forces (f_1 or f_2) of downward action in the trough are introduced into the metal. Pinch-effect, or a contraction in cross-section at a portion or por-

tions of a current-carrying molten mass of metal, is normally due to the converging forces produced in the metal as a result of the current therein, it being apparent that the mass elements under the influence of these forces all tend to move toward an interior point in each plane transverse to the current path. It is this tendency of motion of the mass elements which, when melting metal by current in small amounts in a trough under normal conditions, causes the permanent circuit interruption if a current value greater than the limit is employed. Referring to Fig. 1, the downward forces introduced into the metal 10 tend to move its mass elements toward the bottom of the trough where they further circuit connections, from which it follows that, upon such increase of temperature in the metal 10 as to cause it to melt at a point, any tendency of a break taking place at this point is materially reduced. Moreover, if a break does take place and the current value is not abnormally high (i. e., beyond the limit provided by the invention), the break is merely of a momentary character, as it actually occurs at the bottom of the trough where fluid metal gathers immediately thereafter to reestablish circuit connections. Several breaks may take place in quick succession in this manner, producing a sizzling sound in the trough, each break being accompanied by sparking. The metal nevertheless continues to melt on either side of the breaks, which ultimately come to an end, circuit connections being then continuously maintained so that the metal is permitted to melt throughout its entire mass.

The above method of melting metal only applies where the masses of metal melted are such that permanent circuit interruption therein cannot be overcome by the hydrodynamic head of metal in the trough, i. e., by the action of gravity alone. While not actually dependent on an elimination of the variously directed forces produced by passage of current, it is obviously more effective when that elimination is caused to be carried out, as in Fig. 1. The uniform distribution of the downward forces along the trough in Fig. 1 is another factor contributing to its effectiveness.

Besides the increased range of current values which the above method of melting metal provides, correspondingly greater casting forces may be used in the melting metal. Also the metal may be heated past its melting point in much less time, it being thus possible to increase its temperature at such a rate that successive breaks may occur without checking the melting operation, as already explained. Still another advantage resides in the reduced amounts of metal which may be melted in correspondingly smaller troughs.

Another feature of the invention comprises the narrow V-shaped trough 11 for holding the metal ring. In this connection, it is to be noted that, for a given mass of metal, the narrower the trough is made, the greater will be the height of the metal acted upon by the downward forces therein. Since the height of the column of metal above a duct determines the electrodynamic head producing the casting pressure thereon, I therefore deem it desirable to employ a trough which is as narrow as is practically possible in order to obtain maximum casting pressures with minimum quantities of metal, it being observed that a small amount of working metal is desirable in dentistry in view of the cost of the precious met-

als. This trough construction also contributes to the opposition to permanent circuit interruption in the melting metal, owing to the small cross-sectional space at the bottom toward which the metal tends to move, maximum melting current values being therefore permitted. Because of the minimized amount of metal, the casting apparatus for dentistry is adapted to operate on a standard lighting circuit.

The metal ring, when cool, is of a diameter suitably smaller than that of the trough 11, so that when heated to its melting point it will expand and fit the trough. It may be placed in the trough before the wax patterns have been expelled from the cavities, its contracted form causing it to rest a substantial distance above the bottom of the trough. The heat produced in raising the temperature of the ring to its melting point is thus effectively utilized for expelling the wax patterns from the mold cavities, the wax vapor escaping upwardly to the atmosphere through the ducts 27 and the trough 11. The evaporation of the wax by this means is advantageous in that an intense heat is concentrated directly on the entrances to the ducts 27, which is effective in expelling carbon residue resulting from the vaporized wax. As already stated, complete elimination of this residue is a most important step to follow in casting procedures heretofore employed in dentistry; for if any trace of carbon is permitted to remain, the casting operation is very likely to result in the production of incomplected structures vastly different in configuration from the original patterns, probably due to the effect of gas which is formed when the hot metal comes in contact with the carbon during its sudden inrush into the mold cavities. However, total expulsion of the carbon is believed not as important when casting by the method to which the present invention relates, in view of the ready escape which this method provides for air and other gases from the cavities 26 as the metal is being cast therein. Besides, the metal in the cavities 26 may be kept fluid for a certain period of time by controlling the current in the remaining mass of metal in the trough. After a casting operation, the ring of metal remaining in the trough contracts and, upon detaching the castings and their associated sprues, may be again employed for a succeeding casting operation.

The foregoing description has been particularly concerned with the production of electromagnetic forces directed vertically downwards in the body of casting metal. It is understood, however, that electromagnetic forces of any single direction (f_1 or f_2) may be satisfactorily utilized. For example, it may be desired to cast a metal laterally into its mold. Whereas this may be accomplished by the use of downward forces because of the increased pressure in the metal, yet it may be more advantageous in certain instances to utilize casting forces correspondingly laterally directed in the metal for the purpose. And whatever direction is chosen for the casting forces, treatment will be effected in the metal if the variously directed forces normally produced by passage of current are eliminated. With that elimination carried out the casting forces will in any case establish an induced pressure gradient in the metal, which of course adds vectorially to the pressure gradient produced by gravity. Nevertheless, separation of impurities will always take place in a general direction opposite to that in which the casting forces are produced, so that it will be purified metal to enter

the mold under the influence of the casting pressure.

Details of the dental apparatus I have used in practicing the methods above described are illustrated in Figs. 5 to 8 inclusive. This apparatus comprises a base 31 having a slot into which engages the lower horizontal portion of the transformer core part A, which is rigidly held in a vertical position by the angle pieces 32. An asbestos board 28, formed with suitable apertures through which extend the two legs of the core part A, is secured to the base 31. The primary winding 15, fitted on one of the legs, has its taps 12 connected by wires leading through suitable conduit to the terminals 29, positioned with their associated switch arm 20 on a vertical panel 33, fixed to the board 28 in front of the transformer. Alternately positioned with the studs 29 on the panel 33 is another set of studs 34, the latter being unconnected electrically and of greater height than the studs 29 to prevent short-circuiting of portions of the primary winding 15 as the switch arm 20 is moved from one position into another. To the panel 33 are also attached the switch 16, the ammeter 14, and the plug intake 17. These units, together with the switch arm 20, the primary winding 15 and the fuse block 13 (attached to the board 31 in back of the panel), are wired as shown in Fig. 1. The switch 24, which is used when the bottom or extra secondary is in wire form, is also attached to the panel 33.

The surfaces of contact of the two transformer core parts A and B are ground to provide intimate contact between them. Preferably, the leg of the transformer, around which is fitted the secondary circuits, is formed as a polygon in cross-section (Figs. 6 and 7), to increase its volume of iron per unit length of magnetic path for given diameters of these circuits. In this way, greater transformer efficiency and higher power factor are attained.

The parts A and B of the core are hinged together at 34, so that the part B may be manually raised out of operative engagement with the part A and its end 39 seated on a rest 38 of non-magnetic material, extending upwardly from the board 28. The two parts of the hinge 34 are formed on or secured to channel members 35 and 36, of non-magnetic material, embracing opposite lateral faces of the two core parts to which they are bolted.

At the free end of the core part B, a pair of clips 37, of non-magnetic material, engage the opposite ends of one of the clamping bolts of the core part A, to lock the part B in operative position. To prevent formation of secondary currents through the hinge members 35, 36, clips 37, and their cooperating bolts and nuts, the latter are separated from the conducting parts which they secure by insulating bushings 41, as illustrated in Fig. 6.

The iron walls 30 are fixedly seated on an upper base 40 of heat insulating material by means of screws 42 and, in the embodiment illustrated, are made in three parts, a flat horizontal bottom ring, and inner and outer vertical tubes attached to said ring by the screws 43. The thickness of these walls is such as to obtain proper permeability values of the iron, and preferably the thickness of the inner wall is greater than the outer wall so that the flux density is substantially the same in both inner and outer walls. The three parts of the iron walls 30 are slotted as indicated by 65 (Figs. 4a and 6).

The bottom secondary may be so designed that the moisture and wax are expelled from the plaster mold 23 by the heat provided by said secondary alone, or expelled by said heat in conjunction with the heat provided by the ring in the trough 11. When using the form of bottom secondary 25a, the turns of the wire may be embedded in an annular channel 44 of suitable refractory material, which for convenience may be made in a plurality of sections lining the iron walls 30. The ends of the wire secondary 25a, extend outwardly through lava bushings 45 and 46, and are united by the clamps 47 and 48 to the ends of the conductors 49 and 50, which lead through the panel 33 to the switch 24. The conductor 50 extends along the inner face of the inner iron wall 30, and is insulated by a series of protecting beads. The switch 24 is employed as a convenient means to render the secondary 25a operative or inoperative at will.

A mechanism which facilitates the insertion and removal of the mold 23, comprises a member 60 having an arcuate portion adapted to move vertically within a corresponding recess 61, extending upwardly from the bottom of the base 31. Secured to the member 60 are a plurality of rods 58 extending upwardly through apertures 59, sufficient clearance 51 being provided by the wire secondary 25a to permit these rods, when raised, to abut against the bottom of the mold. An extension 56 projects laterally from the arcuate portion of the member 60, and is also adapted to move vertically within a corresponding recess 57 (Fig. 5). At the free end of this extension 56 is secured a vertical rod 52 adapted to move longitudinally within an upper tubular guide 53 having a base 54 fixed to the board 28. A plurality of stop plates 55 span the recesses 61 and 57 at intervals to limit the downward movement of the member 60 and rod 52. The upper end of the rod 52 carries a knob 62, and a thumb screw 63 is adapted to engage with one or another of a plurality of recesses 64 formed in the rod 52, to clamp the latter in the desired raised position, as when working with molds of different heights. The mechanism described is of non-magnetic material. To insert or remove the mold 23, the knob 62 is lifted and lowered.

The mold 23 is made of a plastic composition such as dental investment plaster, and is provided with a refractory lid 66 having a depending portion 91 engaging the upper portion of the trough 11. Suitable apparatus is used for molding the plastic body 23 with the trough 11 extending therein and the ducts 27 leading from said trough to the enclosed wax patterns 70 (Fig. 7). Each casting operation obviously requires the making of a new mold 23.

In vertical alignment with the trough 11 an aperture 67 is formed through the lid 66, through which aperture 67 the operator may observe the temperature in the trough. Above the lid 66 is a refractory cover 68, having an aperture 69 adapted to correspond with the opening 67. When it is desired to close the latter, the top cover is rotated slightly. If desired, a thermocouple (not shown) may be embedded into the lid 66 with the hot junction of the two dissimilar wires extending into the trough 11, and the two wires of the thermocouple led to a temperature-indicating galvanometer (not shown).

The ring of casting metal is preferably made in the first instance of a plurality of turns of fine wire closely wound. This ring 10a (Fig. 7) may

conveniently be made by forming the wire turns in a trough having a diameter suitably less than the furnace trough 11 to provide for the expansion of the ring when heated. Successive casting operations with one mass of metal are possible until very little of said mass is left in the trough 11. When required, however, masses of metal in wire or other form, such as discarded dental structures, are added to the original ring of metal, these additional masses being melted by conduction of heat from the remainder of the original ring. Preferably, solid rings shaped as washers of minute thickness are added on top of the original mass, in the number required. In this way, these additional rings also serve to generate heat; and they may be used to maintain the amount of metal in the trough substantially constant.

In operating the casting device which has been described, with the mold 23 and ring 10a in place, the upper core part B lowered, the lid openings 67 and 69 in registration, and the switches 16 and 24 closed, first the temperature of the mold 23 is increased gradually by means of the tap switch 20 until all moisture has been expelled. The wax patterns 70 are also expelled during this operation, the vapors from the trough 11 escaping through the openings 67 and 69. With the cover 68 rotated to bring these openings out of registration, the tap switch 20 may then be operated to bring about a quick melting of the ring 10a, by which time molten metal will have cast into the cavities formed by the expelled patterns. The remaining ring of metal may be allowed to solidify under treatment, whereupon the switches 16 and 24 may be opened. With the core part B in its upper seated position on the rest 38, the mold 23 may then be removed from the apparatus and thrown into water for its disintegration, which enables the remaining ring of metal and castings attached thereto to be readily freed from all clinging plaster. If desired, however, the mold 23 may be allowed to cool to any desired temperature either in or out of the apparatus prior to the water disintegrating operation, ring contraction in this case occurring even prior to the water disintegrating operation because of the yielding nature of the plaster.

It is understood that castings may be made with any other shape and location of the bottom secondary within the magnetic walls 30, or by means of the magnetic walls 30 alone, and with locations of the casting ring within said walls otherwise than as shown. Castings may also be produced with the entire body of casting metal positioned slightly above the plane of the upper edges of the magnetic walls 30. The ducts 27 need not be directed vertically downward nor lead from the bottom of the trough 11, but may assume any desired direction and lead from any desired portion of said trough. The moisture and the wax patterns may be expelled solely by the heat produced in the trough 11.

In Fig. 9 I have shown diagrammatically the lines of flux existing when the bottom of the magnetic channel is omitted. For the sake of clarity, the flux lines 4 established by the casting secondary 10 are shown only at the left and the flux lines 3 established by the bottom secondary 25b are shown only at the right. As observed, the flux lines 3 and 4 follow horizontal paths between the magnetic walls both above and below their respective current elements. The total effective forces f_1 and f_2 corresponding

to this arrangement may be obtained approximately from the following formulae:

$$f_1 = \frac{8\pi I_p I_s}{d_s \log_e \frac{d_2}{d_1}} \frac{h'}{1}$$

per unit length of metal;

$$f_2 = \frac{4\pi I_p^2}{d_s \log_e \frac{d_2}{d_1}} \frac{1-2h}{1}$$

per unit length of metal; where h , h' and l are distances defined in Fig. 9.

It is seen that the force f_2 of this system is a maximum and equal to the corresponding force f_2 obtained with the use of the bottom wall when h equals zero, i. e., when the ring 10 is placed in alignment with the upper extremities of the magnetic walls. The force f_1 , on the other hand, is appreciably smaller than the corresponding force f_1 with the use of the bottom wall, but may be increased by increasing the distance h' . It will therefore be appreciated that arrangements comprising the two parallel walls, without the bottom wall, may also be employed to realize the various objects and advantages already described in connection with this invention. The omission of the bottom wall, in view of the simplified construction which it involves, may be found convenient in certain cases, especially where the presence of the bottom secondary is not essential.

The apparatus illustrated in Fig. 10 employs a transformer primary 78 for producing downward forces f_1 in the metal ring 10. The primary 78 is positioned above the ring 10, and its leakage flux (not shown) is modified in both direction and intensity by the magnetic walls 84 to render the forces f_1 suitable for casting the metal 10, as is understood from previous description. Observing that the ring 10 is positioned midway between the upper and lower extremities of the magnetic walls 84, there can be no force f_2 acting on the ring 10 as a whole, as the foregoing equation for the total force f_2 with no bottom wall reveals ($f_2=0$, when $h=\frac{1}{2}$). Internal forces f_2 may be produced in the ring at its upper and lower limits, but are certainly of negligible intensity and counteract one another in direction.

Fig. 11 illustrates an arrangement for producing similar forces f_1 in a small portion of the periphery of the metal ring 10, the required flux 80 being led through such metal portion by suitable iron parts 81 and 82 connected to the transformer core. That is, the flux 80 is established in a manner similar to the transformer flux 79 linking both the primary (not shown) and the secondary 10, and is therefore mutual flux produced by the resultant action of primary and secondary magnetomotive forces, it being of course understood that, in the case of the flux 80, it is not the secondary 10 as a whole which acts, mutually with the primary, to produce the resultant flux 80, but the individual current elements of the secondary. Downward forces f_2 (not shown) may also be produced as a result of leakage flux (not shown) following the low-reluctance path provided by the iron parts 81 and 82 and transformer core in connection therewith. The arrangement of Fig. 11 provides a high casting pressure with only slight lowering in transformed power factor.

It is understood that, in each of the embodiments illustrated in Figs. 9, 10, and 11, increased buoyancy, increased fluidity, and temperature gradient take place in the same manner as pre-

viously described. In Fig. 11, eddy currents are established in the metal portion through which the flux 80 is passed, treatment occurring in that portion only.

The advantages to be derived from the present invention in dentistry are of special importance in connection with the gold-platinum alloys. These alloys have important properties which adapt them admirably for use in dental prosthetics, but have heretofore been difficult to cast, particularly if the alloy used is not essentially perfect in homogeneity in the first instance. The introduction of the high-frequency induction furnace in the dental supply industry has improved their internal structures and, in fact, made production of certain of them possible. Nevertheless the practitioner still experiences difficulties in producing castings with these alloys. Apparently, the homogeneity of the working metal is destroyed as a result of the casting methods now employed in dentistry, so that it must often be returned after a limited period of service to the supply house or producer for a further melt by induction. In accordance with this invention, not only will perfect castings be produced with these alloys, but also will the homogeneity of the working metal be preserved.

Although in the specification reference has been made to the magnetic walls as elements separate from the transformer core, it is to be understood that the wall adjacent the transformer core can be replaced by the transformer core itself. Also, the magnetic walls can be of laminated construction to minimize eddy current loss therein. And the bottom heating secondary may comprise a plurality of separate elements which may be in series or parallel connection with one another or form individual closed circuits having no common connections.

In the claims, the term "unidirectional" applied to the casting forces should be interpreted as meaning that such forces are unidirectional with respect to the path of the current, i. e., that unidirectional forces are produced in each consecutive plane transverse to said path. Further, the term "unidirectional" wherever the character of the current is not specifically mentioned, should be broadly interpreted as meaning that unidirectional steady forces are produced when using direct current and unidirectional effective forces are produced when using alternating current. A similar interpretation should be made of the qualifying term "downward." The current-qualifying term "alternating" should be construed as covering any current which varies periodically with time. The term "eliminated" employed in connection with the variously directed forces normally produced by passage of current should be broadly interpreted as meaning that such forces are either neutralized or converted into unidirectional forces. On the other hand, the stated introduction of unidirectional forces in the metal to be cast should not be regarded as necessarily resulting in an elimination of the said forces of varied directions, unless this elimination is positively mentioned or made evident by the specific apparatus claimed. The term "metal" should be regarded as including both metallic elements and alloys thereof.

What is claimed is:

1. In metal casting requiring a casting pressure other than that which can practicably be produced by gravity alone, the step consisting in introducing unidirectional or substantially unidirectional electromagnetic casting forces into the

metal causing it to flow into the mold under pressure produced in opposition to the resistance to its entry therein and to forcibly impinge on the surface of the mold under the influence of that pressure.

2. In metal casting requiring a casting pressure other than that which can practicably be produced by gravity alone, the step consisting in passing an alternating current through the metal and simultaneously inducing therein in cooperation with said current cyclic electromagnetic forces of unidirectional or substantially unidirectional effective action, said forces being casting forces causing the metal to flow into the mold under pressure produced in opposition to the resistance to its entry therein and to forcibly impinge on the surface of the mold under the influence of that pressure.

3. In metal casting requiring a casting pressure other than that which can practicably be produced by gravity alone, the step consisting in introducing downward electromagnetic casting forces into the metal causing it to flow into the mold under pressure produced in opposition to the resistance to its entry therein and to forcibly impinge on the surface of the mold under the influence of that pressure.

4. In metal casting requiring a casting pressure other than that which can practicably be produced by gravity alone, the step consisting in passing an electric current through the metal and simultaneously producing a magnetic field therein of uniform or substantially uniform direction transverse to the path of said current, whereby unidirectional or substantially unidirectional electromagnetic casting forces are established in the metal causing it to flow into the mold under pressure produced in opposition to the resistance to its entry therein and to forcibly impinge on the surface of the mold under the influence of that pressure.

5. In metal casting requiring a casting pressure other than that which can practicably be produced by gravity alone, the step consisting in melting the metal by passage of an electric current therethrough, and the subsequent step of casting the metal by electromagnetic casting forces induced therein in cooperation with said current, said forces being of unidirectional or substantially unidirectional action causing the metal to flow into the mold under pressure produced in opposition to the resistance to its entry therein and to forcibly impinge on the surface of the mold under the influence of that pressure.

6. In metal casting requiring a casting pressure other than that which can practicably be produced by gravity alone, the step consisting in passing an electric current through the metal and simultaneously inducing therein unidirectional or substantially unidirectional electromagnetic forces in cooperation with said current, the forces of varied directions normally produced by passage of current alone being eliminated or substantially eliminated, said unidirectional or substantially unidirectional forces being treating and casting forces causing treated metal to flow into the mold under pressure produced in opposition to the resistance to its entry therein and to forcibly impinge on the surface of the mold under the influence of that pressure.

7. In metal casting requiring a casting pressure other than that which can practicably be produced by gravity alone, the step consisting in passing an alternating current through the metal and simultaneously inducing therein in coopera-

tion with said current cyclic electromagnetic forces of unidirectional or substantially unidirectional effective action, the cyclic forces of varied directions normally produced by passage of alternating current alone being eliminated or substantially eliminated, said cyclic forces of unidirectional or substantially unidirectional effective action being treating and casting forces causing treated metal to flow into the mold under pressure produced in opposition to the resistance to its entry therein and to forcibly impinge on the surface of the mold under the influence of that pressure.

8. In metal casting requiring a casting pressure other than that which can practicably be produced by gravity alone, the step consisting in passing an electric current through the metal and simultaneously inducing therein downward electromagnetic forces in cooperation with said current, the forces of varied directions normally produced by passage of current alone being eliminated or substantially eliminated, said downward forces being treating and casting forces causing treated metal to flow into the mold under pressure produced in opposition to the resistance to its entry therein and to forcibly impinge on the surface of the mold under the influence of that pressure.

9. In metal casting requiring a casting pressure other than that which can practicably be produced by gravity alone, the step consisting in passing an alternating current through the metal and simultaneously inducing therein in cooperation with the said current cyclic electromagnetic forces of downward effective action, the cyclic forces of varied directions normally produced by passage of alternating current alone being eliminated or substantially eliminated, said cyclic forces of downward effective action being treating and casting forces causing treated metal to flow into the mold under pressure produced in opposition to the resistance to its entry therein and to forcibly impinge on the surface of the mold under the influence of that pressure.

10. In metal casting requiring a casting pressure other than that which can practicably be produced by gravity alone, the step consisting in passing an electric current through the metal and simultaneously subjecting the field of said current to the action of a magnetic body or magnetic bodies causing it to be uniformly or substantially uniformly directed in the metal transversely to the path of said current, unidirectional or substantially unidirectional electromagnetic forces being established in the metal by said field and current to the exclusion or substantial exclusion of the forces of varied directions normally produced by passage of current alone, said forces of single or substantially single direction being treating and casting forces causing treated metal to flow into the mold under pressure produced in opposition to the resistance to its entry therein and to forcibly impinge on the surface of the mold under the influence of that pressure.

11. In metal casting requiring a casting pressure other than that which can practicably be produced by gravity alone, the step consisting in passing an alternating current through the metal and simultaneously subjecting the field of said current to the action of a magnetic body or magnetic bodies causing it to be uniformly or substantially uniformly directed in the metal transversely to the path of said current, cyclic electromagnetic forces of downward effective action being established in the metal by said field and

current to the exclusion or substantial exclusion of the cyclic forces of varied directions normally produced by passage of alternating current alone, said cyclic forces of downward effective action being treating and casting forces causing treated metal to flow into the mold under pressure produced in opposition to the resistance to its entry therein and to forcibly impinge on the surface of the mold under the influence of that pressure.

12. In melting small masses of metal in a trough by passage of electric current through the metal, the step consisting in simultaneously inducing in the metal in cooperation with the melting current electromagnetic forces of downward action in the trough to oppose permanent circuit interruption in the metal.

13. In melting small masses of metal in a trough by passage of electric current through the metal, the step consisting in simultaneously inducing in the metal in cooperation with the melting current electromagnetic forces of downward action in the trough to oppose permanent circuit interruption in the metal, the forces of varied directions normally produced by passage of current alone being eliminated or substantially eliminated.

14. The method of melting small masses of metal by passage of electric current there-through, which comprises conducting the melting operation in a narrow V-shaped trough and simultaneously inducing in the metal in cooperation with the melting current electromagnetic forces of downward action in said trough, whereby permanent circuit interruption in the metal is opposed.

15. In an electric casting device, the combination with a trough for holding the conducting substance to be cast, a mold adapted to communicate by an inlet passage with said trough, and means for passing an electric current through the substance, of further means for electromagnetically inducing in cooperation with said current unidirectional or substantially unidirectional internal casting forces in the substance causing it to flow under pressure through said passage into said mold.

16. An electric casting device comprising a transformer having a closed secondary of the substance to be cast, a trough for holding said secondary, a mold beneath said trough adapted to communicate therewith, and means for producing unidirectional or substantially unidirectional electromagnetic casting forces within the substance causing it to flow under pressure into said mold.

17. In an electric melting and casting device, the combination with a receptacle for carrying the conducting substance to be cast, a mold adapted to communicate with said receptacle, and means for melting the substance by passage of an electric current therethrough, of further means cooperating with said current in electromagnetically inducing unidirectional or substantially unidirectional internal casting forces within the substance causing it to flow under pressure into said mold.

18. In an electric casting device, a receptacle for carrying the conducting substance to be cast, means for passing an electric current through the substance, a mold adapted to contain wax patterns and to communicate with said receptacle, the substance being melted by said current and the heat produced by said current also serving to expel wax from said mold, and means co-

operating with said current in electromagnetically inducing unidirectional or substantially unidirectional internal casting forces within the substance causing it to flow under pressure into said mold.

19. In an electric casting device, the combination with a receptacle for carrying the conducting substance to be cast, a mold adapted to communicate with said receptacle, and a conducting element for heating said mold, of means for passing an electric current through said element and an electric current through the substance, and means cooperating with said currents for electromagnetically inducing unidirectional or substantially unidirectional internal casting forces within the substance causing it to flow under pressure into said mold.

20. An electric wax evaporating, melting and casting device, comprising a receptacle for carrying the conducting substance to be cast, a mold adapted to contain wax patterns and to communicate with said receptacle, a conducting element for heating said mold and expelling wax therefrom, means for passing a heating current through said element and a melting current through the substance, and means cooperating with said currents for electromagnetically inducing unidirectional or substantially unidirectional internal casting forces in the substance causing it to flow under pressure into said mold.

21. In an electric casting device, the combination with a container for carrying the conducting substance to be cast, a mold adapted to communicate with said container, and means for passing a current through the substance, of a magnetic structure comprising spaced walls positioned with respect to the substance to cause the flux produced by said current to pass from one wall to the other, said structure cooperating with said current in electromagnetically inducing unidirectional or substantially unidirectional internal casting forces within the substance causing it to flow under pressure into said mold.

22. In an electric casting device, the combination with a container for carrying the conducting substance to be cast, a mold adapted to communicate with said container, and means for passing a current through the substance, of a magnetic channel having its spaced portions positioned with respect to the substance to cause the flux produced by said current to pass from one portion to the other, said channel cooperating with said current in electromagnetically inducing unidirectional or substantially unidirectional internal casting forces within the substance causing it to flow under pressure into said mold.

23. In an electric casting device, the combination with a body having a trough formed therein to carry the conducting substance to be cast, a mold adapted to communicate with said trough, and means for passing a current through the substance, of magnetic walls extending upwardly one on either side of said trough for electromagnetically inducing in cooperation with said current downward internal casting forces within the substance causing it to flow under pressure into said mold.

24. In an electric casting device, the combination with a trough for containing the conducting substance to be cast, a mold adapted to communicate with said trough, and means for passing a current through the substance, of a magnetic structure having a lower portion located below said trough and upper free end portions

positioned one on either side of said trough, said structure cooperating with said current in electromagnetically inducing downward internal casting forces within the substance causing it to flow under pressure into said mold.

25. In an electric casting device, a transformer having a closed secondary of the substance to be cast, a trough for holding said secondary, a mold adapted to communicate with said trough, and a magnetic channel having its bottom wall disposed below said trough and its side walls disposed one on either side of said trough, said channel cooperating with the current in said secondary in electromagnetically inducing internal casting forces within the substance causing it to flow under pressure into said mold.

26. In an electric casting device, a transformer having a closed secondary of the substance to be cast, a trough for holding said secondary, a mold adapted to contain wax patterns and to communicate with said trough, said secondary being melted by the current therein and the heat produced by said current also serving to expel wax from said mold, and magnetic walls having upper free end portions one on either side of said trough for electromagnetically inducing in cooperation with said current internal casting forces within the substance causing it to flow under pressure into said mold.

27. In an apparatus for casting electrically conducting materials, a body having a narrow V-shaped trough formed therein to hold the material to be cast, a mold adapted to communicate by an inlet passage with said trough, and means for producing downward electromagnetic casting forces within the material causing it to flow under pressure through said passage into said mold.

28. In an apparatus for casting electrically conducting materials, a narrow V-shaped trough for holding the material to be cast, a mold, said trough being adapted to communicate with said mold by a passage leading from its bottom, and means for electromagnetically inducing downward internal casting forces in the material causing it to flow under pressure through said passage into said mold.

29. An electric casting device comprising a transformer having a primary with a plurality of taps and a closed secondary of the substance to be cast, a trough for carrying said secondary, a mold adapted to contain wax patterns and to communicate with said trough, a second secondary for heating said mold and expelling moisture and wax therefrom, said taps operating in association with switching means to provide a gradual increase of temperature in said mold, and means for producing unidirectional or substantially unidirectional electromagnetic casting forces in the substance causing it to flow under pressure into said mold.

30. In a combined wax evaporating and casting device, a transformer having a closed secondary of the substance of the cast, a trough for holding said secondary, said secondary being normally of a diameter smaller than that of said trough to provide for its expansion when heated by the current therethrough, a mold adapted to contain wax patterns and to communicate with said trough, the vaporized wax escaping through said trough, and means for producing unidirectional or substantially unidirectional electromagnetic casting forces in the substance causing it to flow under pressure into said mold.

31. An electric wax evaporating, melting and

casting device, comprising a receptacle for carrying the conducting substance to be cast, a mold below said receptacle and adapted to contain wax patterns and to communicate with said receptacle, a conducting element for heating said mold and expelling moisture and wax therefrom, means for passing a heating current through said element and a melting current through the substance, and a structure of magnetic material comprising walls disposed one on either side of said element and mold and having upper free end portions extending above said element on opposite sides of said receptacle, the internal forces electromagnetically induced in the substance causing it to flow under pressure into said mold.

32. An electric casting device comprising a receptacle for carrying the conducting substance to be cast, a mold adapted to communicate with said receptacle, a conducting element for heating said mold, means for passing a heating current through said element and a melting current through the substance, and a structure of magnetic material comprising walls disposed one on either side of said element and mold and having free end portions extending beyond said element on opposite sides of said receptacle, the internal forces electromagnetically induced in the substance causing it to flow under pressure into said mold.

33. An electric casting device comprising a transformer having a closed secondary composed of the substance to be cast, a trough for holding said secondary, a mold below said trough and adapted to communicate therewith, a second secondary for heating said mold, and a structure of magnetic material comprising walls disposed one on either side of said second secondary and mold and having upper free end portions extending above said second secondary on opposite sides of said trough, the internal forces electromagnetically induced in the substance causing it to flow under pressure into said mold.

34. An electric casting device comprising a transformer having a closed secondary composed of the substance to be cast, a trough for carrying said secondary, a mold adapted to communicate with said trough, a second secondary having elements one on either side of said mold for heating said mold, said elements having their upper extremities in substantial alignment with the bottom of said trough, and a structure of magnetic material comprising walls disposed one on either side of said second secondary and mold and having upper free end portions extending above said second secondary on opposite sides of said trough, the internal forces electromagnetically induced in the substance causing it to flow under pressure into said mold.

35. An electric wax evaporating, melting and casting device, comprising a transformer having a closed secondary of the substance to be cast, a trough for holding said closed secondary, a mold below said trough and adapted to contain wax patterns and to communicate with said trough, a second secondary for heating said mold and expelling moisture and wax therefrom, and a structure of magnetic material comprising walls disposed one on either side of said second secondary and mold and having upper free end portions extending above said second secondary on opposite sides of said trough, the substance being melted by the current therein and the internal forces electromagnetically induced within

it causing it to flow under pressure into said mold.

36. An electric wax evaporating, melting and casting device, comprising a transformer having a closed secondary of the substance to be cast, a trough for holding said secondary, a mold below said trough and adapted to contain wax patterns and to communicate with said trough, a second secondary for heating said mold and expelling moisture and wax therefrom, said second secondary comprising side elements and a bottom element respectively between which and

above which said mold is disposed, and a magnetic structure comprising side walls and a bottom wall respectively between which and above which said second secondary and mold are disposed and having its side walls projecting above said side elements on opposite sides of said trough, the substance being melted by the current therein and the internal forces electromagnetically induced within it causing it to flow under pressure into said mold.

WALTER W. HOKE.

CERTIFICATE OF CORRECTION.

Patent No. 2,083,022.

June 8, 1937.

WALTER W. HOKE.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 1, first column, line 13, for the word "objects" read object; page 2, first column, line 49, strike out the colon after "connections" and insert instead a semicolon; page 6, first column, line 11, strike out the words and comma "gradient produced by gravity alone," and insert instead in the body of casting metal, which; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 27th day of July, A. D. 1937.

Henry Van Arsdale

Acting Commissioner of Patents.

(Seal)

it causing it to flow under pressure into said mold.

36. An electric wax evaporating, melting and casting device, comprising a transformer having a closed secondary of the substance to be cast, a trough for holding said secondary, a mold below said trough and adapted to contain wax patterns and to communicate with said trough, a second secondary for heating said mold and expelling moisture and wax therefrom, said second secondary comprising side elements and a bottom element respectively between which and

above which said mold is disposed, and a magnetic structure comprising side walls and a bottom wall respectively between which and above which said second secondary and mold are disposed and having its side walls projecting above said side elements on opposite sides of said trough, the substance being melted by the current therein and the internal forces electromagnetically induced within it causing it to flow under pressure into said mold.

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