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OF HIGH-MELTING-POINT METALS
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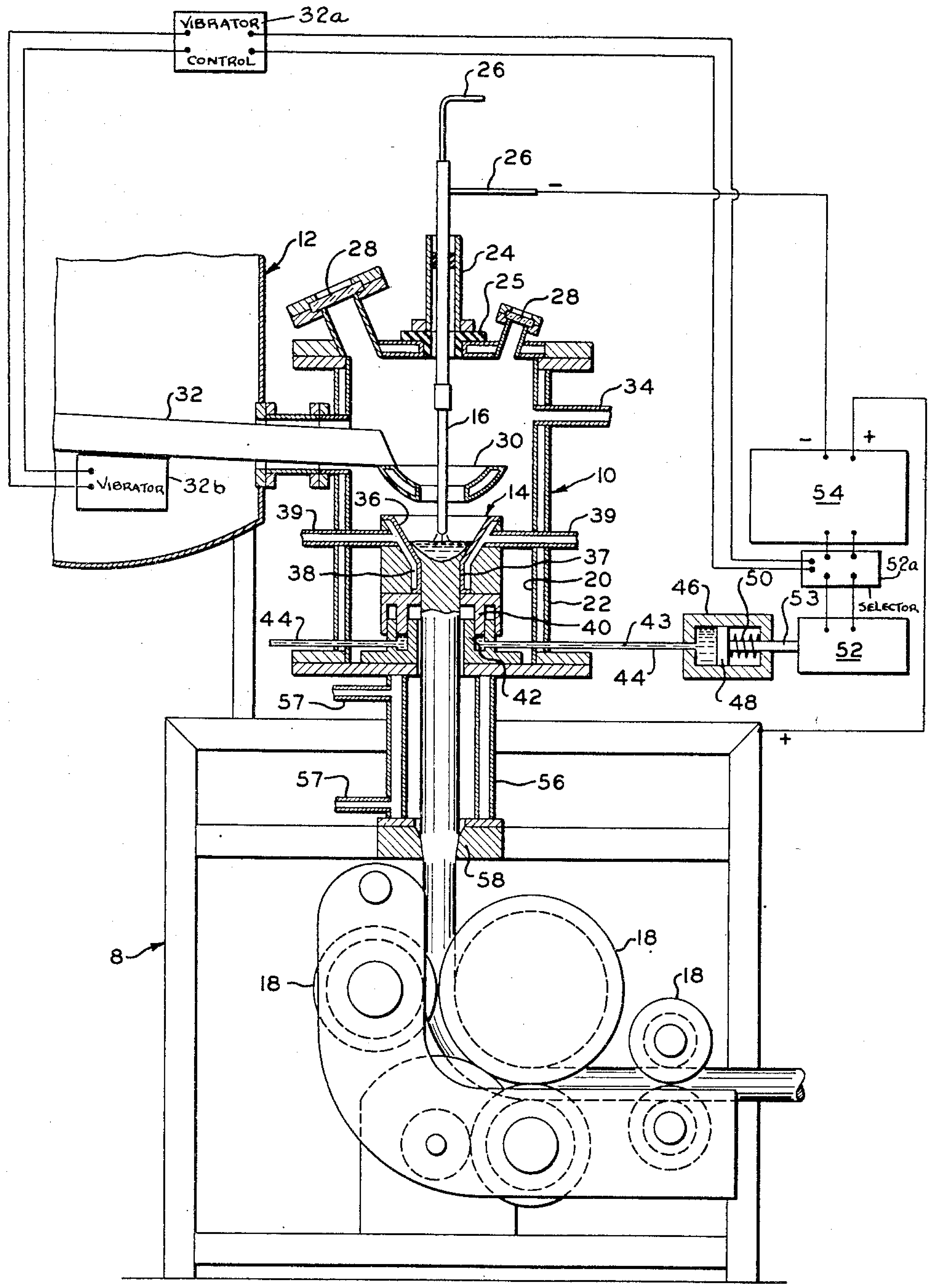

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APPARATUS FOR CONTINUOUS CASTING OF HIGH-MELTING-POINT METALS

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This invention relates to the production of metals and more particularly to the production of ingots of high-melting-point metals, such as titanium, zirconium and the like. The melting of metals such as titanium and zirconium to form solid ingots thereof is complicated by the fact that these metals, at temperatures above their melting point, are both extremely sensitive to contamination by oxygen and nitrogen and highly reactive with practically all known crucible materials. As a consequence of these two facts workers in the art have turned to the use of a "cold" mold technique for arc melting and casting ingots of titanium and zirconium.

A principal object of the present invention is to provide an improved "cold" mold apparatus for casting continuous ingots of high-melting-point metals such as titanium and zirconium.

Another object of the invention is to provide, in an apparatus of the above type, an improved system for controlling the degree of melting in the "cold" mold so that a sound continuous ingot is formed.

Still another object of the invention is to provide improved control of such continuous casting to prevent overheating of the metal being cast in the ingot while assuring adequate heating to give a uniformly sound ingot.

Still another object of the invention is to provide an improved system for forming a vacuum-tight seal between the casting apparatus and the ingot being withdrawn continuously therefrom.

Other objects of the invention will in part be obvious and will in part appear hereinafter.

The invention accordingly comprises the apparatus possessing the construction, combination of elements and arrangement of parts which are exemplified in the following detailed disclosure, and the scope of the application of which will be indicated in the claims.

For a fuller understanding of the nature and objects of the invention reference should be had to the following detailed description taken in connection with the accompanying drawing which is a diagrammatic, schematic, sectional view of one preferred embodiment of the invention.

In general this invention is directed to the production of high purity continuous ingots of metals such as titanium, zirconium and the like. In melting these metals prior workers in the art have developed certain techniques, such as the use of cold molds and water-cooled electrodes, for arc melting these metals under a vacuum or in an inert atmosphere. Typical of such prior patents is the patent to Herris et al., 2,541,764, issued February 13, 1951. The present invention contemplates several advances over the prior "cold" mold arc-melting furnaces, these advances being directed primarily to improvements in control of the arc with relation to the withdrawal of the ingot. In one preferred embodiment of the invention the ingot mold, which is preferably a "cold" mold, is tapered so as to reduce the cross section of the forming ingot as it is withdrawn downwardly

in the mold. Due to the fact that the mold is cooled the metal first solidifies at the mold walls. The downward movement of the ingot thus deforms this solidified metal. The cold mold is preferably carried by a resilient support and means are included for withdrawing the ingot from the bottom of the mold with a withdrawal force which is a direct function of the degree of solidification of the ingot in the mold. This withdrawal force will increase as the amount of metal which must be deformed in the mold increases, and will decrease as the amount of metal to be deformed decreases. The apparatus also includes a means for measuring the withdrawal force as a function of the movement of the ingot mold with respect to the resilient support. In a preferred embodiment of the invention the measured withdrawal force is used to control the intensity of the arc. Thus, if the force is below a predetermined amount it indicates that an insufficient amount of metal is being solidfied in the tapered portion of the mold. This indicates that too much power is being put into the melting of the metal in the mold. If the withdrawal force is too high, not enough power is being put into the metal.

In a preferred embodiment of the invention the resilient support for the mold comprises a hydraulic piston, the pressure of this piston on a hydraulic fluid being utilized to control a second hydraulic piston which in turn is coupled to the control element for the arc power supply. As a result of this arrangement any deviations from the optimum melting conditions are immediately translated into corrective increases or decreases in the power being provided by the arc. This control system is of extreme practical importance in obtaining sound ingots, since it prevents overheating of the metal in the mold, which might be completely destructive of the mold walls, and also assures sufficient heating so that a sound ingot is obtained.

While the invention has been described above in connection with a preferred embodiment thereof, where a withdrawal force is measured by movement of the ingot mold, other means of measuring this force may be provided. Equally, changes in the withdrawal force may be utilized to control the feed of metal to the mold in addition to, or in lieu of, controlling the intensity of the arc.

A preferred embodiment of the apparatus also includes an improved mechanism for forming an air-tight seal between the apparatus and the surface of the ingot being withdrawn therefrom. This mechanism preferably comprises a reducing die which physically deforms the surface of the newly formed ingot and reduces the cross section thereof, thus providing a smooth surface on the ingot which bears, with a high force, on the reducing die surface to form an essentially vacuum-tight seal.

Referring now to the drawing there is illustrated one specific preferred embodiment of the invention briefly outlined above. In this illustrated embodiment there is included a frame 8 which carries an arc-melting chamber generally indicated at 10. This arc-melting chamber is connected to a second chamber 12 which constitutes a supply chamber for holding a predetermined quantity of metal to be melted, which may be in the form of granules, powder, chips, or the like. Positioned within the melting chamber 10 is a cold mold 14 above which is located a water-cooled electrode 16. For withdrawing the continuously formed ingot there is provided a plurality of withdrawing rolls, generally indicated at 18.

The melting chamber 10 preferably comprises an inner wall 20 and an outer wall 22, this double wall construction being advantageous to permit water cooling of the chamber walls. The water-cooled electrode 16 is supported within the melting chamber by means of a flange 24, which is insulated from the remainder of the apparatus by an insulating bushing 25. Water-cooling connections are shown at 26 for providing an adequate flow of cooling water to the electrode, a typical electrode of this type being shown in more detail in the previously mentioned Herris patent. For permitting visual observation of the melting operation, several sight glasses 28 are conveniently provided in the walls of the melting chamber 10. In a preferred mechanism for feeding the solid metal to the arc, there is provided a water-cooled funnel 30 which is carried on the end of a chute 32 leading from the titanium supply chamber 12. This chute is preferably of the oscillating feed type, the rate of feed of the metal being readily controlled by the degree of oscillation imparted to the chute by a vibrator *32b* whose intensity of vibrations is controlled by a controller *32a*. Numerous examples of such oscillating feeders and control means therefor are illustrated in U. S. Patents 2,164,812, 2,289,186, 2,450,479, 2,609,965 and 2,618,406. The funnel 30 preferably completely surrounds the electrode 16, while being sufficiently spaced therefrom so that there is no danger of arcing between these two elements. This arrangement provides for feeding of the solid metal to the molten pool in the mold near the center thereof, this central portion of the molten pool, of course, being the hottest.

The melting chamber 10 is preferably provided with a pumping port 34 connected to a suitable vacuum system, not shown, through which all of the air in the system may be evacuated. If desired the evacuation of the melting chamber may also evacuate at the supply chamber which is in open communication therewith. It is, of course, apparent that a separate vacuum pumping system may be provided for this supply chamber 12. Suitable means are also included, although not illustrated, for introducing, if desired, an inert atmosphere of argon, helium, or the like.

The cold mold 14 comprises, in a preferred embodiment, an upper tapered portion 36 in which the metal is melted and in which at least the outer surfaces of the forming ingot are solidified. At the bottom of this tapered portion there is provided a straight portion 37 in which the solidification of the ingot is completed. As the forming ingot passes downwardly in the tapered mold the solidified surfaces of the ingot are forced inwardly to consolidate the ingot and to form a straight continuous ingot. The mold 14 is provided with a fluid cooling passage 38 in which a cooling medium, such as water, a fused salt, or a liquid metal, may be circulated to maintain the inner surface of the ingot mold at a temperature below the melting point of the titanium or other metal being melted therein. Suitable fluid circulating lines 39 are schematically indicated for providing circulation of the cooling medium through the mold. The mold is supported by several hydraulic pistons 40, there being two schematically indicated in the drawing. These pistons operate in cylinders 42 which contain a hydraulic fluid 43. The pressure generated in the hydraulic cylinder is transmitted through hydraulic lines 44 to a hydraulic control cylinder 46. The hydraulic fluid in the cylinder 46 exerts a predetermined force on a hydraulic piston 48 within the control cylinder 46. The position of the control piston 48 is normally maintained by a spring 50, this spring being adjusted so that it just balances the force generated in the hydraulic fluid by the withdrawal of the ingot under optimum melting conditions. Movements of the control piston 48, due to deviations from the optimum hydraulic pressure, are transmitted to a generator control 52 by means of a connecting rod 53. The generator control 52, operating through a selector *52a*, in turn controls the current output of a generator 54 which furnishes current to the electrode. This generator 54 may comprise a standard low voltage, high amperage electric welding generator. As indicated in the drawing the positive side of this generator is preferably connected to the frame 8, while the negative side is connected to the insulated electrode 16.

Positioned below the ingot mold is double-walled ingot cooling chamber 56 in which the ingot may be cooled to a sufficiently low temperature so that it will not be attacked by air upon being withdrawn from the apparatus. Suitable water inlet and outlet pipes 57 are included for providing flow of cooling water between the double walls of chamber 56. At the bottom of the ingot cooling chamber there is preferably provided a reducing die 58 which reduces the cross section of the ingot as it passes through the die. This reducing action removes any irregularities in the surface of the ingot, and forms a completely smooth surface thereon which, due to the high surface pressure generated in the reducing die, forms an essentially vacuum-tight seal between the ingot and the surface of the reducing die. In a preferred embodiment of the invention the inner wall 20 of the melting chamber 10 is formed of stainless steel while most of the other portions of the apparatus are formed of mild steel. The ingot mold 14 is preferably formed of a refractory metal such as molybdenum and is cooled by a liquid metal such as sodium, lead or the like, although water can be used with very high flow rates. The electrode 16 preferably includes a tungsten tip and is cooled by water or oil.

In the operation of the device of Fig. 1, when melting zirconium for example, a supply of zirconium powder, free of oxides, nitrides, and volatile contaminants such as magnesium chloride, is placed in a suitable hopper (not shown) in the supply chamber 12. A tapered zirconium ingot, having its largest diameter about equal to the straight portion 37 of mold 14, is inserted in the mold and withdrawn through the reducing die 58 until sufficient reduction of the ingot is achieved to form a vacuum-tight seal between the ingot surface and the die 58. At this point, the top of the ingot should extend slightly into the tapered portion 36 of mold 14. The whole apparatus is then evacuated through pumping port 34 to remove essentially all of the air, and an atmosphere of argon is introduced through a suitable inlet. The electrode 16 is then moved downwardly to the ingot to strike the arc. When the arc is established, it quickly melts the top of the ingot and forms a molten pool of zirconium. Feed of zirconium sponge is now started, as is the withdrawal of the ingot. Feed of the zirconium metal can be controlled by measuring the level of molten zirconium in the mold, the feed being decreased when this level becomes too high and being increased when it becomes too low. This level may be measured visually, optically, by the use of thermocouples in the mold walls, or by other suitable means. The withdrawal of the zirconium ingot is now commenced, the rate of withdrawal being set so as to be about equal to the average rate of feed of zirconium to the mold. As the ingot moves downwardly, the hot, semiplastic conical top part thereof is consolidated to form a dense ingot. The degree of plasticity of the forming ingot controls the amount of force necessary to pull the ingot downwardly in the mold. This force is transmitted, through the hydraulic mold support, to the generator control piston 48. If this hydraulic force is greater than the spring loading on spring 50, it will cause the piston 48 to move to the right, thus increasing the power delivered from the generator 54 to the electrode 16. This increase in power to the electrode will melt the ingot more deeply and thus will decrease the force necessary to withdraw the ingot. This decrease in force will decrease the hydraulic pressure on piston 48, thus allowing the piston to move to the left and causing a decrease in the generator power output.

As the ingot moves downwardly, it is continually reduced in size by the reducing die 58 to form a vacuum-tight seal with the ingot surface. While the reducing die seal 58 is a preferred form of the invention, it is not essential since it can be replaced by a rubber sleeve or the like for forming the seal. This is particularly true when the melting operation is conducted under an argon pressure of one atmosphere or more, since the air inleakage past the seal will be very slight, or nonexistent, if the argon pressure inside of the melting chamber is equal to, or in excess of, atmospheric pressure.

While one preferred form of the invention has been described above, numerous modifications thereof are possible. For example, the ingot withdrawal force may be measured at the withdrawal rolls, this modification being particularly feasible when the reducing die **58** is replaced by a rubber sleeve type of seal. Equally, as mentioned previously, the variations in ingot withdrawal force may be utilized to control the rate of feed of the metal to the arc either in addition to, or in lieu of, controlling the intensity of the arc. If the withdrawal force is too high (indicating that not enough of the metal is molten), the feed of cold metal to the molten pool is slowed down by the action of controller **32***a* upon vibrator **32***b*. As the cold-metal feed slows down, with a steady power input to the arc, more of the metal in the mold will be molten so that the withdrawal force will be decreased. Decrease of the withdrawal force will cause a corresponding increase of the metal feed. Clearly, a single control signal can be utilized for controlling both the power to the electrode **16** and the amount of metal feed from chute **32**. If the withdrawal force is high, the control signal can (*a*) increase the amount of power to the electrode and (*b*) decrease the feed of cold metal to the molten pool. Conversely, if the withdrawal force is too low, the control signal can (*a*) increase the feed of cold metal to the molten pool and (*b*) decrease the feed of power to the electrode. Equally, the control signal can be utilized for controlling only the feed of cold metal to the molten pool by suitably manipulating selector **52***a*.

Since certain changes may be made in the above apparatus without departing from the scope of the invention herein involved, it is intended that all matter contained in the above description, or shown in the accompanying drawing, shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. Apparatus for forming an ingot of a high-melting-point metal such as titanium, zirconium and the like, said apparatus comprising means defining an air-tight melting chamber, an ingot mold in said chamber, said ingot mold being tapered so as to reduce the cross section of the forming ingot as it is withdrawn downwardly in said ingot mold, said mold being cooled so that said metal first solidifies at the mold walls, a resilient support for said ingot mold, means for withdrawing said ingot from the bottom of said mold with a withdrawal force which is a direct function of the degree of solidification of said ingot in said mold, means for measuring the withdrawal force as a function of the movement of said mold with respect to said resilient support, means for maintaining an arc to the surface of a forming ingot in the ingot mold to melt solid metal added to the ingot mold, and means controlled by the measuring means for decreasing the intensity of the arc as the measured withdrawal force decreases.

2. Apparatus for forming an ingot of a high-melting-point metal, such as titanium, zirconium and the like, said apparatus comprising means defining an air-tight melting chamber, a movable ingot mold in said chamber, said ingot mold being tapered so as to reduce the cross section of the forming ingot as it is withdrawn downwardly in said ingot mold, means for adding solid metal to said ingot mold, means for adding heat to said metal in said mold to melt said added solid metal, said heat-adding means comprising an electrode for maintaining an arc to the surface of the molten metal in the ingot mold, means for withdrawing said ingot from the bottom of said mold with a withdrawal force which is a direct function of the degree of solidification of the ingot in the mold, means for measuring the withdrawal force as a function of the movement of said ingot mold, and means, operated by said measuring means and operatively connected to at least one of said adding means, for controlling the operation of said one of said adding means as a function of the movement of said ingot mold to maintain said force substantially constant.

3. The apparatus of claim 2 wherein said controlling means is effective to decrease the feed of solid metal as the measured withdrawal force increases.

4. The apparatus of claim 2 wherein said controlling means is effective to increase the intensity of the arc as the measured withdrawal force increases.

5. The apparatus of claim 2 wherein said ingot mold comprises a hydraulic support and said measuring means includes means for measuring the hydraulic pressure in said support.

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