United States Patent

Fritsche

[15] **3,650,311**

[45] **Mar. 21, 1972**

[54] **METHOD FOR HOMOGENEOUS REFINING AND CONTINUOUSLY CASTING METALS AND ALLOYS**

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[73] Assignee: **Sandel Industries, Inc.**

[22] Filed: **May 14, 1969**

[21] Appl. No.: **824,589**

[52] **U.S. Cl.** 164/52, 164/82, 164/252, 164/266

[51] **Int. Cl.** **B22d 27/02**

[58] **Field of Search** 164/83, 85, 50, 51, 52, 250, 164/251, 252, 266

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Assistant Examiner—**John E. Roethel**
Attorney—Carothers and Carothers

[57] **ABSTRACT**

A process and apparatus for electroslag remelting to metallurgically refine and cast metal alloys in a controlled environment and confined area under electroslag, consisting of an electro-energized molten flux bath blanketing the molten metal bath. The original constituents of the metal alloys are fed, in a heated or unheated state, to the area of the molten bath until they have been melted and converted into a metallurgically refined molten alloy, and then the refined molten alloy is withdrawn from the confined feeding area to form a product such as by continuous casting.

The principal feature, therefore, is the continuous blending and refining to produce a super alloy ingot that possesses low impurity level and has good grain structure.

The confined, offset or laterally disposed feeding of the metal alloy entraps any unmelted materials and insured only the casting of the liquified molten metal and permits more accurate control of the different areas of the melt as well as the control of the thermodynamics of the liquid-solid interface formed in the continuous casting area.

20 Claims, 17 Drawing Figures

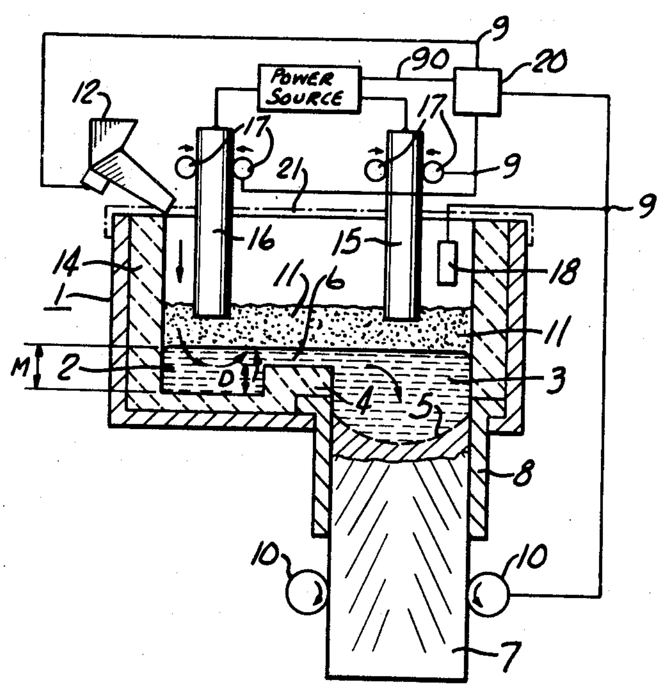

Fig. 1

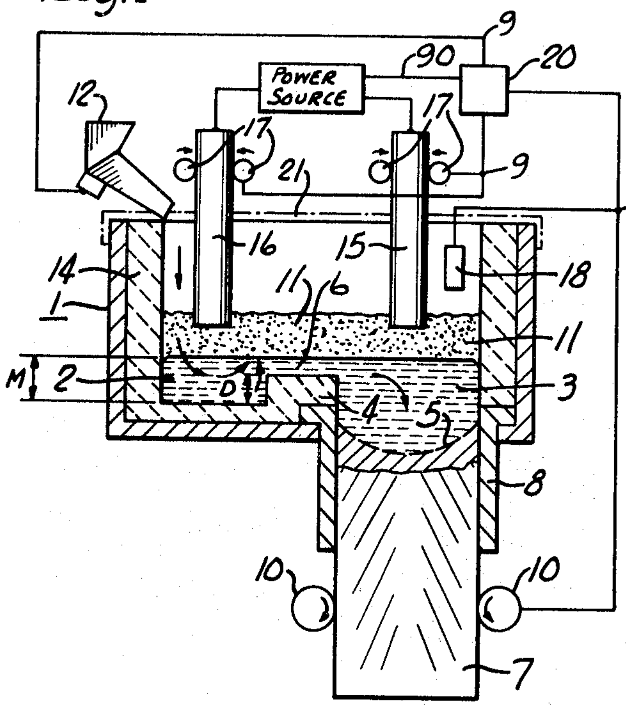

Fig. 3

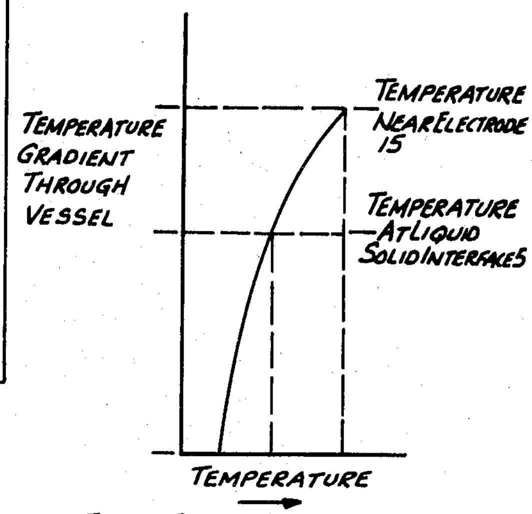

Fig. 4

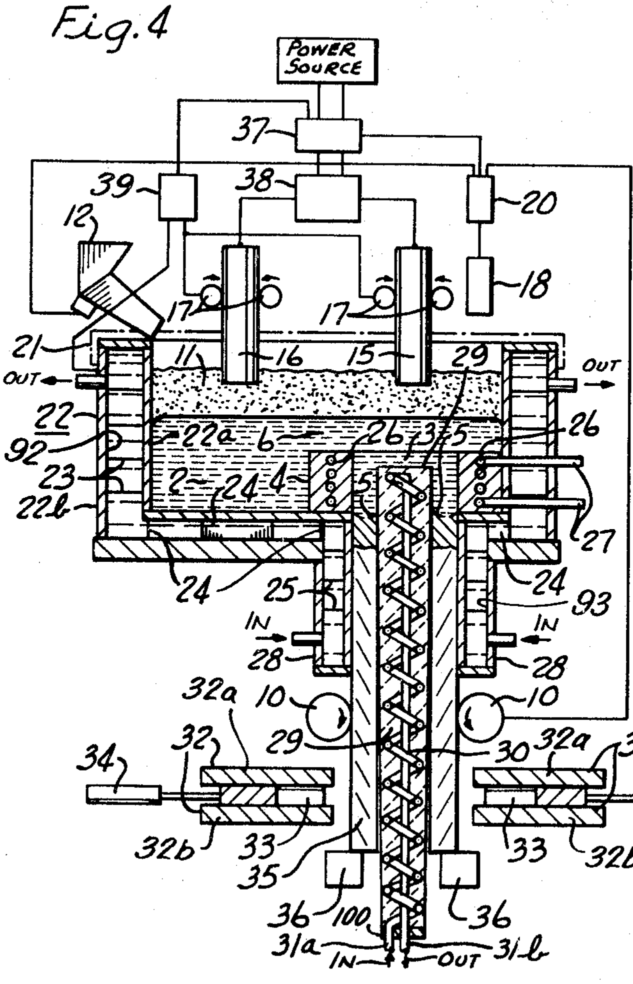

Fig. 2

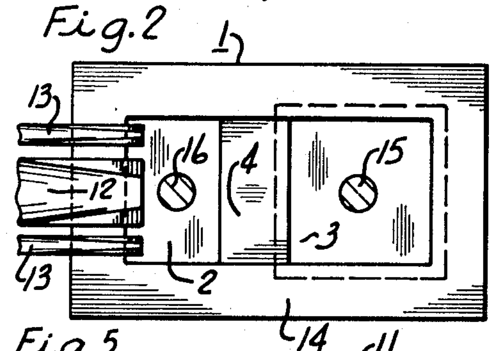

Fig. 5

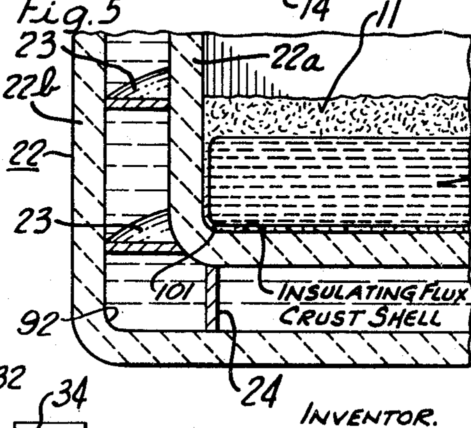

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Fig. 6

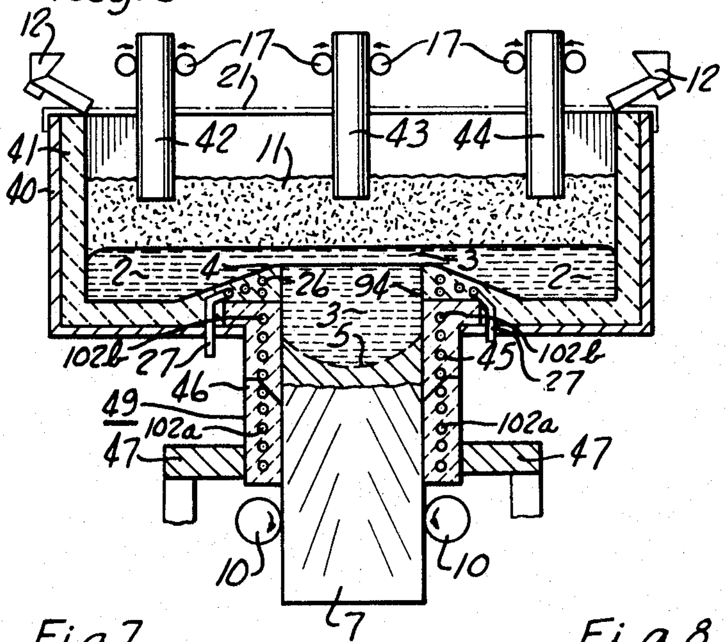


Fig. 9

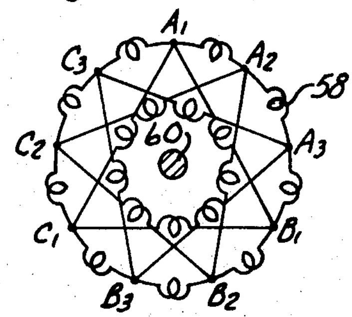


Fig. 7

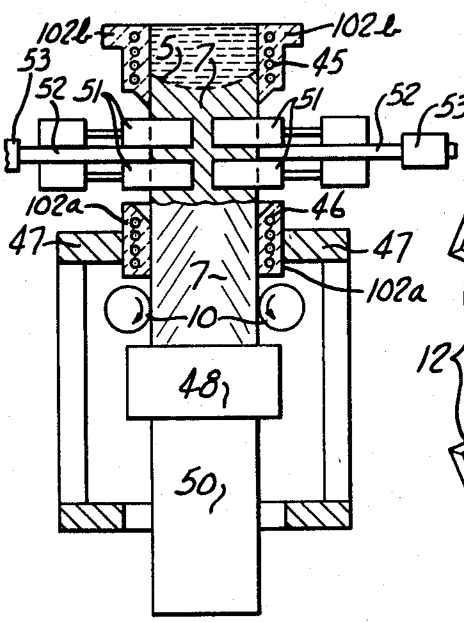


Fig. 8

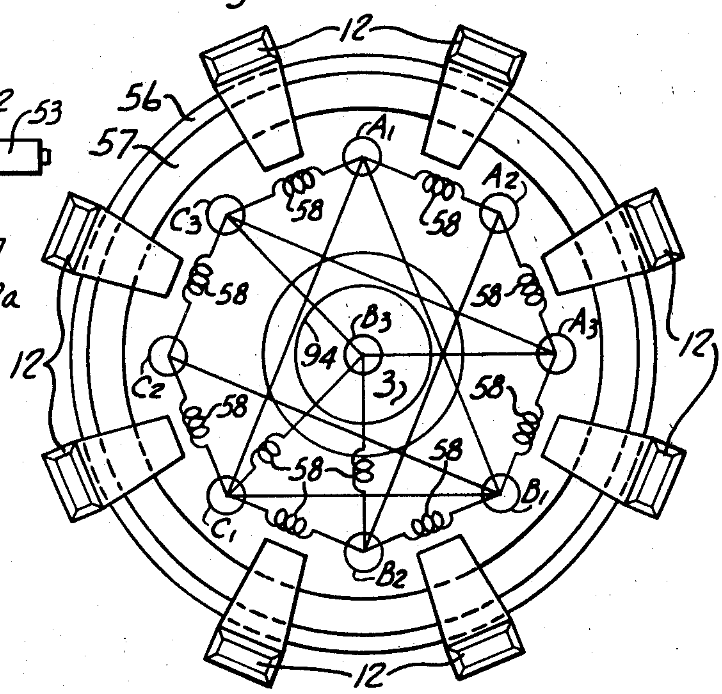
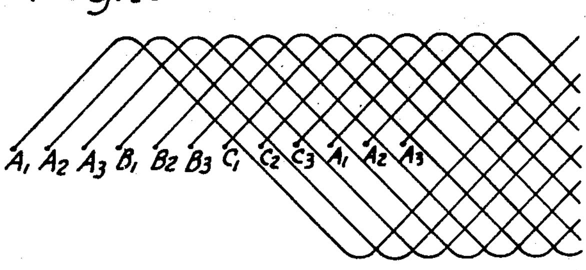


Fig. 10



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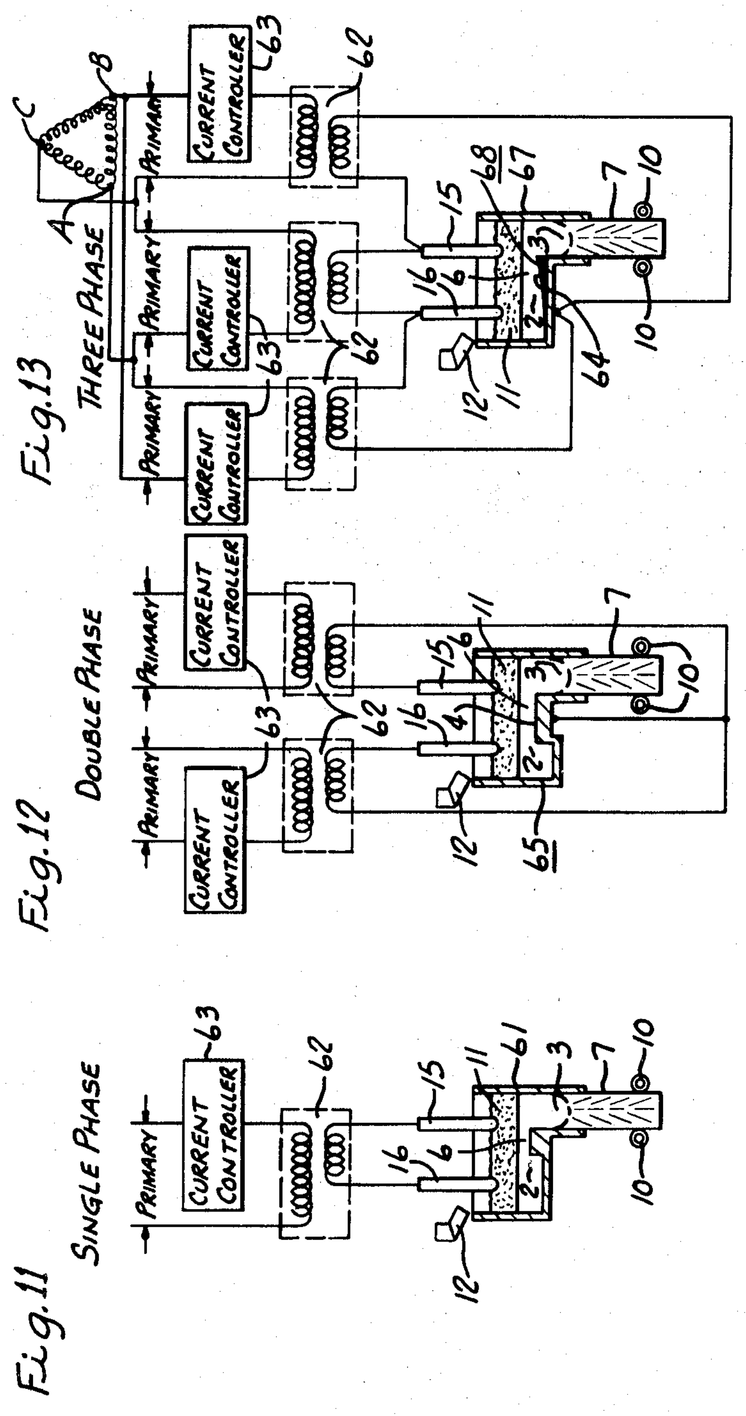

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Fig. 14

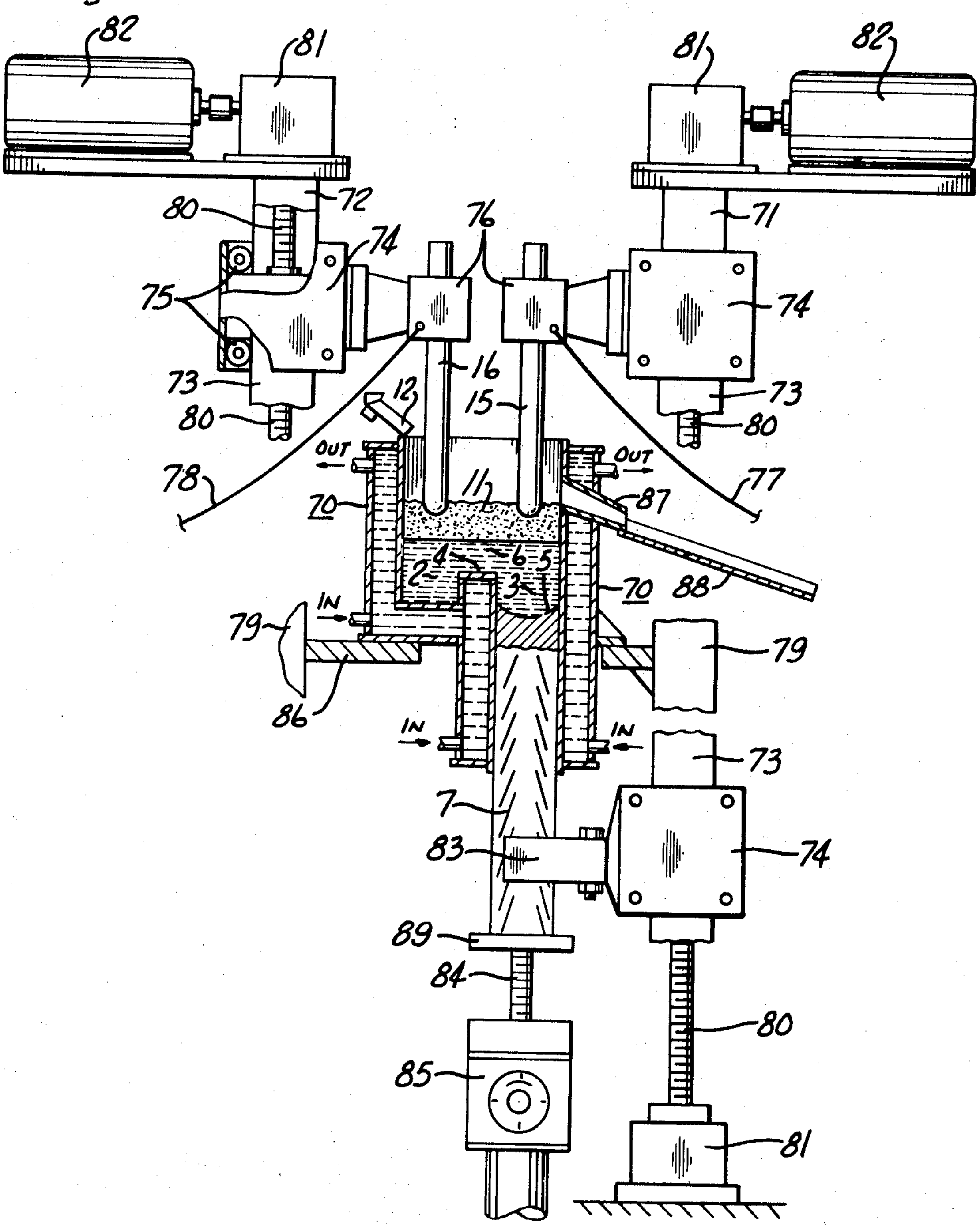

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Fig. 16

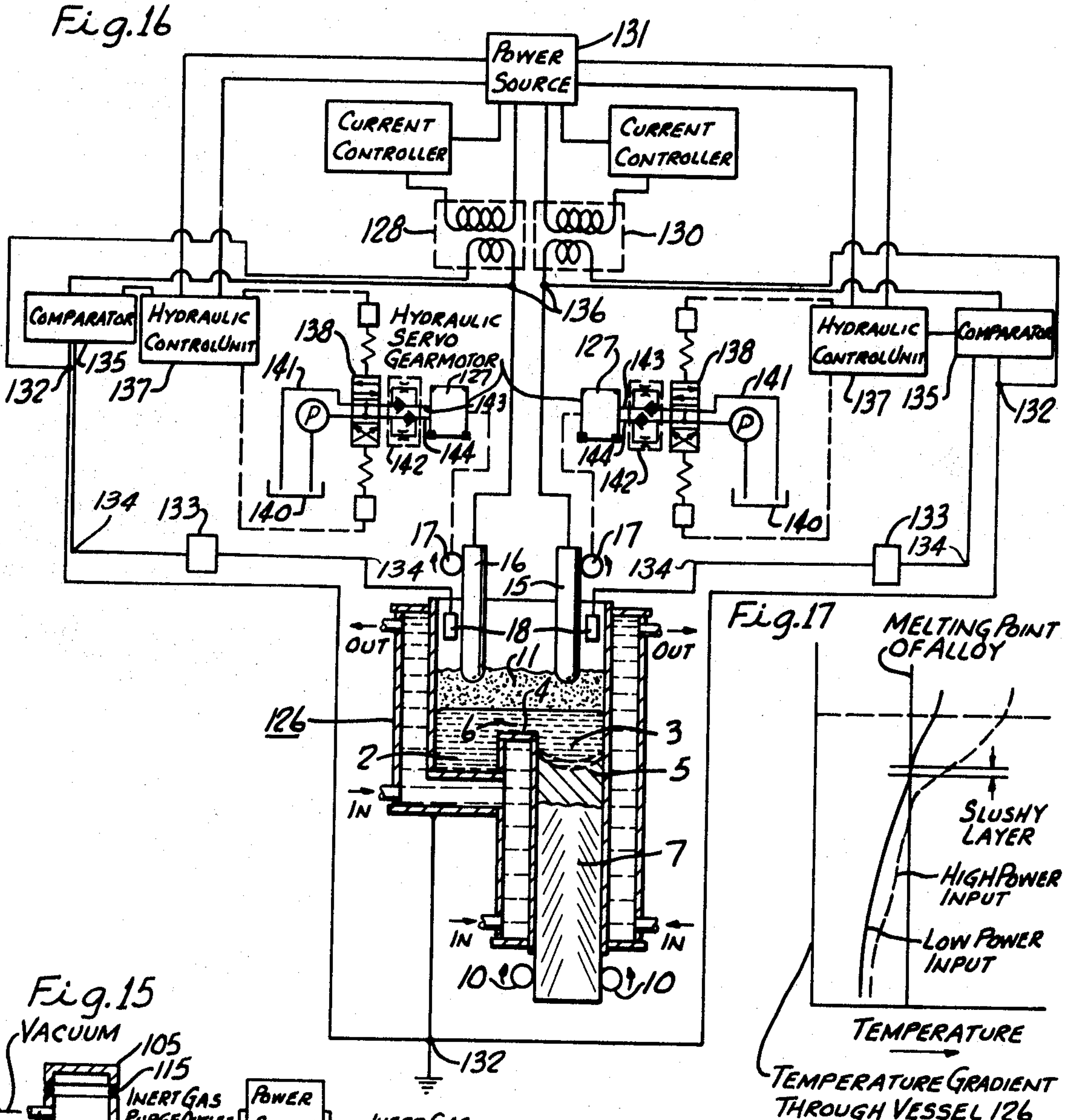
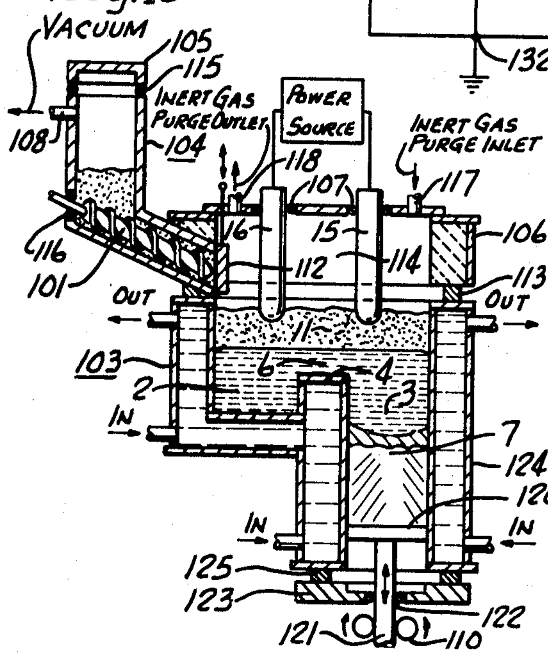


Fig. 17

Fig. 15



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METHOD FOR HOMOGENEOUS REFINING AND CONTINUOUSLY CASTING METALS AND ALLOYS

BACKGROUND OF INVENTION

This invention contemplates apparatus that permits a true continuous electroslag process wherein the alloy constituents can be continuously charged to the apparatus and heated to a high temperature and the electroslag flux can be continuously refurbished or changed in the apparatus, and the cast ingot can be continuously drawn from the apparatus and severed without interrupting the entire overall process.

An undesirable characteristic of the prior art is the inability to properly control the resistance heating through a consumable metallic electrode which is melted into a molten superheated flux bath or pool. Without proper and efficient control in heating, fusing, blending, refining, melting and subsequent cooling, there results nonhomogeneous metal ingots, possessing higher impurity levels than desired. This has plagued the metal refining and casting art for many years resulting in the necessity of a two-step operation wherein the alloy is first refined and then formed into a consumable electrode which then is used in a second heated crucible process wherein an ingot is remelted and formed on a continuous basis. The U.S. Pats. to Hopkins, No. 2,369,233 and Peras, No. 3,234,608, would fall in this category.

Another problem that has plagued the prior art is arc discharging at the electrodes when submerged in the flux blanket, such as disclosed in Hopkins U.S. Pat. No. 3,067,473, which not only causes defects, such as cavities, blow holes, pores, etc., in the cast ingot but also permits unmelted inclusions to be presented into the ingot.

Another problem that has plagued the art has been not only controlling the melting process and the consumable metal electrode, but also taking into consideration chemical control, that is, tailoring fluxes to be utilized as the molten flux bath to properly refine the particular alloy that is desired to be produced and continuously cast.

The prior art structures and methods employed have been unable to make alloy additions during melting of a consumable metal electrode without causing defects, such as, inclusion stringers, alloy segregation, and coherent brittle phases in the cast ingot.

Two important examples of prior art references are the U.S. Pats. of Herres, No. 2,763,903 and Sunnen, No. 3,344,839.

Herres U.S. Pat. No. 2,763,903, lacks the use of a flux bath or blanket and cannot produce successfully a homogeneous ingot because of nonuniformity in heat input from the electrodes. This is particularly true at the mouth of the casting section. There is no means provided for controlling the solidification in the casting section through control of the thermogradients and as a result, the ingot will not have the desired axial solidification structure and crystalline orientation at the liquid, solid interface.

Sunnen, U.S. Pat. No. 3,344,839, lacks control of the proper fusing and blending of the metallic powders adhering to the metallic strip or bar electrode in the molten bath in attempting to refine and concurrently therewith continuously cast an alloy ingot. The powder particles are freed from the electrode as it progresses into the molten bath because they progressively lose their magnetic attraction to the magnetic strip or bar electrode and are not given a complete opportunity to melt or otherwise fuse and blend into a homogeneous manner and become entrapped in the solidifying unit being formed substantially directly beneath the molten bath. Thus, an impure, undesirable ingot is produced having unwanted inclusions. Since Sunnen utilizes a vertical arrangement with a consumable electrode directly above the casting area, it is a matter of necessity that he use fine particles rather than the granules so that these particles will melt quickly before they enter the casting area. This is the principle reason why undesirable inclusions are formed in the casting.

SUMMARY OF INVENTION

The basic objective of this invention is to produce on a continuous basis a super alloy having the desired metallurgical properties and impurity level including axial oriented grain structure. The orientation of the grain structure is controlled at the interface in the casting section by controlling the thermodistribution through the interface. This is done by controlling the heat input in the casting area which may be accomplished by electroheating or if necessary induction coil heating at the mouth of the casting section.

Provision is made for continuous refining in casting metal alloys under a molten flux blanket covering the molten metal bath by melting their constituents of the selected alloy to, first, metallurgically form, blend and refine the alloy in one zone or area and, then, withdrawing the refined alloy to another zone or area to continuously cast the same. Means are provided by which the refining and casting of alloys such as those known as "super alloys" is carried out in a single continuous operation.

Reference is made to this zoned refining and casting process as the "offset" method wherein a practical control referred to above, is employed in regard to heating and temperature distribution through the use of a molten flux medium as well as the employment of a solid flux crust on the surfaces of the ingot mold. The ultimate aim is to refine the metal alloy, which may contain reactive elements, under controlled heat conditions while eliminating impurities and solid inclusions from entering the casting area and maintaining temperature uniformity at the mouth of and in the casting section of the ingot mold.

The offset method with adequate heat containence and distribution provides a practical and commercially accepted method of controlling the fusion and blending of the alloy materials before they are allowed to enter the continuously casting area. In this manner, unrefined and unmelted inclusions are not permitted to contaminate the ingot.

The electrical control of the crucible or vessel must be designed to supply sufficient power to maintain in a molten state the flux bath as well as melt the incoming metal feed. Also there must be a balance of power input between the melting refining section and the continuously casting section so that the liquid-solid interface is maintained below the intermediate area of the ingot mold cavity.

The offset method is accomplished within and under an electroslag or an electrically energized molten flux bath that blankets and melts the constituents by functioning as a flux as well as a refining constituent so that part of the flux may selectively enter the molten alloy bath as an operation or "curing" constituent. The term "electroslag" referred to herein is a molten bath of flux or flux blanket which covers the molten metal feeding zone or area as well as the casting zone or pouring area and this flux is known in the art as a slag or electroslag. Since the flux must melt constituents forming the alloy, the flux bath must be maintained at a higher temperature than the constituents. The temperature of the molten bath may be from 10 to 60 per cent higher than the melting temperature of the metal or metals being refined and cast.

The preferred flux bath is electro-conductive containing material such as calcium floride (CaF_2) and/or lithium floride in combination with one or more of the oxides of calcium, magnesium, aluminum, titanium, and silicon, which is heated by the resistance by the flow of an electric current passing between at least two electrodes. Consumable electrodes may be used and may contain additives to refine the alloy and, in fact, may be precast alloy electrodes. However, it is the main purpose of the present invention to eliminate the necessity of preforming precast alloy electrodes and thus performing the refining operation and immediately thereafter continuing with a casting process.

Examples of molten conductivity values and the approximate melting temperatures of certain fluxes that may be used in the refining and casting process herein are as follows:

Conductivity-ohm-cm.

Flux Composition	1,600 C.	1,700 C.	1,800 C.	Melting Temperature
70% CaF_2, 30% Al_2O_3	1.29	2.02	2.85	1,270 ± 10 C.
65% CaF_2, 30% Al_2O_3, 5% TiO_2	1.42	2.03	2.76	1,290 ± 10 C.
50 % Al_2O_3, 50% CaO	0.19	0.38	1.02	1,340 ± 10 C.
30% CaF_2, 40% Al_2O_3, 17% CaO, 13% MgO	0.90	1.36	1.92	1,320 ± 10 C.

Thus fluxing oxides are in addition which can be used to decrease conductivity and, thus, power consumption, and at the same time increase the melting point and viscosity and heating capacity of the process. Sodium oxide may be added to increase initial conductivity and, later on in the melting process, it volatilizes and, thus, prevents the necessity of making a later power consumption correction.

As mentioned, a flux layer or crust may be provided on the walls of the crucible or vessel in the vicinity of the molten metal bath to form a flux shell therein to aid in maintaining heat uniformity and minimize heat loss.

Metal and alloying components are fed into and through the flux blanket into the molten metal bath where they become heated from the uniformly heated flux blanket until the components as fed reach a molten state and thence become mutually soluble. There can be during this melting process a refining action, such as, removal of nonmetallic materials to improve impurity by flotation, absorption, and reaction due to the presence of the oxidents having higher chemical potential than the undesirable impurities, such as, metal oxides. These metal oxides have already been referred to above.

From what has already been mentioned in connection with this summary, it can be seen that use of the process and apparatus herein, eliminates the necessity of prealloy electrodes which, by their nature, are limited in length and being readily consumable in the process, places a limitation on the total heat time of a production run. It is the purpose of this invention to employ nonconsumable electrodes to not only eliminate the necessity of limited production runs but also eliminate many of the problems of heat control previously mentioned in connection with the prior art. Furthermore, it is of great expense to prepare prealloyed electrodes which by their nature often require vacuum induction melting facilities. These electrodes, as such, have only been refined and do not have the metallurgical properties usually desired until they are again remelted under controlled heat conditions in a continuous casting operation. From the foregoing, it becomes further evident that the primary purpose of the present invention is to eliminate the necessity of initially refining the alloy by forming prealloy electrodes and thereafter in a second process producing a continuous cast ingot possessing the desired metallurgical properties including the desired grain structure.

Plasma arc, electric arc and electron beam heating of the flux bath may also be employed. All of these systems are representative as an electro-energized molten flux bath as employed herein. Melt rates can be increased by the use of supplemental heating within the molten metal bath in the melting and metal feeding area, such as by induction heating.

The temperature of the molten flux bath is controlled by temperature sensing means which regulate the current to the electrodes through the employment of a feedback temperature control system.

The metal and other constituents forming the alloy, is fed to a melting vessel at a predetermined rate usually commensurate with the rate of continuous casting and is maintained so that the melting power requirements are within the wattage capability of the melting vessel.

The molten flux bath heats these materials above their melting point which forms and maintains a molten metal bath below the molten flux bath as the latter bath segregates to the bottom of the melting vessel with the alloy constituents owing to the higher density of the molten metal. The flux bath and metal bath are separated by a distinct flux-metal interface due to the large difference in the respective thermodynamic properties of the materials making up these two different baths.

The molten bath is withdrawn from the feeding zone by a continuous casting process from a common molten bath of metal and is directed to the solidification area of this molten bath which is laterally disposed and separated from the feeding zone. This prevents the movement of unmelted solids to the solidification or casting zone and, therefore, eliminates the necessity for a cast ingot to be used as a remelt or consuming electrode, as previously indicated above.

The offset method is augmented by a weir in a cross dam below the molten metal surface to confine the feeding area from the withdrawing and casting area. The offset can be advantageously made into an annular dam with a surrounding feeding area of 360° in scope with the casting area in the center and controlled by a system of electrodes and energized to induce an annular movement to the molten metal in the annular feeding area due to operation of electrodes under the influence with a high frequency alternating current and with a central electrode provided in the central casting area. The height of such dams may vary from a few inches to one foot depending on metal feed rate to maintain uniform depth in the molten liquid above the top of the dam.

The withdrawal of the molten liquid in the casting area also creates movement to the molten liquid above to further aid in the refining of the molten metal alloy.

The molten metal is preferably continuously cast rather than being poured or run off to prevent oxidation of the hot metal alloy due to the surrounding atmosphere which would cause it to oxidize and thus change its consistency metallurgically since it will contain impurities in the form of oxides of the metals incorporated in the alloys being refined.

In the casting area, heat is extracted and withdrawn from the molten metal flowing down into the casting area continuously forming the ingot which is preferably, but not necessarily, shaped symmetrically relative to its cross sectional center of mass and the vertical axis of the casting area. This central casting in the case of an annular feeding area provided in the vessel or crucible, functions as a whirlpool or driving force to aid in the movement and, thus, better refine the qualities in the molten metal bath.

The formed ingot is extracted preferably at a continuous rate proportional to that of the feeding of the constituents to maintain a substantially constant level of the molten metal bath in the cavity of the vessel or crucible. This is aided by the axial nonconsumable electrode submerged in the flux blanket over the axial center of the casting area in the annular feeder embodiment referred to above.

The heat supplied to the apparatus is carefully regulated and the rate of cooling in the casting area or zone where the ingot is being formed is regulated to control the depth and shape of the liquid-solid interface that is located at the top of the continuously cast ingot. It is preferable to have a shallow interface to accurately shape the formation of the ingot and, in this manner, control the homogeneity of the ingot microstructure to align the crystalline structure of the metal longitudinally of the ingot which is highly important in connection with the working characteristics to which the alloy ingot is subjected to in later commercial applications. This is an important object of this invention in that it involves the heart of the control of this process to produce such commercially acceptable alloy ingots, particularly those employing super alloys, having the proper longitudinally aligned grain structure which is necessary in most commercial applications.

Supplemental induction heating above the liquid-solid interface can provide an additional degree of control over the solidification and casting process in the casting area.

As previously stated, electroslag molten flux bath blankets this whole surface of the molten metal and this molten flux bath being electrically conductive becomes very hot due to the electric current which passes from one or more electrodes into the molten metal bath and assists in properly containing the developed or generated resistance heat to melt the feed metal while providing metallurgical cleansing of the molten metal by carrying off unwanted impurities by evaporation, absorption, and flotation. Thus, it is preferable to allow a portion of the molten flux to be continuously discharged while simultaneously being refurbished at the opposite side of the bath adjacent the feed area or areas so that the revitalized flux is more effectively moved into the refining area of the alloy product. In this manner, the chemical potential of the flux is maintained at a sufficiently high level to provide satisfactory refining action.

The depth of the molten electroslag or flux bath varies with the alloy being processed and the flux constituents. A light flux bath of one or two inches is adequate for some low temperature alloys whereas other alloys because of their high temperature melting points may require from eight to 20 inches thickness in the flux bath. The latter is more favorable for high temperature alloys containing reactive elements.

The metal alloy materials, which may consist of chunks, granules, or powder, are fed into the baths where they penetrate the molten flux and commence to become partially melted. They may further penetrate into the molten metal bath in a semi or solid condition and therefore cause intense localized cooling and agglomerate together without thorough melting. This is why it is necessary to have an offset in the form of a dam or other means the height of which is sufficient to retain such unmelted particles or agglomerates in the feeding area until they have had an opportunity to be blended and fused to completely melt and metallurgically synthesize in forming the refined metal alloy. This is one affirmative reason why it is highly undesirable to utilize consumable electrodes over the casting area since unmelted semisolid particles may fall directly into the casting area thereby forming inclusions in the ingot making the ingot impractical for commercial application.

In the use of an offset structure in performing the process comprising this invention, impurities are prevented from gathering in the center of the ingot being formed in the continuous casting section and by controlling the formation of the ingot as the liquid-solid interface in the casting section, cracks or otherwise referred to dendrites, can be prevented from growing outwardly from the longitudinal axis of the ingot.

The apparatus in the form of a melting vessel with an annular dam, previously referred to, provides an additional advantage in that it may conveniently contain a high frequency induction coil to control the temperature of the throat or vortex of the casting area wherein there commences the flow of the molten metal bath into the continuous casting area which regulates the potential speed of withdrawing the metal into the casting area by the amount of heat transferred from the molten metal to initially form and thereafter control the dished-shaped interface and its vertical location within the casting area.

The location of the interface can be changed by controlling the temperature in the molten metal bath above the casting and to a lesser degree the arrangement and movement of the coolant in the mold through which the continuous casting is formed. Thus, control can be maintained whether the casting area is heated by nonconsumable electrodes or by high frequency stimulation in the surrounding annular structure in the area of the dam or in the casting section per se.

The casting mold inner surface is coated by the casting process which is conducive to withdrawing the continuously cast ingot and creates a withdrawal or flow of the molten metal to the casting area as previously indicated. After the casting ingot has come of sufficient weight, it must be supported and drawn by, for example, the lowering of the supporting elevator or screw lift.

The casting mold may be severed at a point where the ingot is solidified but still hot enough to be hot sheared with little difficulty. The sheared portion may be dropped away and the stub of the cast ingot continues to move into a funnel-shaped opening forming a lower section of the casting mold to continue the casting process without interruption. Independent lateral embracing clamps engage and move with the ingot as the cutting or severing occurs, after which it is withdrawn and the lower mold section is moved upwardly into position to engage and encompass the stub.

The combination of the magnetic stirring action and the phase relation of the electro-energized molten flux in the feeding area as well as the offset withdrawing of the molten metal by continuous casting creates a metallurgical refining of the product in this imposed lateral partially resistive movement which is novel in the process herein and was not possible in the prior art where feeding and casting are carried on in an axially arranged alignment.

When feeding the constituents in powders, granules, chips, chunks, pieces and bars of stock, control of the weight and volume must be maintained by the use of controlled vibratory feeders and vibratory gravimetric feeders which are calculated to weigh the materials as they are fed. Such control, although not extremely sophisticated, can be made to accurately measure the supply per unit of time which, when coordinated with the weight and volume of the casting produced, provides accuracy in the metallurgical makeup of the alloy.

By continuously monitoring the chemical content of the casting, and by continuously adjusting the proportions of the alloying components, the variations in the chemical content in the cast ingot can be maintained with narrow limits which will provide a uniformity never before possible in using the conventional consecutive two heat process for producing super alloy ingots of low impurity and desired grain structure.

Other objects and advantages appear hereinafter in the following description and claims.

The accompanying drawings show, for the purpose of exemplification without limiting the invention or the claims thereto, certain practical embodiments illustrating the principles of this invention wherein:

FIG. **1** is a diagrammatic view in vertical cross section of a melting vessel or crucible structure comprising this invention having a confined feeding area separated from the continuous withdrawing and casting area.

FIG. **2** is a graph showing the temperature gradient through the vessel or crucible, that is, through the molten flux bath, molten metal bath, the liquid-solid interface and the cast ingot in relation to the vessel structure shown in FIG. **1**.

FIG. **3** is a diagrammatic plan view of the vessel or crucible structure as shown in FIG. **1**.

FIG. **4** is a vertical sectional diagrammatic view of a continuously melting and casting vessel structure comprising this invention wherein the casting section or area is provided with an internal mold mandrel to produce hollow ingots.

FIG. **5** is a vertical sectional view of the portion of the structure shown in FIG. **4** showing in better detail the formation of an insulating flux crust shell on the inner surfaces of the mold cavity.

FIG. **6** is a vertical sectional diagrammatic view of a continuous melting and casting vessel structure wherein there is provided an annular feeding area offset from a centrally but lineally symmetrical throat forming the entrance to the casting section or area, the induction heating coil of which is independently heated.

FIG. **7** is a diagrammatic view in vertical section of the casting section or area of a continuous casting vessel wherein the casting mold is separable to hold secure the continuously cast ingot upon the application of a hot shear operation.

FIG. **8** is a diagrammatic plan view of a continuous melting and casting vessel structure wherein the vessel is of the type shown in FIG. **6** and provided with a plurality of electrodes connected in multiphase in circular fashion, adjacent and above which are provided in an annular series of vibratory feeding conveyors.

FIG. 9 is a symmetrical diagram of the electrode connections that may be employed with the melting and casting vessel of FIG. 8.

FIG. 10 is a graphic illustration of the phase sequence of the electrode connections shown in FIGS. 8 and 9.

FIG. 11 is a diagrammatic view of an offset vessel with a single phase arrangement for heating a continuous melting and casting vessel of the type illustrated in FIGS. 1 and 4.

FIG. 12 is a diagrammatic view of an offset vessel with a two phase arrangement for a continuously melting and casting vessel of the type illustrated in FIGS. 1 and 4.

FIG. 13 is a diagrammatic view of an offset vessel with a three phase arrangement for a continuously melting and casting vessel of the type illustrated in FIGS. 1 and 4.

FIG. 14 is a diagrammatic view in vertical cross section of a continuous melting and casting vessel structure wherein there is provided a continuous flux discharge together with specific controls for the electrodes and the continuous casting process.

FIG. 15 is a diagrammatic view in vertical cross section of an offset melting and casting vessel having a material feeding facility as well as being purged with an inert atmosphere.

FIG. 16 is a diagrammatic view of electrode positioning control utilizing a voltage feedback signal for maintaining a constant power input and thus uniform controlled heat in the vessel.

FIG. 17 is a graph illustrating the temperature gradient through the vessel of FIG. 16, that is, through the molten flux bath, the molten metal bath, the liquid-solid interface, and the cast ingot, as effected by power input.

Referring to FIG. 1 of the drawings the vessel or crucible shown at 1 is provided with an outer metal structure with an inner wall refractory liner 14. A plan view of this vessel is illustrated in FIG. 2. A particular feature of this vessel is the provision of the feed area 2 and the continuous casting area 3 which are spaced from each other as illustrated and separated by an offset in the form of a dam 4. The dam 4 extends upwardly above the bottom liquid-solid surface of the vessel in the feed area 2 and is positionally above the interface 5 of the casting area 3. The distance from the top of the dam 4 to the bottom of the feed area is indicated by D and the depth of the molten metal bath or pool 6 is indicated at M.

The interface 5 is the point of formation of the casting of the continuous ingot or billet 7 which starts within the casting area 3 and extends downwardly through the water cooled mold section 8. After passing through a sufficient length of the water cooled section mold 8, the cast ingot 7 becomes sufficiently solidified and cooled to permit it to be exposed to the atmosphere and may be treated with water sprays as it progressively moves out of the section mold 8. The ingot pinch rollers or extractors 10 engage the opposite sides of the ingot 7 and are motor operated to produce a withdrawing action on the ingot 7 from the mold section 8.

The insulated vessel 1 retains a molten electroslag or molten flux bath 11 above the molten metal bath 6. The molten flux bath being materially lighter in density than the molten metal bath floats on the surface of the molten metal bath 6. The materials making up the alloy are supplied by the vibratory or gravimetric feeder or conveyor 12 which vibratory feeder is supplied with adequate controls for accurately measuring materials per unit rate of time. An example of such a gravimetric feeder system is illustrated in U.S. Pat. Nos. 3,221,827 and 2,863,589. Small feeders 13 indicated on opposite sides of main feeder 12 are vibratory feeders for supplying the flux constituents for supply and refurbishing the molten flux bath. As previously stated, the molten flux bath 11 is maintained at a temperature higher than the melting point of the materials supplied to the molten metal bath 6 so that when they are fed by the vibratory feeder 12 to the top of the molten flux bath where they will intermingle and mix through the flux layer and subsequently melt as they pass into the feed area 2.

The constituents for the alloy being cast, that is, the base material, scrap and alloy additions, are preferably supplied and continuously charged in dust, granules, nut size or chunks or even consist of larger portions of a precast ingot of the same material. As these materials are not supported by the molten flux bath 11, they will drop into the molten metal in the feed area 2 and there descend to the bottom of the vessel until they become molten at which time they will be caused to circulate with the metal flow. The smaller and lighter sized materials may be melted by the molten flux bath before they actually reach the molten metal bath.

Although the vessel 1 is shown to be provided with a liner, it may be water cooled such as indicated in FIG. 4. Many other different characters of vessels or crucibles are shown and described herein.

The molten flux bath 11 is preferably heated by the electrodes 15 and 16 which in this instance are shown to be of circular cross section and are fed by electrode feed rollers 17 driven at substantially constant speed by suitable drive means such as a motor and gear drive to one of the rollers 17 of each of the pair of such rollers. These feeder rollers would be controlled according to the necessary heat consumption, capacity of production run of the vessel 1, and upon the material content therein. The electrode 15 which extends over the casting area 3 would always preferably be a nonconsumable type electrode, such as a tungsten or graphite electrode, secured to a water cooled hanger to reduce the temperature of the support and current connection to the tungsten electrode. Such an electrode, or a similar graphite electrode, would be regulated up and down in the molten flux bath to the proper degree to produce the proper temperature gradient in the bath for melting and performing the molten flux bath operation. The second electrode 16 is also of the nonconsumable type; however, it is quite possible that this electrode be a precast ingot of the same alloy material being cast in the vessel. The feeder motor 17 of the consumable electrode 16 would have to be independently operated so as to produce a constant feed of the electrode into the molten flux bath commensurate with the rate of melting of the consumable electrode 16. As mentioned, it is generally highly undesirable to use a consumable electrode at 15 since occasional chunks or pieces may be precipitated from a consumable electrode, which, in view of the vertically aligned portion of electrode 15 over the casting area would fall directly into the casting of the ingot. This is the main problem that has been experienced in the process of Sunnen, U.S. Pat. No. 3,344,839. Chunks, foreign matter or impurities that are precipitated into the casting of an ingot will affect the properties of the cast ingot which is the reason for a consumable electrode over the feeding area 2 when using such an electrode in the offset system comprising this invention wherein these impurities would only fall directly into the feed area 2 and not into the casting area 3.

As shown in FIG. 1 the alloy material is fed by means of one or more vibratory feeders 12 and the flux is fed by means of the vibratory feeders 13 into the vessel feed area where the alloy materials, when they reach the molten flux bath, can only pass through this area before ever finally arriving at the feed area 2 of the vessel.

A thermal sensor indicated at 18 may be suspended in different portions of the vessel or crucible for reading the temperatures of the molten flux bath or even indicate the depth of the bath, which temperature information is supplied to the amplifier and controller 20 which, in turn, through independent circuits, may be made to control the feeders 12 and 13 as well as the electrode feeders 17 and the ingot extractor rollers 10 as indicated by the various circuit control lines 9 illustrated in FIG. 1. The controller 20 of the sensing device 18 is provided with different circuits for the purpose of operating each of the feeding mechanisms 17 as well as the ingot extractor mechanism 10. Controller 20 may be also employed to change the temperature by a control through the power source as illustrated by line 90 connected to the power source. As previously stated, the power source is preferably that of an alternating current type when electrodes are used regardless of whether they are of the consumable or nonconsumable type. As is well known, the alternating current may be of the high frequency type to aid in causing a stirring action in the molten metal bath 6.

A cover **21** is shown in dotted lines to enclose the vessel with the exception of the positions immediately beneath the feeders and sensor **18** as well as around the electrodes **15** and **16**. This cover is preferably made of an insulating material and will retain in the chamber **11** above the molten flux bath an inert gas which may be supplied through the cover at a constant rate and discharged through the openings provided therein for the feeders **12** and **13**. A purge of inert gas is not of necessity in the present invention since the flux bath **11** blankets the molten metal bath **6** preventing oxidation from being carried on in the metal bath. However, in the case of highly reactive alloys, it is preferable to purge chamber **9**, with an inert gas to keep the oxygen above the flux bath at a low level. An example of a situation where an inert gas purge is desirable, is the case of titanium alloys.

As shown and previously described, the alloy materials are fed to the molten flux bath **11** from whence they are at least initially melted and may pass through the molten flux bath and enter the molten metal bath **6** and become fused, blended and refined while passing through the molten flux bath. Some of the reactive materials added to the flux bath are added from the flux to the molten alloy as the alloy initially melts. Thus, some of the alloy materials fed as well as some of the reactive materials making up the molten flux bath have an opportunity to reach a thermodynamic state wherein their elements react to perform the refining of metal alloy in the molten metal bath **6**. This electroslag refining process utilizing the offset method will improve the material quality and also the product yield of the alloy. Such alloys are known as high performance special purpose alloys such as, super alloys, including titanium alloys and even titanium metals. Examples of such materials are listed hereinbelow in the following table as they are known by trademark in the industry and market places.

Group I—Materials Containing Reactive Elements

1. Inco 200 series
2. Inco 300 series
3. Monel
4. Maraging Steels, 18Ni and 12Ni
5. A-286
6. Incoloy 825
7. Rene 41
8. Inco 718
9. Hastelloy X and C
10. Discaloy
11. Udimet 500 and 700
12. Titanium Alloys (Ti-6Al-4V, Ti-15Mo, Ti-2Cr, Pure Ti, Ti-13V-11Cr-3Ae, Ti-5Ae-2.5Sm-5Zr-2Ae)
13. Inco Nickel 204, 205, 220 and 225
14. Inco Perma Nickel 300
15. Inco Dura Nickel 301
16. Monel Alloy 404
17. K-500 and K-501
18. Inco Nelx - 750
19. Ni-Span-C 902
20. Nickel base super alloys

Group II—Aircraft Quality Materials Not Containing Reactive Elements

1. AISI 4,100 series materials
2. AISI 4,300 series materials
3. 52,100 bearing steel
4. Ladish D6AC
5. 300M Steel
6. 9 Ni-4Co Steels
7. H-11
8. 609L Stainless
9. Maraging Steels 18Ni and 12Ni

The electrical resistance level of the molten flux converts the electric energy passed therethrough to thermal energy. The thermal energy developed is conditioned on this resistance level and the power input supplied to the electrodes. This heat is not only used to maintain the temperature of the molten metal bath **6** but also to melt the alloy materials that are fed through the molten flux bath into the feed area **2**. The proper balance in the heat of the molten metal below the electrode **15** must be maintained to properly position the liquid-solid interface **5** in the continuously casting mold section **8**. This balance is maintained by having a larger metal pool at this particular position and also by controlling and balancing the cooling effect brought about by the water cooled mold section **8**. By maintaining such a proper balance the interface **5** of the continuously cast ingot **7** will be maintained shallow, as shown, which is indicative of the formation of longitudinally disposed crystalline growth that materially aids in later longitudinal working of the ingot. Thus, approximately half of the heat requirement is employed to maintain a molten metal bath and approximately one-half to three-fourths of that heat requirement is employed in melting the metal feed and maintaining the molten flux bath and the balance is employed as a loss of heat through the continuous casting process which induces the loss of heat by radiation, conduction and convection through the operation of water cooled mold **8**.

The electroslag is formed by the use of flux compositions such as calcium fluoride and aluminum oxide titanium oxide and calcium oxide, magnesium oxide. Many other different oxides and well known fluxes having desired refining properties may be employed in combinations to meet a particular situation, such as, (a) 60 percent to 80 percent CaF_2 plus 40 percent to 20 percent Al_2O_3 for air craft quality steels; (b) 30 percent to 50 percent CaF_2 plus 20 percent to 40 percent Al_2O_3 plus 10 percent to 50 percent CaO and MgO for nickel base super alloys; or (c) 100 percent CaF_2.

As shown in FIG. **3**, adjacent to FIG. **1**, a temperature chart illustrates the relative temperature of the molten flux bath, the molten metal bath, and the temperature at which the liquid-solid interface **5** occurs within the cooling ingot **7**.

Referring now to FIG. **4**, the crucible or melting vessel **22** is made of steel plate or copper plate comprising interface **22*a*** and outerface **22*b*** being welded to form an inner chamber **92** for cooling the vessel as by the employment of water. Annular helical baffles such as illustrated at **23** are for the purpose of circulating the water through the upper portion of the vessel. Support baffles **24** are indicated underneath the bottom of the vessel to direct the cooling fluid under different portions of this part of the vessel. Again helical baffles as indicated at **25** are employed in the mold section **28** for circulating the liquid through the inner chamber **93** to cool the mold as the metal is cast therethrough.

The dam **4** is in the form of an induction furnace which is circular and provided with induction coils **26** connected to the exterior of the vessel **22** through the lines indicated at **27**. The principal difference between the mold as shown in FIG. **4** and that as shown in FIG. **1** is that the latter is square and the former is circular. The bore of the cooling and casting mold **28** and the bore of the induction furnace **26** are in alignment having a common vertical axis. The furnace can be equipped with a central core member **29** as supported within the bore of the mold **28**. The core member or mandrel **29** is water cooled as indicated by the coils **30** passing therethrough and externally tapered as indicated to allow for ingot contraction during cooling. The entrance **31*a*** and discharge end **31*b*** of the coils **30** are at the bottom of the core **29** and the bottom of the core is supported on a movable platform **100**. Below the ingot extracting rolls **10** are a pair of movable guides **32** to control the operating position of the cutter bar members **33** actuated by the cylinders **34**. In lieu of cutting bar members **33**, a series of annularly positioned cutting torches around the ingot **35** may be utilized to perform the cutoff operation. When the tubular ingot **35** is lowered to a length sufficient for production use by its elevators **36**, the movable guides **32** are moved inwardly to engage the tubular ingot **35** at which time the shearing members **33** are actuated to cut the ingot during that period of withdraw where the temperature is still sufficiently hot to make it readily and easily workable as by the cutting operation of the shearing members or cutting torch. When the sheaving members **33** are withdrawn, however, the upper guides **32*a*** are employed to retain the tubular ingot above the severed ingot and the lower guides **32*b*** are extended further to engage the core member 29 and hold the same while the severed ingot is stripped downwardly therefrom. The guides 32 and the cutting members 33 must of course be capable of movement in synchronism with the movement of the casting in order to be cooperative with the continuous casting process. In order that the severed ingot can be removed from the mandrel 29 while the casting process continues, the mandrel and water cooling leads 31*a* and 31*b* together with the mandrel support can be longitudinally aligned and positioned.

The power supply for the structure as shown in FIG. 4 is connected through the current regulator 37 which in turn supplies current to the controller 38 and thence current to the respective electrodes 15 and 16. The sensing device 18 supplies the proper signal to electronic controller 20 for controlling the regulator 37 as well as vibratory conveyor, feeding alloy and flux materials to the vessel. As shown, the electronic controller 20 is effective on the regulator 37 which controls the voltage to the electrodes as well as the voltage to the feeders 12 and 13 and the ingot extractor rolls 10. The electrode feeder or regulating rolls 17 are controlled by the control depth or electrode submergence regulator 39 which is connected to drive the rolls 17 on one side and is connected to the grounded vessel 22 or casting mold section 28 to receive a thermal detection signal from controller 37 according to the desired temperature level.

Thus, in FIG. 4 we have an offset feed arrangement with, if necessary, a water cooled grounded vessel and the heat of the metal being formed to cast the hollow ingot 35 is controlled not only by the electrode 15 but also by the high frequency induction furnace 26 and the cooling of the mold 35 as well as the mandrel 29. In this manner accurate control of the formation of the continuous hollow casting 35 may be obtained.

The hollow casting, of course, does not have to take the particular shape of a circular tube as illustrated in FIG. 4 but nevertheless a symmetrical casting is known to be more readily produced accurately. However, the castings of square, rectangular and hollow U-shaped members may be provided depending upon the actual use to which the product is to be eventually placed. Thus, the continuous casting by this process and structure may provide a closer tie-up between the end product use and the actual shape of the casting. This is one of the novel features of this invention, that is, alloys containing reactive elements can now be produced and cast into the desired shapes, which cannot be accomplished by the conventional continuous casting and investment casting processes.

FIG. 5 is an enlarged sectional view of the structure of FIG. 4 to show in greater detail, the insulating flux crust shell 101. The flux shell is formed on the surfaces of the interfaces 22*a* during the initial heat-up of the flux constituents prior to the feeding operation of the metal alloys to be refined and thereafter continuously casted. The flux crust shell 101 helps to protect the wall faces 22*a* and to act as an insulating medium to not only retain heat supply within the vessel but also to aid in heat transfer therein to enhance thermal uniformity in heat distribution within the vessel.

In the structure shown in FIG. 6, the annular cylindrical-shaped vessel 40 may or may not be a water cooled metal vessel but is provided with a refractory liner such as indicated at 41 for heat retention. An annular feeding area 2 is provided as shown with the casting area 3 intermediate thereof and surrounded by a coil induction furnace 26 which structure also provides the dam 4. This type of a vessel is readily adaptable for employment of three or more electrodes which may be powered by a three phase circuit. These electrodes are indicated at 42, 43 and 44. The center electrode 43 can be aligned to be over the axial center of the casting area 3 and the casting throat 94. The continuous casting mold 49 can be formed in two parts, the upper part 45 and the lower part 46. Both of these parts 45 and 46 are water cooled as indicated at 102*a* and 102*b*. The lower casting mold 46 is movable away from the upper casting mold 45 such as illustrated in FIG. 7 wherein the ingot extractors 10 are supported in combination with the lower mold section 46 so as to be withdrawn below the same when the mold sections 45 and 46 are separated as illustrated in FIG. 7. The lower mold section 46 is supported by the elevators 47 which passes through ingot clamp member 48 that supports the ingot 7.

The ingot clamp member 48 is supported from the withdrawing elevator member 50 and the elevator 47 for the lower mold portion 46 will bypass the ingot clamp member 48 and the ingot 7 when the latter is dropped therebelow. When the ingot is sufficiently long, the elevator 47 is caused to withdraw the lower ingot mold section 46 as well as the ingot extractor rolls 10 to permit the ingot clamping members 51 to embrace the ingot 7 and provide a guide for the shear members 52 to be actuated by the reciprocating motors 53 for the purpose of cutting the ingot 7 just below that short portion of the ingot mold 45. As with the structure in FIG. 4, the temperature of the ingot at this time is sufficiently soft to permit a smooth slice and quick cut of the ingot, however, a circular saw or other similar device such as a cutting torch may be employed as mentioned in conjunction with the structure of FIG. 4. The cutting device and the clamps, of course, must be mobile to move downwardly as the ingot continues to move downwardly at the same velocity at which the ingot extractor rolls 10 would withdraw the same.

As soon as the ingot has been cut and withdrawn by the elevator 50 the lower half of the mold section 46 is moved upwardly to engage the stub of the ingot 7 and accept the same in its throat as shown in FIG. 6. The ingot extractor rolls 10 again continue to operate on the ingot as the ingot is being formed.

As shown in FIG. 8 the vessel or crucible 56 is an annular water cooled vessel being provided with a liner such as shown at 57 and is provided with nine electrodes being numbered A1, A2, and A3, B1, B2 and B3 and C1, C2 and C3. The B3 electrode is placed in the center of the vessel over the axial continuous casting throat 94. With this type of circular vessel, alloy material may be added annularly around the edge of the vessel as indicated by the positioning of each of the vibratory feeders 12. Lines connecting each of the nine electrodes are illustrated as being provided with the secondary coils 58 representing the secondary of the transformer winding of this multi-three-phase structure. Such a coil 58 is shown in the connecting line between A1 and A2, and between A2 and A3, and A3 and B1, and B1 and B2, and B2 and B3, which is the center electrode, then back in the line between B3 and C1, and in the line between C1 and C2, and in the line between C2 and C3, and in the line between C3 and A1.

If a DC electrode such as illustrated at 60 in FIG. 9 were placed in the center over the casting area 3, then the nine electrodes would be uniformly distributed around the perimeter of the circular vessel, as illustrated in that figure. Such an arrangement of electrodes may be employed even with the use of a high frequency induction furnace such as indicated at 26 at the throat of the continuous casting area 3 of FIG. 6.

As shown in FIG. 10, the three-phase system A1, A2, A3 which is different than the three-phase system B1, B2, B3 and the three-phase system C1, C2, C3 is employed so as to provide a progressive voltage movement around the circumference of the furnace which induces an electromagnetic field in the manner of electromagnetic field produced in an alternator or an AC induction field. Thus, the voltage for the phase A1 leads an equal amount of the voltage for A2 and A3 and again the B phase is set up to produce a similar series of voltage progression and likewise C phase. After 360°, the A phase again starts the same voltage cycle with relation to the voltage of its other phases. Since these three-phase currents are distributed through the flux in a circular manner, as described, their electromagnetic effect will have a tendency to rotate the molten flux bath as well as the molten metal and, at the same time, be withdrawn at the center of the casting area 3 continuously which will cause the melted moving and refined metal position to flow to the center and into the casting area 3 in the manner of a rotating vortex. Such a magnetic stirring action will produce refinement in the alloy which is conducive to an improved finished product. The use of DC current on the electrode 60 is shown at FIG. 9 would be independently controlled and in the manner of the use of the high frequency induction furnace 26 as illustrated in FIGS. 4 and 5.

A typical vessel installation would utilize 9 12 inch diameter peripheral electrodes with a 30,000 kv.-a. transformer having several voltage taps ranging from 260 volts to 800 volts. The bottom and side walls can be lined with brick or graphite depending on the aggressiveness of the flux blanket. The vessel would be capable of 1,500 to 2,000 pounds per minute production rate.

Referring now to FIG. 11 it will be seen that the water cooled furnace 61 is offset and the feeding area again would be as indicated by the vibratory feeder 12 to the offset position or feeding area 2, and the water cooled casting throat over the casting area 3 will be provided with a form of ingot extractors such as indicated by the rollers 10.

The offset being sufficient to retain the solids, the molten metal flow is the only flow aside from a magnetic means for moving the pool which does not have sufficient velocity for moving the solids from within the feeding area 2. Here the electrodes 15 and 16 are supplied through the transformer 62 controlled by the current controller 63 which may be controlled by a sensing device such as illustrated in FIGS. 1 and 4. It is, of course, understood that such controls are employed in any of the vessels illustrated and described herein.

In the structure of FIG. 12 the water cooled vessel 65 is actuated by a two-phase system with current controllers and the common side of the dual phase is connected to the water cooled furnace itself.

In the structure shown in FIG. 13 the vessel 67 is water cooled and is provided with an upwardly sloping floor 68 in place of a dam 4. This is to illustrate that a dam can be formed not only by an abutment type dam as illustrated in previous figures, but also can comprise a slight gradual slope 64 because there is not a very swift movement within the molten bath 6 and any solid materials that find their way into the feeding area 2 are not apt to even pass over the gradual slope 64 to the casting area 3 which may permit better control of the interface of the casting mold because of the uniformity and the depth of the whole of the molten metal bath. Such a structure would be ideal for use in the circular furnace as shown in FIG. 6 with a high frequency induction furnace 26 surrounding the throat 94 of the casting area. In FIG. 13, the two electrodes 15 and 16 are connected to a three-phase supply circuit wherein the return of the opposite phases B and C is made directly through the water cooled vessel. As stated, the structure of these vessels of the water cooled type may readily be employed by using plates of steel, such as one-fourth inch thick; however, they will also equally function with higher efficiency when made of material such as copper which tests have shown that the plates can be three-eighth to one-half inch in thickness.

In the structures of FIGS. 11 to 13, inclusive, a sensing device such as indicated at 18 in FIG. 1 can be utilized for not only operating the withdrawing rollers 10 but also in controlling the voltage of the current controller for each of the different phase constructions in each of these figures. Thus a uniform voltage control as well as a uniform temperature control may be maintained throughout the operation of the process.

In summary, the three possible power control systems shown in FIGS. 11 to 13 are controlled by the current controller which is manually set proportional to the metal feed. A feedback signal may be utilized from the thermal sensing device 18 near the flux surface to automatically control the current supplied to the electrodes. The balance of current input between the melting and casting sections or areas is controlled by the depth of electrode submergence. The power input in any one area can be decreased by positioning the electrode closer to the molten metal surface of the molten metal bath 6. The power (I^2R) is reduced because the current path through the flux is reduced and this can be determined by a reduction in voltage across the molten metal bath 6 and the electrodes 15 or 16. This voltage signal, therefore, is measurable from each electrode across the flux bath 11 and is proportional to the power input and can be used as reference signals for electrode positioning motors, such as in the case shown in the embodiment of FIG. 16, and aid to automatically balance the power input at any desired level. The two phase and three phase systems as shown in FIGS. 11 and 12, respectively, can have separate current controllers which can be used to automatically control power input using an electrothermal sensing device 18 placed near the surface of the flux bath 11. The current controllers can be a saturable reactor, although not indicated in the embodiments of FIGS. 11 and 13. Additional heat can be supplied in connection with the casting area or the melting area for better heat control by employing induction coils, as exemplified in FIGS. 4 and 6.

Referring now to FIG. 14 wherein more graphic illustrations are employed to show different controls for actuating the electrodes as well as for withdrawing the ingot wherein a column such as illustrated at 71 and 72 and 73 provide a trackway for the vertical movement of their respective carriages 74 which in turn are guided by the supporting rollers 75. The carriages 74 on the columns or tracks 71 and 72 are provided with a clamp 76 to support the electrodes 15 and 16 and also function as the means for connection to the power supplies as indicated by the leads 77 and 78.

The carriage 74 for the column 72 supports the electrode 16 through its clamp 76 and is connected to the power source by the cable member 78. Each column also can contain a screw member 80 which is rotated by a suitable means such as the speed reducer 81 and which is coupled to and operated by the motors 82 for regulating the vertical position of the electrodes 15 and 16 which motors will, of course, be controlled by the proper control means necessary to change the position of the electrodes in the molten bath to regulate the voltage of the bath and thus the rate of melting and the rate of producing the molten metal. A block and pulley mechanism can also be used for regulating the vertical position of the electrodes. The carriage 74 for supporting the continuously cast ingot 7 is provided with a clamp member 83 which is electrically operated. This carriage can also be provided with a screw jack 80 which is rotated through a speed reducing mechanism 81 operated by a suitable motor (not shown) that is likewise controlled commensurate with the other controls of the vessel in order to maintain the liquid-solid interface 5 of the ingot at the particular required zone of elevation in the throat 3 as described above.

A support member 89 is arranged on the screw jack 84 and is electrically operated by the mechanism 85 to allow the ingot 7 to drop or be fed from the furnace at the particular rate for maintaining the interface 5 at the proper position in the casting area 3. Such controls as illustrated in the previous figure would be employed to actuate these motors in synchronism with the process and with each other.

The water cooled crucible or vessel 70 is supported on the centrally open platform 86 by means of the columns such as indicated at 79. These columns may or may not be connected with the columns that carry the carriages 74 for operating the ingots. In a structure of this character it is obvious that the heat loss of the crucible owing to the water circulation as well as the radiation would account for approximately half of the heat required to maintain the flux molten. The water cooled mold will only be required in applications where the fluxes, such as CaF_2 base fluxes, will attack conventional insulating materials and dissolve the insulating brick thereby reducing its thickness.

Another and very important feature shown in FIG. 14 is the use of the flux overflow spout 87 which takes the upper portion of the flux from the molten flux bath on a continuous basis. This molten flux is carried off by the trough 88. The whole purpose for continuously discharging a portion of the flux is for the purpose of maintaining the flux with the desired constituents, some of which are quite volatile and very reactive when they are employed in combination with the impurities within the alloy charge. Thus the discharge of the flux may be continuously checked to determine whether or not the proper constituents are present in the molten flux. At the same time that the flux is discharged an equal or equivalent amount of flux material is added by means of the vibratory flux feeders **13** as shown in FIGS. **1** and **2**. The application flux overflow spout **87** is, of course, adaptable to every other type of structural showing of the crucible or alloy producing vessel.

The vessel or crucible **103** shown in FIG. **15** is very similar in structural features to the vessel **1** shown in FIG. **1** except that vessel **103** is liquid cooled and is provided with a different type of feed system wherein there is provided the hopper **104** having the removable lid **105** for receiving metal alloy material to be fed to the vessel **103**. The vessel **103** is provided with a cover **106** through which is supported the electrodes **15** and **16** which are of the nonconsumable type. The electrodes **15** and **16** are supported in the elastomer annular bushing **107** which is a high temperature elastomer which can withstand the extensive heat generated in the vessel **103**. In this connection the electrodes **15** and **16** are of the water cooled type.

The feed hopper **104** is provided with an outlet **108** to impose upon the interior chamber **110** of the hopper **104** a vacuum in order to draw off, as much as possible, the air environment from the metal feed. The lower portion of the hopper **104** is provided with a rotary screw conveyor **101** which feeds the metal alloy material into the interior of the vessel **103**. The rate of feed of the metal materials into the vessel **103** may be regulated by positioning of the hopper shuffle valve **112**.

The vessel **103** is water cooled and is provided with appropriate inlets and outlets as shown for circulation of water as a coolant within its wall structure. The cover **106** is provided with a seal **113** around its perimeter to provide a substantially hermetically sealed chamber **114** within the vessel **103** above the flux blanket or bath **11**. The same type of seal is employed at **115** in connection with the cover **105** for the hopper **104**. The rotary screw conveyor **101** is supported by the antifriction bearing member **116** supported within the back wall of the hopper **104**.

While a vacuum is being maintained within the hopper **104**, a inert gas purge, such as argon, may be provided within the chamber **114** of the vessel **103**. The inlet for the inert gas purge is shown at **117**. Thus, the inert gas may enter at **117** and carry away from chamber **114** oxygen and other gases that have been removed by the molten flux blanket **11** from the molten metal bath. These gases can thereafter be carried away through outlet **118** or **108**.

The structure of FIG. **15** in employing an inert gas purge finds its best application in connection with those metal alloys which have an extremely high potential for solubility of oxygen. One example of such type of metal alloys in this group are the titanium alloys. Oxygen has a solubility in the flux blanket **11** and because of this can be transmitted to the alloy. In the case of titanium, the solubility of oxygen is very high and is an impurity detracting from the desired properties. For example, the inclusion of oxygen will make titanium hard and brittle. By using an inert atmosphere in chamber **114**, one can keep the oxygen content level above the flux bath at a low level. However, there can be small parts of oxygen entrapped in part of the feed metal material from hopper **104** and therefore this is the reason why a vacuum environment is the most practical and feasible in hopper **104** since it would be more effective than the inert gas purge in inducing oxygen, entrapped in the metal feed, to separate and pull out of outlet **108**.

In FIG. **15** the elevator **120** supports the ingot **7** formed having the support rod **121** supported within the seal **122** of the cover **123** of the casting mold section **124**. Cover **123** is sealed to the casting mold section **124** by means of the perimetral seal **125**. Here the extractor rollers **110** engage the elevator support rod **121** to aid in the withdrawal of the ingot being formed at the interface **5**.

In FIG. **16** there is shown the crucible or vessel **126** which is identical in form and construction to those vessels shown in FIGS. **1** and **13**. However, in FIG. **16** there is shown in more detail an improved positioning control for the electrodes **15** and **16** to provide the desired temperature gradient within the melting and casting area. By operation of the hydraulic servo gear motor **127** with respect to the drive rollers **17**, the electrodes **15** and **16**, which are of the nonconsumable type can be selectively positioned within the molten flux bath **11**.

As is well known, the current to be supplied to electrodes **15** and **16** to produce a heat within the vessel **126** is a function of the electrical resistance of the molten flux bath **11**. The electrodes **15** and **16** are independently supplied by means of the transformers **128** and **130** from the current controllers connected to the two phase power source **131**. Thus, the arrangement shown is identical to the double phase hook-up as shown in FIG. **12**.

With the aid of the thermal sensor **18** together with the connection on the ground lines **132** to the monitor controllers **133**, a signal can be obtained from line **134** indicative of the actual temperature within any desired area within the vessel **126** depending upon the location of the temperature sensor **18**. This electrical signal is passed through the comparitor **135** by means of the lead **134**. This thermal related signal is thus compared with the actual voltage drop across the vessel **126** between lines **136** and **132** and depending whether or not the thermal sense signal is higher or lower than the desired voltage level across the vessel **126**, the hydraulic control unit **137** will operate the hydraulic servo valve **138** which in turn will operate the hydraulic servo gear motor **127** in either a forward or reverse direction. In this manner, the penetration of the electrodes **15** and **16** into the molten flux bath **11** can be varied to obtain the desired heat level within the vessel **126**. In this manner, the voltage reference across leads **136** and **132** represents the preset value of the power supply to electrodes **15** and **16**. The voltage comparing signal from the monitoring controller **133** is proportional to the preset value of the controller relative as to the desired temperature within the molten flux bath **11**. Thus if the voltage comparing signal on line **134** is higher than the voltage reference signal, the comparitor will send a signal to the hydraulic control unit to operate the servo valve **138** which in turn operates servo gear motor **127** to lower the corresponding electrode into the molten flux bath and thus reduce the temperature within the bath. Inhibitor means may be provided in the monitoring controller **133** to prevent the controller from working continuously in order to give the temperature within the vessel **126** sufficient time to obtain its value of the new temperature level caused by operation of the servo gear motor **127**.

As shown in FIG. **16**, the servo control valve **138** is provided with an input lead to supply hydraulic fluid to servo gear motor **127** by means of the pump P. The pump P connected to the reservoir supply **140**. The servo control valve **138** is provided with a return lead **141** to the reservoir **140** when the valve **138** is not being operated by the hydraulic control unit **137**. Restriction check devices **142** are provided in the fluid supply lines **143** and **144** between the control valve **138** and the servo gear motor **127** to permit the gear motor **128** to operate in a limited finite manner.

FIG. **17** shows the temperature gradient through the vessel **126** and, in an accurate manner, shows the "slushy" layer actually formed at the liquid-solid interface **5**. The graphic illustration of FIG. **17** shows an example of the melting point of a particular alloy and its relationship to this slushy layer. FIG. **17** also shows the different of the temperature gradient through the vessel **126**, that is, through the molten flux layer, the molten metal layer, the slushy layer **5** and ingot **7** wherein there is a low power input as indicated by the solid line and a high power input as indicated by the dotted line. It should be noted the higher thermal gradient across the slushy layer in connection with the higher power input. In this connection, it should be noted that the bigger the temperature differential across this zone comprising the slushy layer, the more narrow in depth this zone will be which will result in a finer dispersion of the alloy content in the resulting ingot and provides a higher level of metallurgical properties particularly in connection with the micro-segregation of alloys in the ingot as well as improved grain structure aligned with the formed ingot.

I claim:

1. The process of electroslag melting, refining and continuous casting in a unitary vessel having a casting zone with a continuous casting mold and an adjoining melting and refining zone offset from the casting zone, comprising the steps of
 - continuously feeding metallic constituents into the melting and refining zone,
 - melting and refining the metallic constituents in said melting and refining zone,
 - confining a bath of said metallic constituents being melted in said melting and refining zone until all of said metallic constituents are thoroughly melted,
 - flowing the melted and refined metallic constituents from said melting and refining zone to said adjoining casting zone to form a molten metal pool therein,
 - maintaining the molten surfaces of said bath and said pool substantially at the same level thereby imposing a lateral resistance to the flow of unmelted metallic constituents from said melting and refining zone to said casting zone,
 - blanketing said molten surfaces with a common molten flux bath containing metallic refining properties,
 - electro-energizing the molten flux blanket by a uniform heating method selected from at least one of the heating methods in the group consisting of induction heating and arc heating, and
 - continuously casting said molten pool by continuously withdrawing molten metal from said pool through a casting mold while cooling the same to form a liquid-solid interface in said mold.

2. The process of claim 1 characterized by the step of independently controlling the applied heat to said zones to control the level of said liquid-solid interface in the casting mold so that the level of said interface is maintained substantially adjacent the bottom of said metallic constituent bath in said melting and refining zone.

3. The process of claim 2 characterized by the step of erecting a dam in the unitary vessel at the bottom of said metallic constituent bath between said zones above the level of said interface confining the metallic constituents to the melting zone until melted and refined and electro-energizing in accordance with at least one of the heating methods of claim 1 by inserting the same in said dam to control the heat level of said molten metal pool and to control the throat of said casting mold to the level of said interface and regulate the speed of withdrawal of the molten metal in forming an ingot.

4. The method of claim 2 characterized by arranging at least one electrode over said melting and heating zone and one electrode over said casting zone, establishing an electric arc between said electrodes and said flux bath to electro-energize the same and thereafter adjusting the position of said electrodes relative to said bath to control the applied heat to said zones.

5. The process of claim 2 characterized by the step of controlling the thermal gradient through the casting zone to control temperature rates of heating and cooling necessary to produce a shallow concave liquid-solid interface in the ingot being formed below the molten metal pool.

6. The process of claim 1 characterized by the step of maintaining the depth of said molten flux to be no greater than approximately one-half the casting diameter of said casting mold.

7. The process of claim 1 wherein said molten flux is an electro-conductive flux both comprising a fluoride and one or more of the oxides of calcium, magnesium, aluminum, titanium and silicon.

8. The process of claim 1 characterized by the step of sup-

porting a mandrel within the casting mold to produce tubular ingots.

9. The process of claim 1 characterized by the step of supplying multiphase alternating current to the uniform heating method in the form of nonconsumable electrodes inducing, inter alia, a magnetic stirring action in the melting and refining zone.

10. The process of claim 1 characterized by casting the withdrawn molten metal pool at a solidification rate commensurate of the liquification and refining of the bath of molten metallic constituents while maintaining the level of the surface of both said bath and pool.

11. The process of claim 1 characterized by generating a liquid-solid interface below the surface of the molten metal pool in said casting mold by controlling the temperature distribution and thermal gradient through the liquid-solid interface and by controlling the rate of cooling of the solidifying ingot being produced at said interface.

12. The process of claim 11 characterized by controlling the depth of the liquid-solid interface to produce an ingot having micro-segregation dispersion of the metallic constituent content and aligned grain structure relative to the longitudinal length of the ingot formed.

13. The process of claim 1 characterized by the step of erecting a dam in the unitary vessel at the bottom of said metallic constituent bath between said zones confining the metallic constituents to the melting zone and allowing the refined molten metal to transfer thereover for subsequent continuous casting.

14. The process of claim 1 characterized by the step of erecting an annular dam in the unitary vessel at the bottom of said metallic constituent bath, confining the metallic constituents to an annular melting zone and allowing the refined molten metallic constituents to transfer thereover for subsequent continuous casting centrally of the annular dam.

15. The process of claim 14 characterized by electro-energizing in accordance with at least one of the heating methods of claim 1 by inserting the same in the annular dam to control the heat of the molten metal pool in the casting area while continuously casting the refined molten metallic constituents.

16. The process of claim 14 characterized by the steps of annularly arranging a plurality of electrodes in the annular melting zone with their ends submerged in the flux bath, supplying multiphase alternating current to the annularly arranged electrodes to supply arc heating inducing an annular directed flow of said metallic constituent bath to produce a thermodynamic energy state causing metallurgical refining of the same and thereafter inducing the refined molten metallic constituents to transfer over the dam for continuous casting.

17. The process of claim 16 characterized by the steps of arranging a central electrode in cooperative engagement with the molten flux bath and centrally over the molten metal bath within the annular dam to control vertical temperature gradient therein to produce a uniform continuous casting.

18. The method of claim 1 characterized by the steps of supporting the continuously cast ingot from below, weighing the constituents supplied to the feeding area, weighing the supported continuously cast ingot, comparing the measured weights to control the rate of feeding of said metallic constituents and the rate of withdrawing the supported ingot.

19. The process of claim 1 characterized by the steps of continuously discharging a portion of the flux bath, replenishing the flux bath discharged to rehabilitate and maintain the desired level of flux characteristics in the flux bath to produce the desired metallurgical characteristics in the resultant cast ingot.

20. The process of claim 1 characterized by the step of forming a flux crust on the inner surface of the unitary melting vessel prior to feeding said metallic constituents to the melting zone of said metallic constituent bath.

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