US 20180185912A1

(19) United States

(12) Patent Application Publication

Wickett et al.

(10) Pub. No.: US 2018/0185912 A1

(43) Pub. Date: Jul. 5, 2018

(54) **UNIT CELL TITANIUM CASTING**

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(21) Appl. No.: **15/848,566**

(22) Filed: **Dec. 20, 2017**

Related U.S. Application Data

(60) Provisional application No. 62/440,033, filed on Dec. 29, 2016, provisional application No. 62/440,040, filed on Dec. 29, 2016, provisional application No. 62/440,038, filed on Dec. 29, 2016.

Publication Classification

(51) **Int. Cl.**

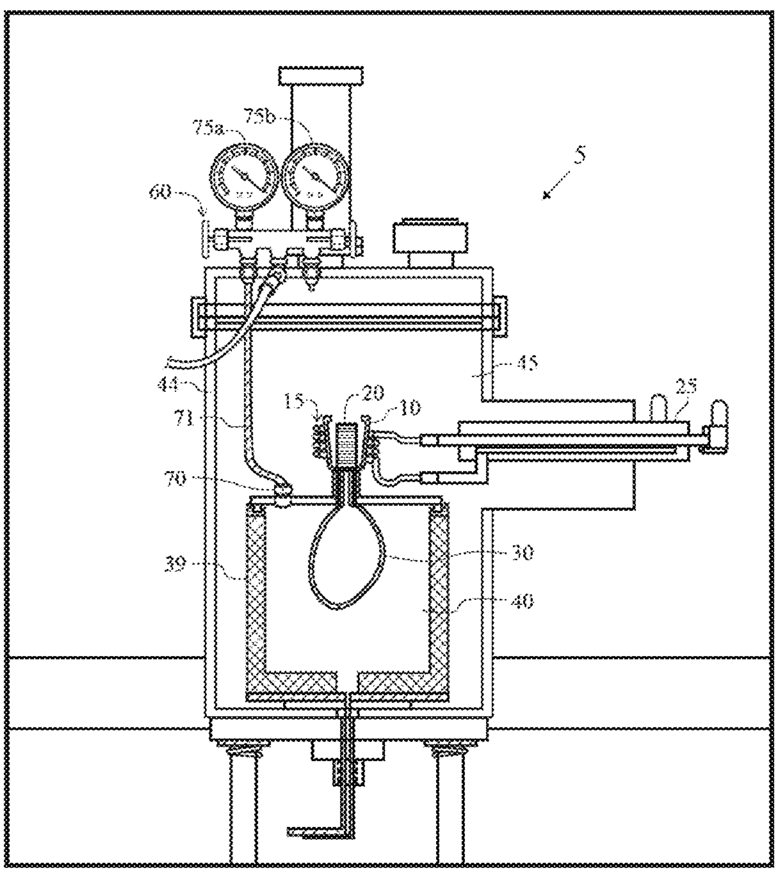
B22D 18/06	(2006.01)
B22D 18/08	(2006.01)
B22D 41/01	(2006.01)

(52) **U.S. Cl.**

CPC ***B22D 18/06*** (2013.01); ***B22D 41/01*** (2013.01); ***B22D 18/08*** (2013.01)

(57) **ABSTRACT**

A system (**5**) and method (**800**) for unit cell casting of titanium or titanium-alloys is disclosed herein. The system (**5**) comprises an external chamber (**45**), a crucible (**10**) positioned within the external chamber (**45**), an induction coil (**15**) positioned around the crucible, an internal chamber (**40**) positioned within the external chamber (**45**), and a mold (**30**) positioned within the internal chamber (**40**). The external chamber (**45**) is evacuated and a pressurized gas is injected into the evacuated external chamber (**45**) to create a pressurized external chamber (**45**). An ingot (**20**) is melted within the crucible utilizing induction heating generated by the induction coil (**15**). The internal chamber (**40**) is evacuated to create an evacuated internal chamber (**40**). The titanium alloy material of the ingot (**20**) is completely transferred into the mold (**30**) from the crucible (**10**) using a pressure differential created between the external chamber (**45**) and the internal chamber (**40**).



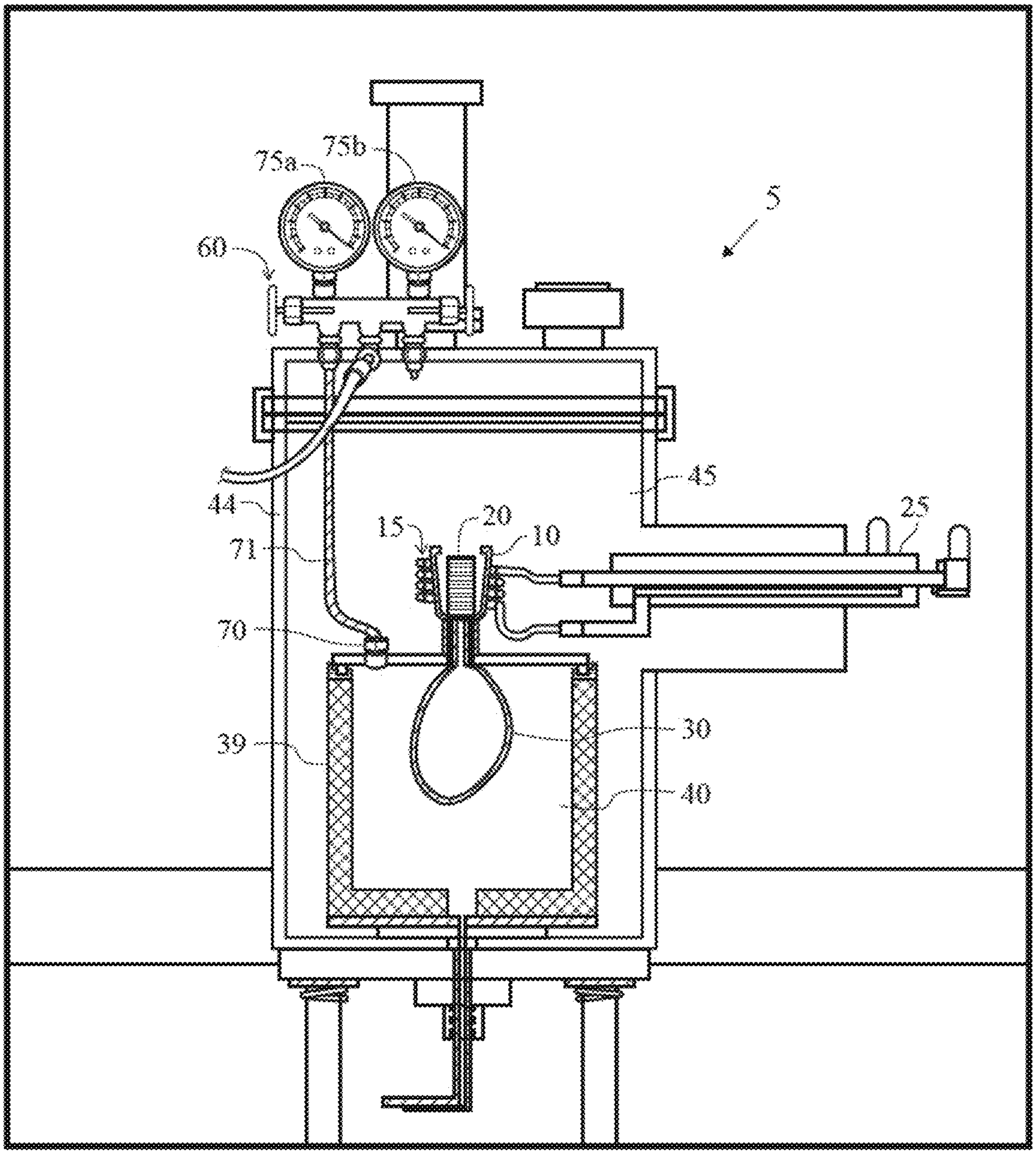


FIG. 1

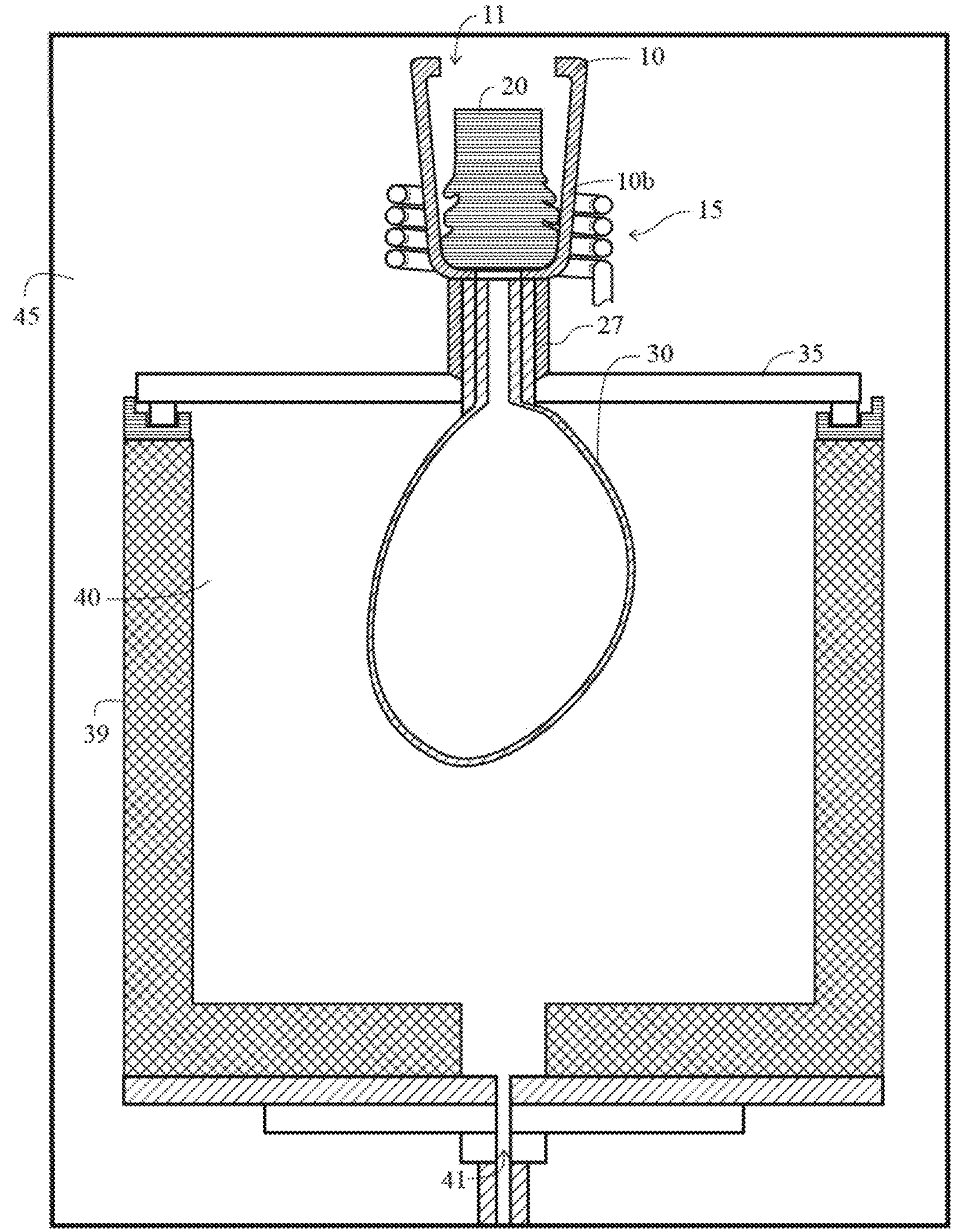


FIG. 2

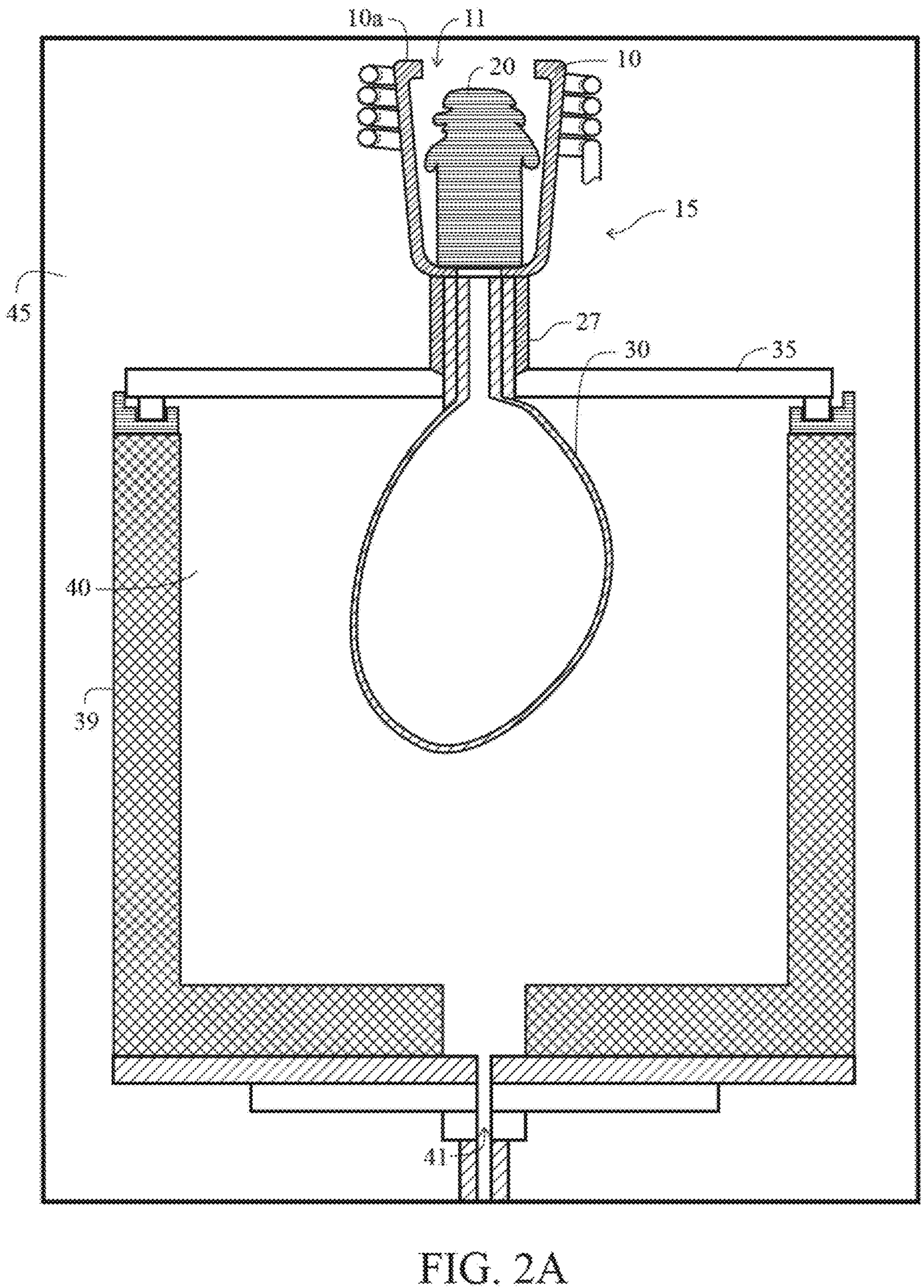


FIG. 2A

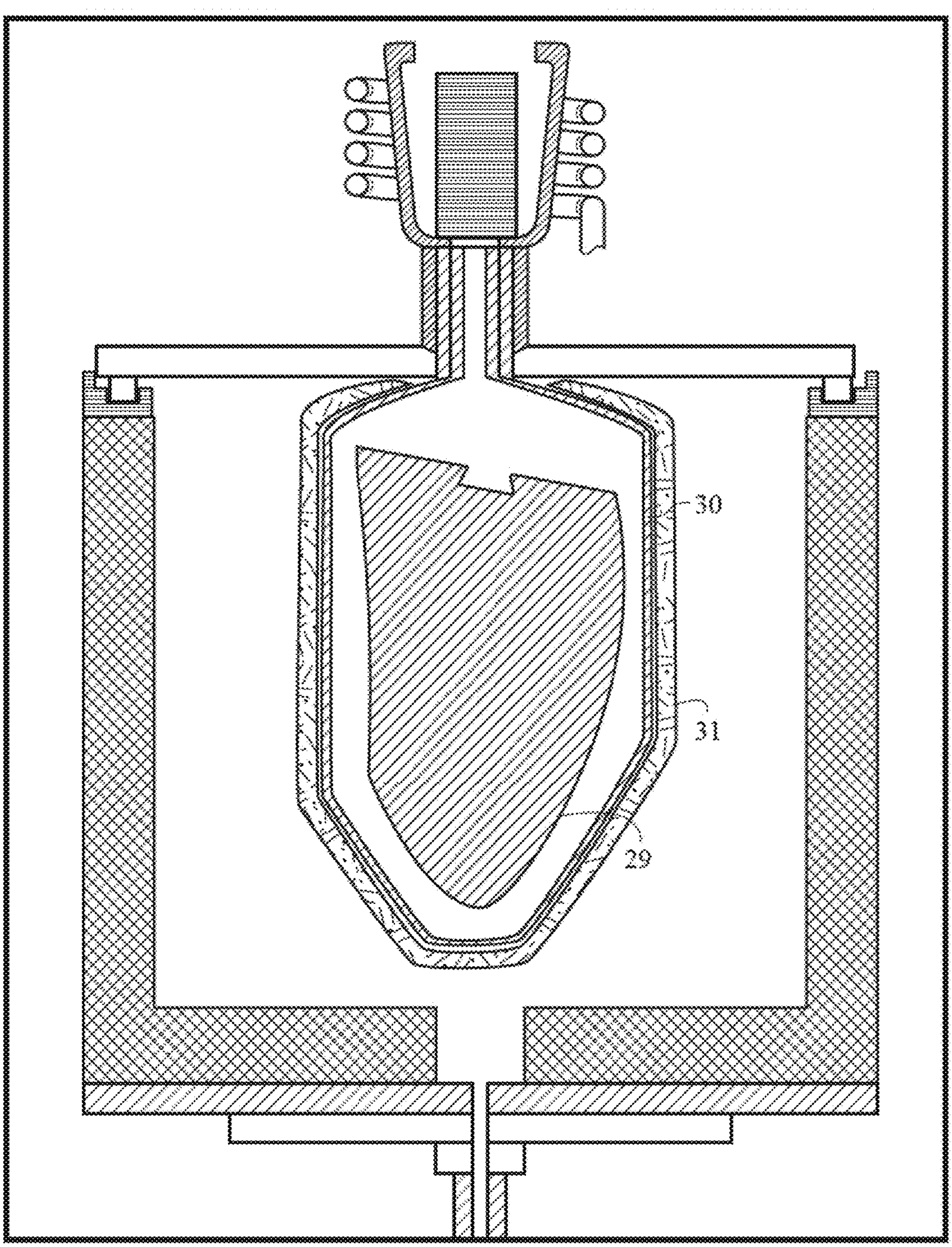


FIG. 2B

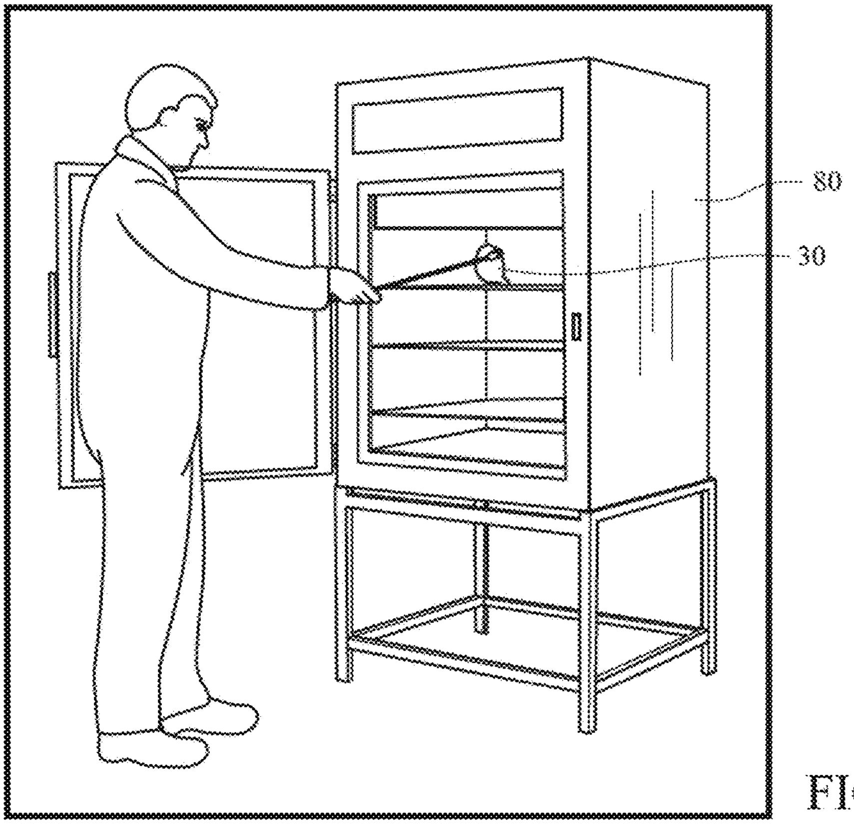


FIG. 3A

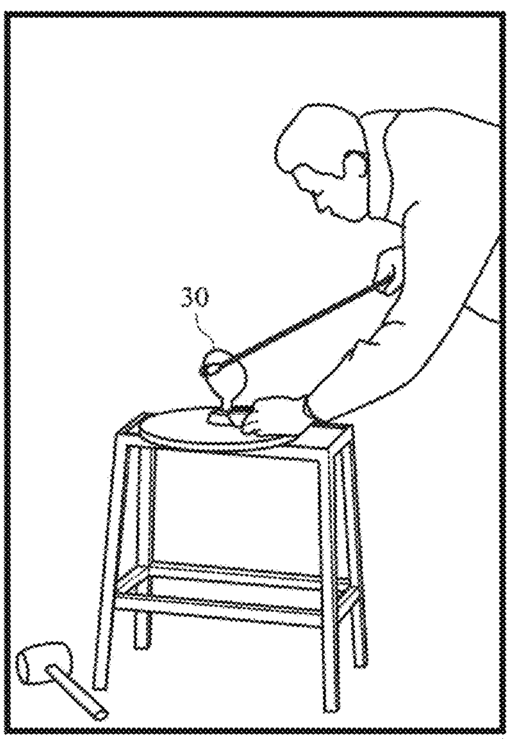


FIG. 3B

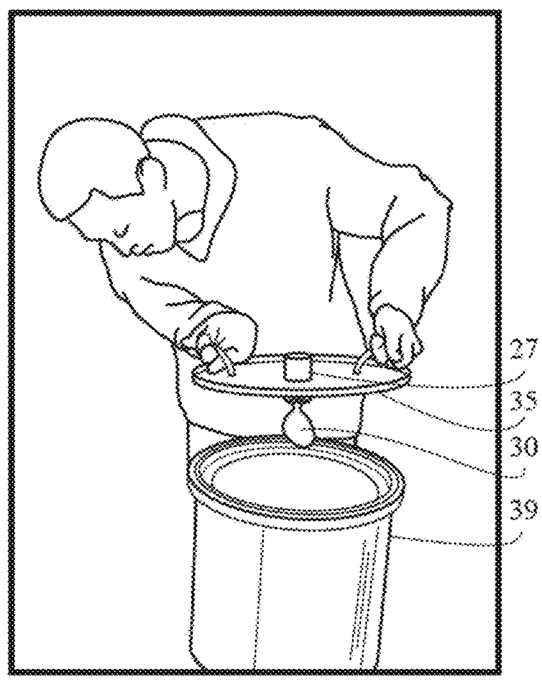


FIG. 3C

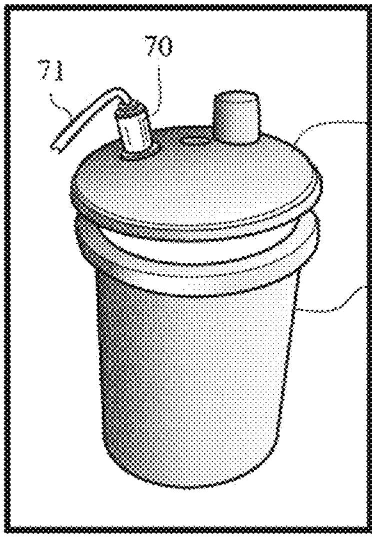


FIG. 3D

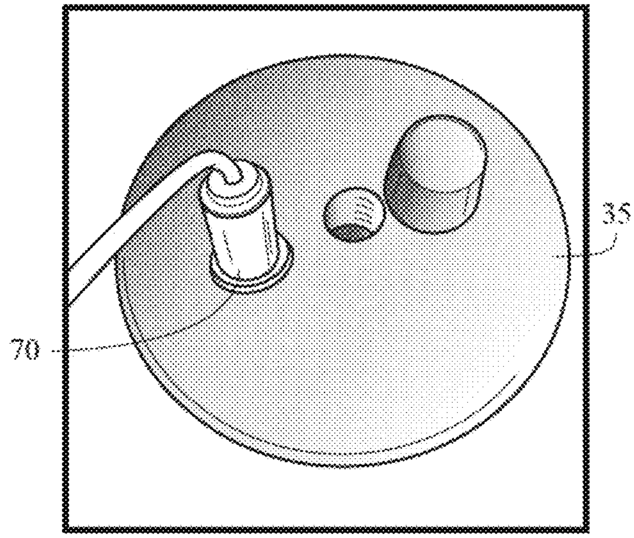


FIG. 3E

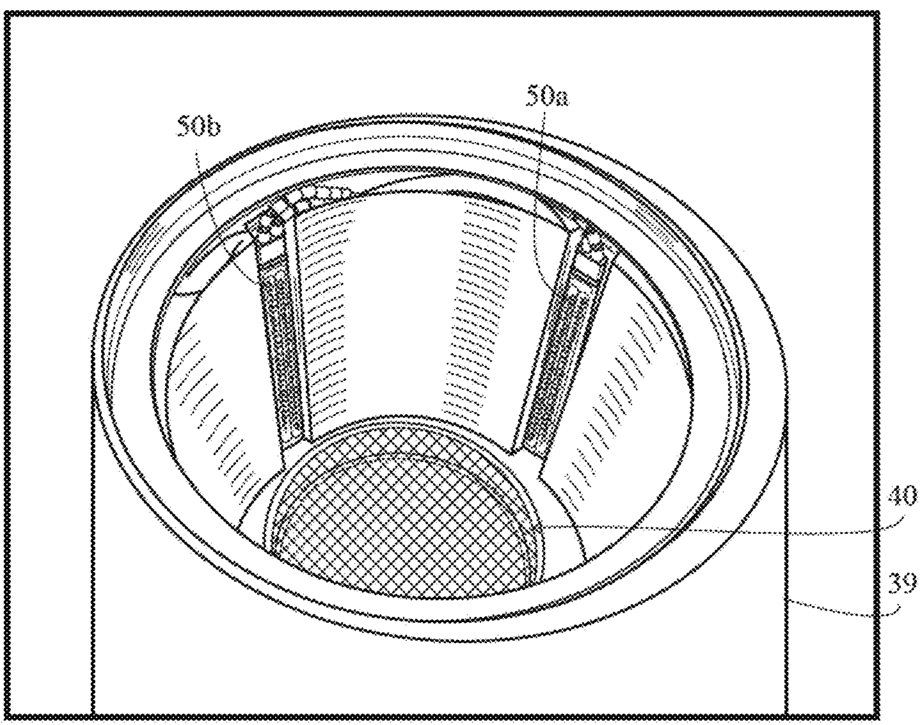


FIG. 3F

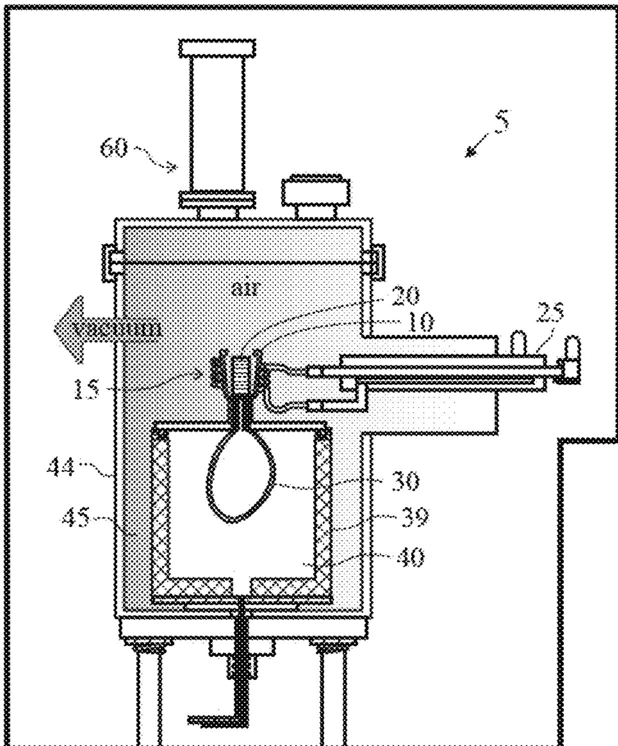


FIG. 4

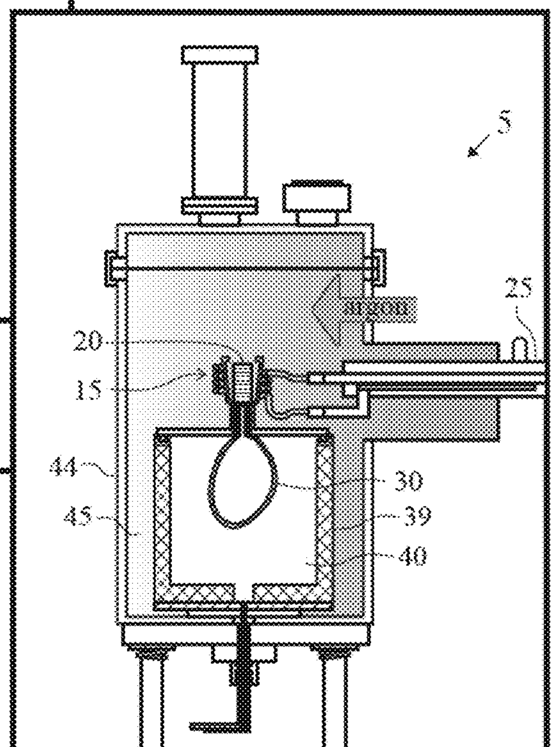


FIG. 4A

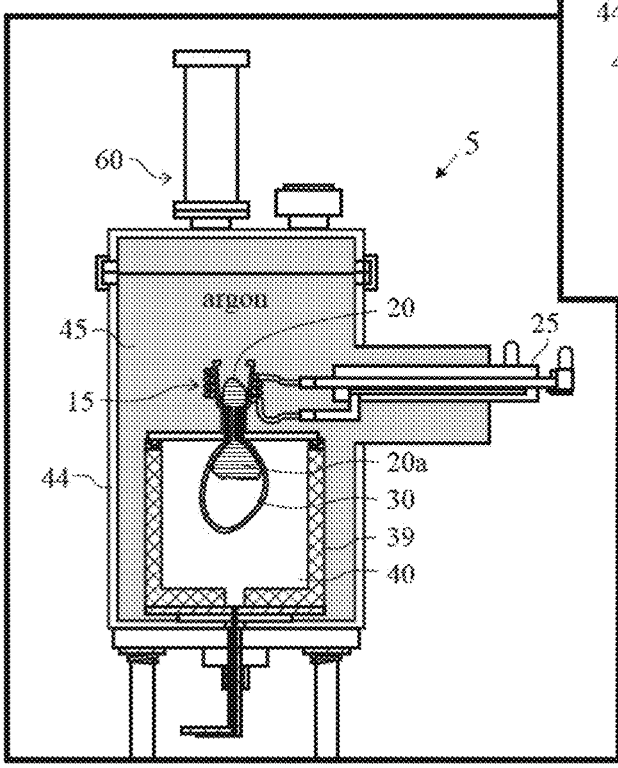


FIG. 4B

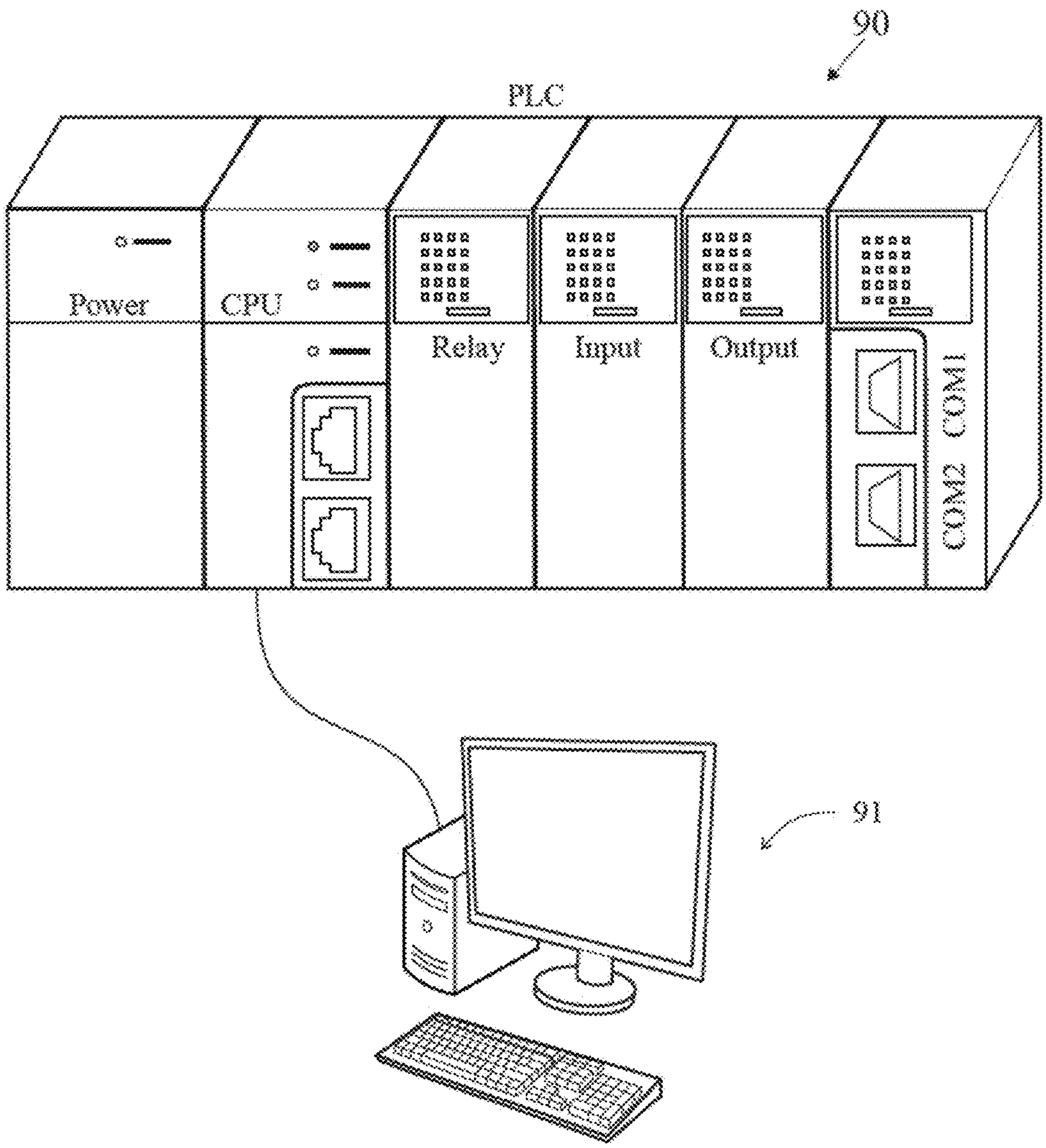


FIG. 5

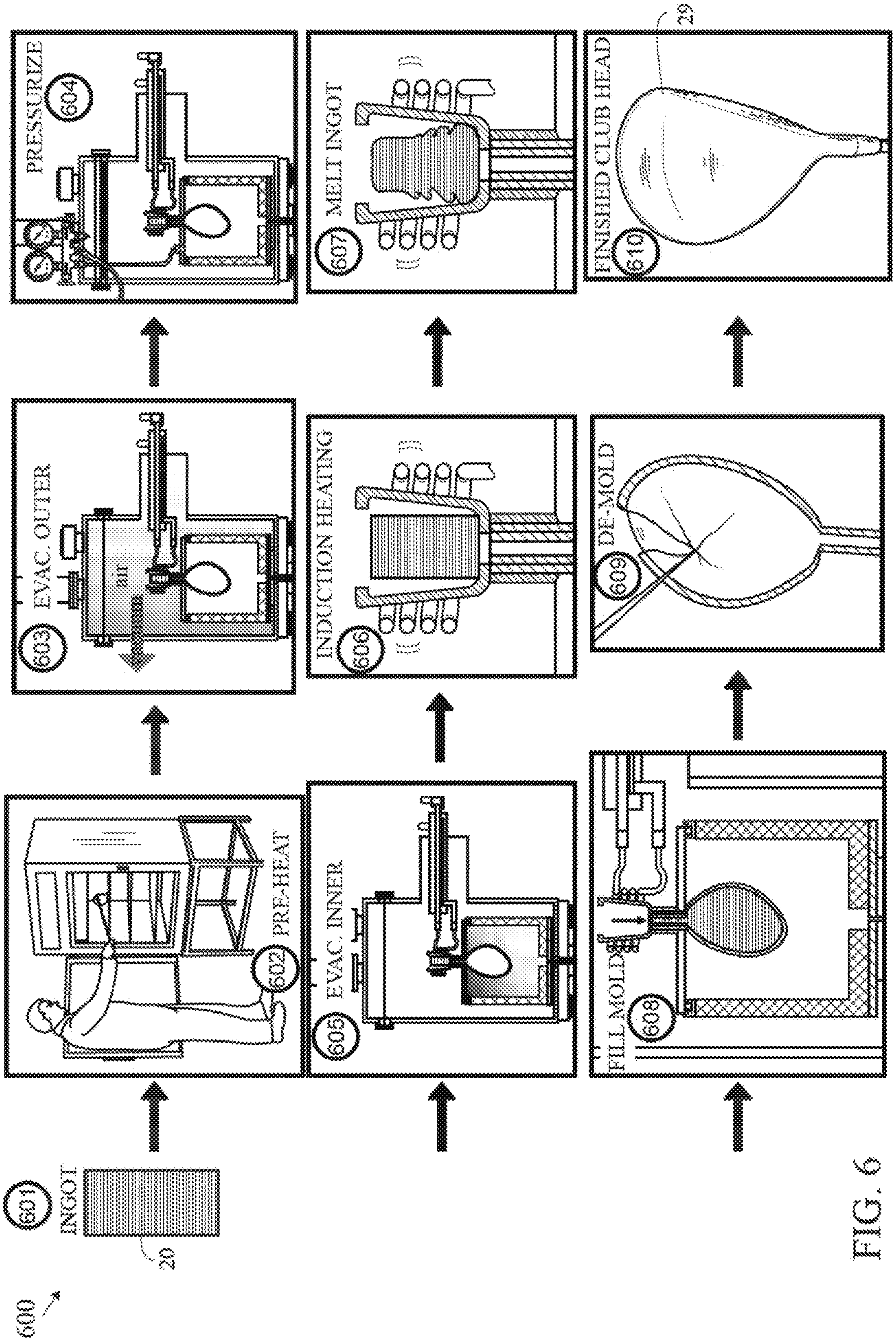

600
601
INGOT
20
602
PRE-HEAT
603
EVAC. OUTER
604
PRESSURIZE
605
EVAC. INNER
606
INDUCTION HEATING
607
MELT INGOT
608
FILL MOLD
609
DE-MOLD
610
FINISHED CLUB HEAD
29

FIG. 6

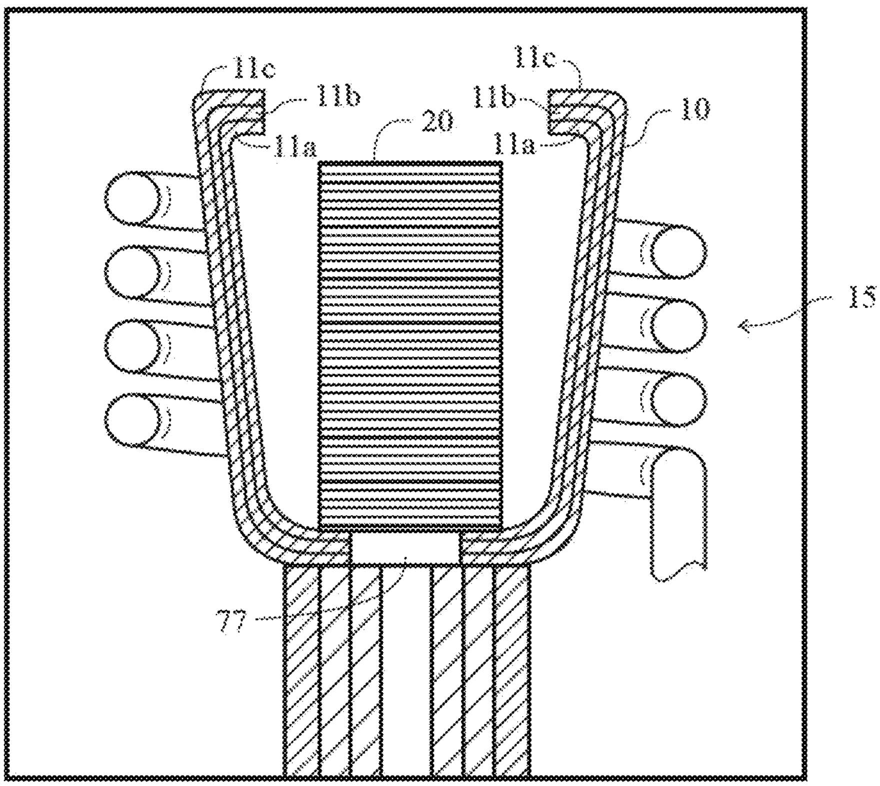


FIG. 7

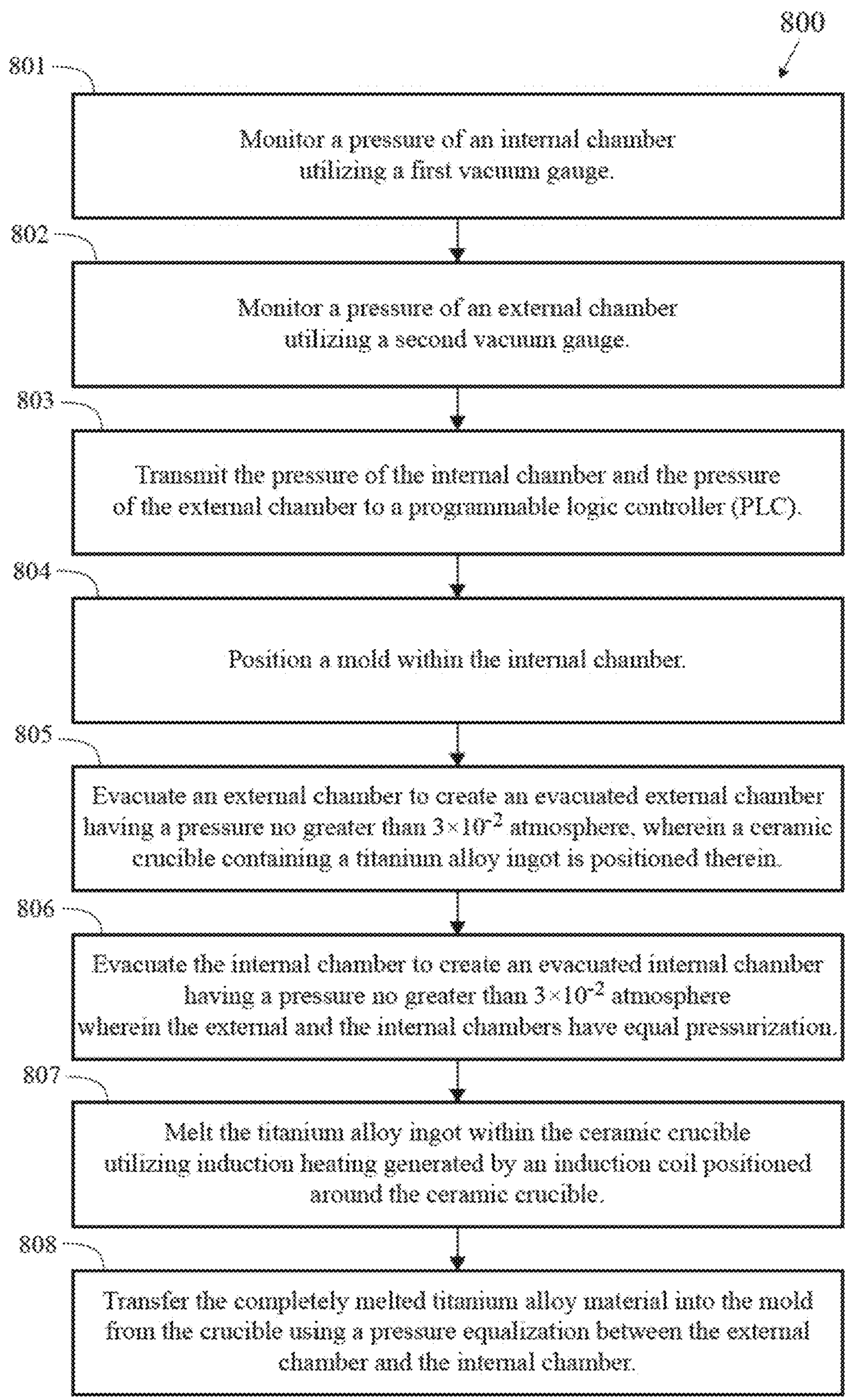

800
801
Monitor a pressure of an internal chamber utilizing a first vacuum gauge.
802
Monitor a pressure of an external chamber utilizing a second vacuum gauge.
803
Transmit the pressure of the internal chamber and the pressure of the external chamber to a programmable logic controller (PLC).
804
Position a mold within the internal chamber.
805
Evacuate an external chamber to create an evacuated external chamber having a pressure no greater than 3×10^-2 atmosphere, wherein a ceramic crucible containing a titanium alloy ingot is positioned therein.
806
Evacuate the internal chamber to create an evacuated internal chamber having a pressure no greater than 3×10^-2 atmosphere wherein the external and the internal chambers have equal pressurization.
807
Melt the titanium alloy ingot within the ceramic crucible utilizing induction heating generated by an induction coil positioned around the ceramic crucible.
808
Transfer the completely melted titanium alloy material into the mold from the crucible using a pressure equalization between the external chamber and the internal chamber.

FIG. 8

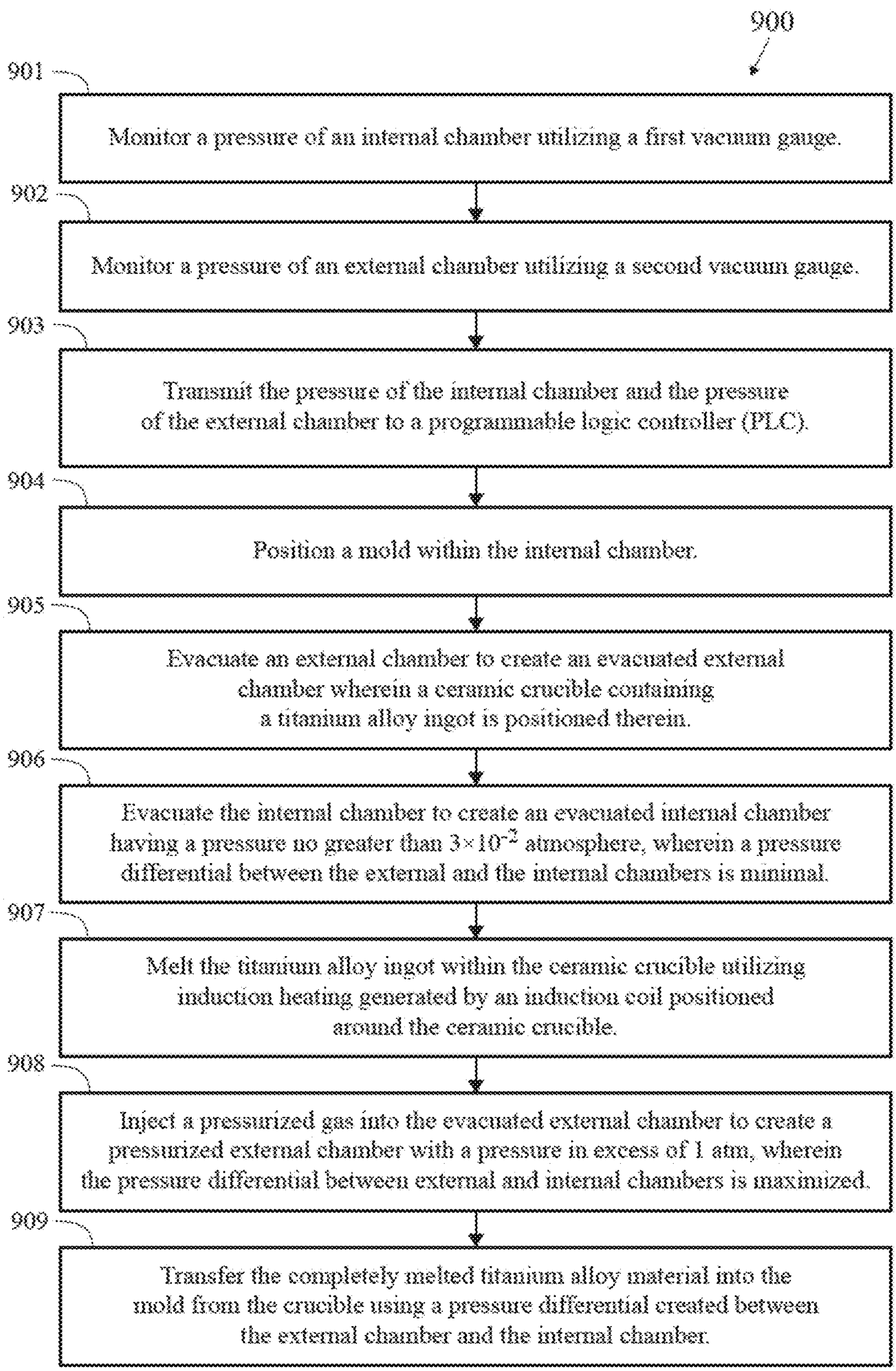

900
901
Monitor a pressure of an internal chamber utilizing a first vacuum gauge.
902
Monitor a pressure of an external chamber utilizing a second vacuum gauge.
903
Transmit the pressure of the internal chamber and the pressure of the external chamber to a programmable logic controller (PLC).
904
Position a mold within the internal chamber.
905
Evacuate an external chamber to create an evacuated external chamber wherein a ceramic crucible containing a titanium alloy ingot is positioned therein.
906
Evacuate the internal chamber to create an evacuated internal chamber having a pressure no greater than 3×10^-2 atmosphere, wherein a pressure differential between the external and the internal chambers is minimal.
907
Melt the titanium alloy ingot within the ceramic crucible utilizing induction heating generated by an induction coil positioned around the ceramic crucible.
908
Inject a pressurized gas into the evacuated external chamber to create a pressurized external chamber with a pressure in excess of 1 atm, wherein the pressure differential between external and internal chambers is maximized.
909
Transfer the completely melted titanium alloy material into the mold from the crucible using a pressure differential created between the external chamber and the internal chamber.

FIG. 9

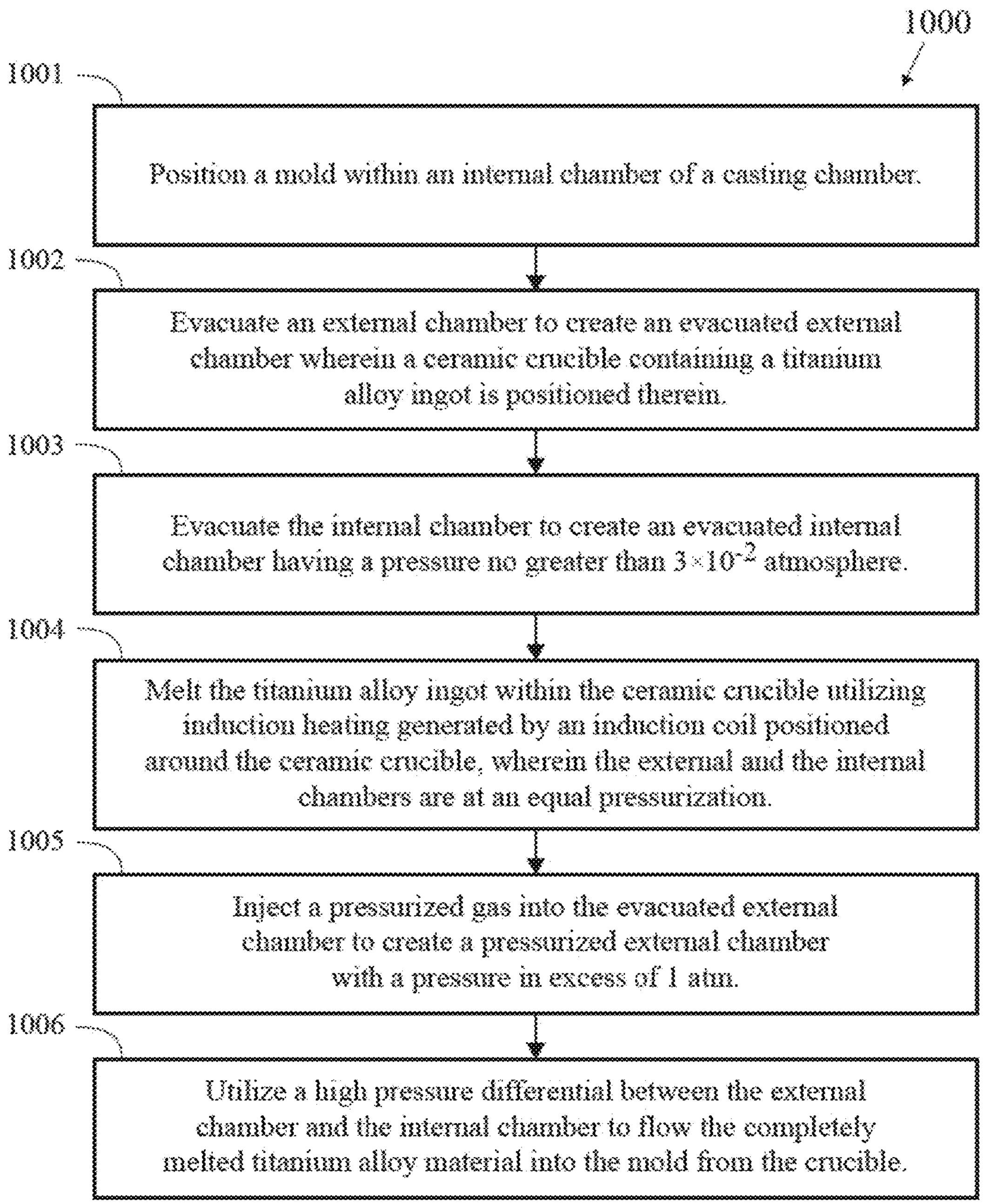

1000
1001
Position a mold within an internal chamber of a casting chamber.
1002
Evacuate an external chamber to create an evacuated external chamber wherein a ceramic crucible containing a titanium alloy ingot is positioned therein.
1003
Evacuate the internal chamber to create an evacuated internal chamber having a pressure no greater than 3×10^{-2} atmosphere.
1004
Melt the titanium alloy ingot within the ceramic crucible utilizing induction heating generated by an induction coil positioned around the ceramic crucible, wherein the external and the internal chambers are at an equal pressurization.
1005
Inject a pressurized gas into the evacuated external chamber to create a pressurized external chamber with a pressure in excess of 1 atm.
1006
Utilize a high pressure differential between the external chamber and the internal chamber to flow the completely melted titanium alloy material into the mold from the crucible.

FIG. 10

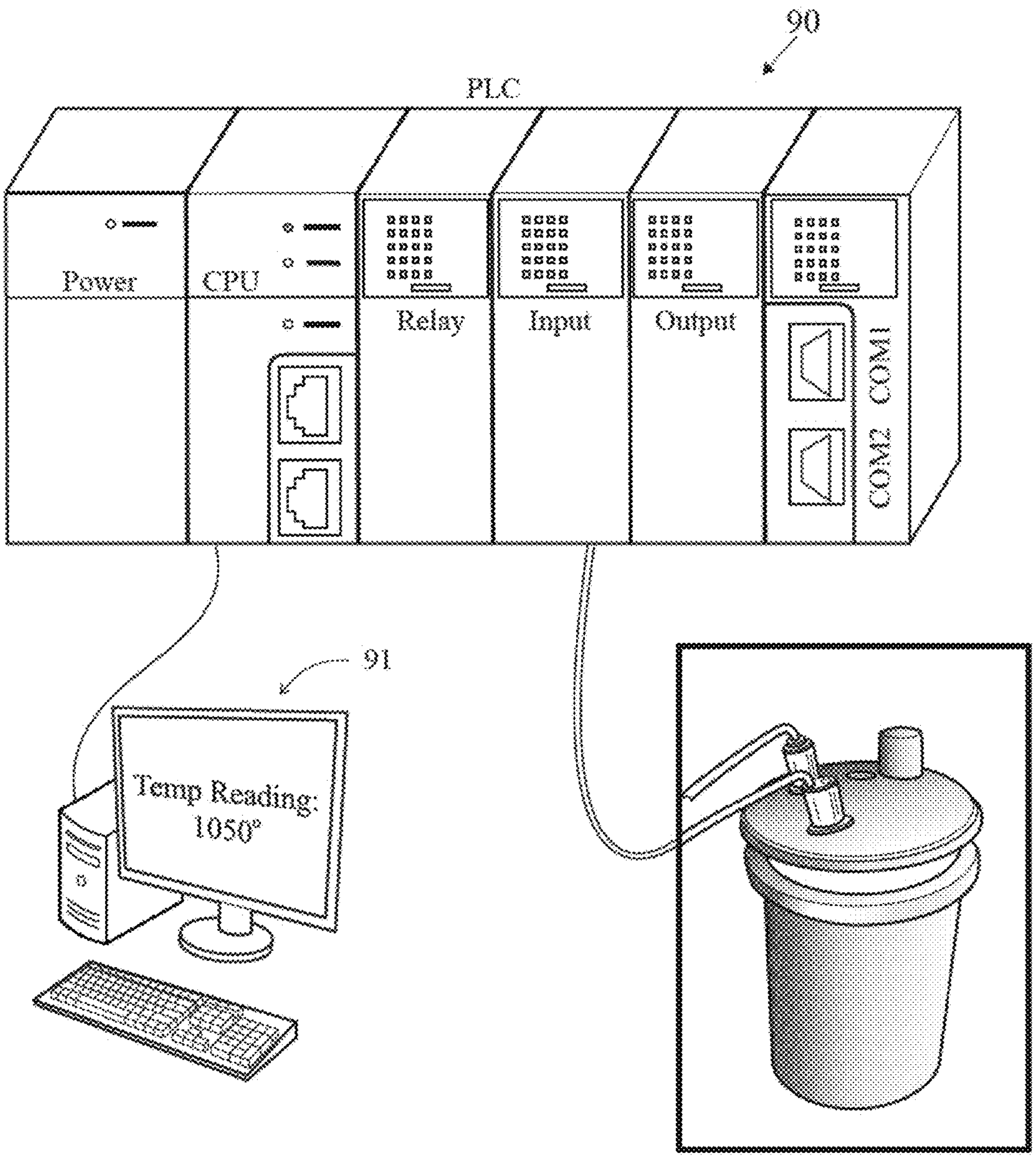

90
PLC
Power
CPU
Relay
Input
Output
COM1
COM2
91
Temp Reading:
1050°

FIG. 11

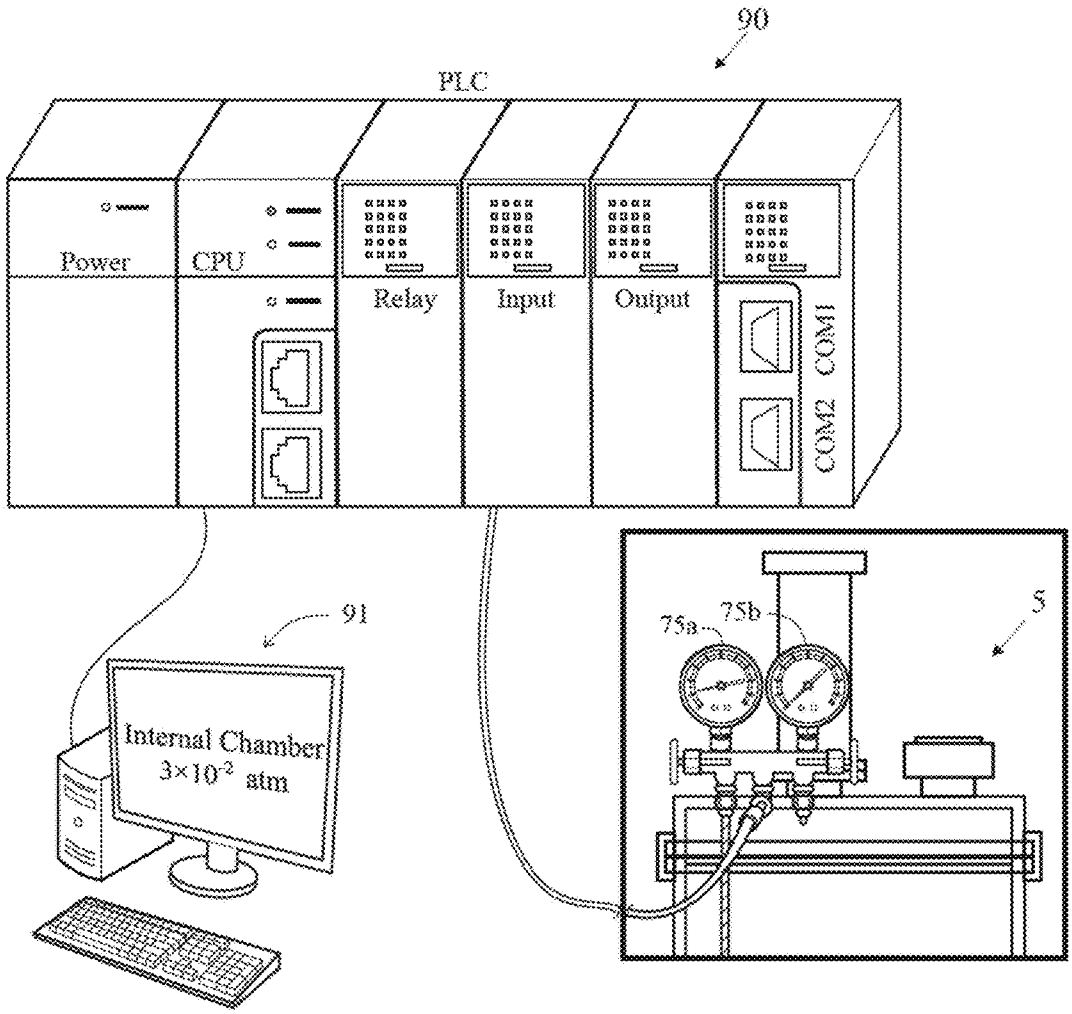

90
PLC
Power
CPU
Relay
Input
Output
COM1
COM2
91
Internal Chamber
3×10⁻² atm
75a
75b
5

FIG. 12

UNIT CELL TITANIUM CASTING

CROSS REFERENCES TO RELATED APPLICATIONS

[0001] The present application claims priority to U.S. Provisional Patent Application No. 62/440,033 filed on Dec. 29, 2016, U.S. Provisional Patent Application No. 62/440,040 filed on Dec. 29, 2016, and U.S. Provisional Patent Application No. 62/440,038 filed on Dec. 29, 2016, each of which is hereby incorporated by reference in its entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not Applicable

BACKGROUND OF THE INVENTION

Field of the Invention

[0003] The present invention relates to precision titanium casting. More specifically, the present invention relates to an apparatus and method for precision titanium casting utilizing induction heating.

Description of the Related Art

[0004] Various methods of titanium casting are well-known. One such method is investment casting which involves a lost wax procedure.

[0005] Vacuum electric arc smelting is another method in which a titanium ingot is melted by substantial heat generated by mutual discharging in a high current state by respectively using a titanium ingot crucible and a water-cooled copper crucible as a positive electrode and a negative electrode, thereby forming a molten liquid metal in the crucible and completing the casting of the titanium.

[0006] Another method is vacuum induction smelting in which an induction coil is wrapped outside a split-type water-cooled copper crucible. The electromagnetic force generated by the induction coil passes through a nonmetal isolation portion between splits of the copper crucible and then acts on a titanium ingot placed inside the crucible. Then the molten metal forms a molten metal liquid inside the crucible and the casting of the titanium is completed.

[0007] Vacuum induction smelting and vacuum electric arc smelting require the use of a water-cooled copper crucible which results in the loss of substantial heat. The actual power consumed is very little (only 20% to 30% of the power actually acts on the titanium). Furthermore, the preparation of the molding shell is very complex and time consuming, which adds to the costs. In the traditional casting technology, the operation time of a single furnace is usually 60 to 80 minutes, and the loading and discharge process requires the coordination of many people. In the traditional casting technology, the process from the preparation of the wax pattern to the clearing of the molding shell can take ten days.

[0008] Titanium is an extremely reactive metal. During melting via traditional casting processes, a water cooling environment is required. The molten titanium liquid will come into direct contact with water if the crucible cracks, resulting in a fierce reaction, or even explosion, which poses a great threat to production safety.

[0009] To solve the above problems, a new kind of titanium alloy induction melting vacuum suction casting device is urgently needed, to solve the problems with existing titanium alloy casting, such as low efficiency, high cost, complicated technology, heavy workload, difficulty with preparing high-quality molding shells, long cycle and potential hazard.

BRIEF SUMMARY OF THE INVENTION

[0010] Utilizing the two chamber casting system, one of the primary tenets is the use of a crucible in order to contain the target material during melt and prior to evacuation into the pattern mold. In order to accelerate the melting of the target material and reduce cycle times, it is necessary to preheat the crucible to higher temperatures (>500 C). This causes a faster heating and subsequent melting of the target material thus reducing the time necessary to evacuate the material from the crucible into the pattern mold. The accelerated process also reduces the potential for reaction of the target material and may allow for more complete fill of complex geometries.

[0011] One aspect of the present invention is a method for unit cell casting of titanium or titanium-alloys. The method includes positioning a mold within an internal chamber. The method also includes evacuating an external chamber to create an evacuated external chamber wherein a ceramic crucible containing a titanium alloy ingot is positioned therein. The method also includes evacuating the internal chamber to create an evacuated internal chamber having a pressure no greater than 3×10^{-2} atmosphere. The method also includes injecting a pressurized gas into the evacuated external chamber to create a pressurized external chamber with a pressure in excess of 1 atm. The method also includes pre-heating the crucible to a temperature greater than 500° C. The method also includes melting the titanium alloy ingot within the ceramic crucible utilizing induction heating generated by an induction coil, wherein a position of the induction coil begins at a upper third of the titanium alloy ingot and during the melting of the titanium alloy ingot the position of the induction coil is lowered relative to the titanium alloy ingot to terminate at a bottom of the titanium alloy ingot. The method also includes transferring the completely melted titanium alloy material into the mold from the crucible using a pressure differential created between the external chamber and the internal chamber. A high pressure differential in maintained between the external chamber and the internal chamber during the transfer of the melted titanium alloy material. The PLC controls power to the induction coil to superheat the titanium alloy ingot in the ceramic crucible, and the PLC also controls the positioning of the induction coil. The placement of the induction coil first acts on the upper portion of the ingot melting the material from the top down, causing molten material to cascade around the still-solid ingot and forming a seal before the electromagnetic forces of the induction coil affect the remaining material. The pressure of the internal chamber and the pressure of the external chamber are monitored and communicated to the PLC during the casting process, and wherein the PLC controls the casting process based on the pressure of the internal chamber and the pressure of the external chamber.

[0012] Another aspect of the present invention is a system method for unit cell casting of titanium or titanium-alloys. The system comprises an external chamber, a ceramic crucible positioned within the external chamber, an induction coil positioned around an upper third of the ingot within the ceramic crucible, an internal chamber positioned within the external chamber, a mold positioned within the internal chamber, a first vacuum gauge positioned within the internal chamber, a second vacuum gauge positioned within the external chamber, a PLC in communication with the first vacuum gauge, the second vacuum gauge, and the induction coil. The crucible is preheated to a temperature greater than 500° C. The pressure of the internal chamber and the pressure of the external chamber are monitored and communicated to the PLC during the casting process, and wherein the PLC controls the casting process based on the pressure of the internal chamber and the pressure of the external chamber. Placement of the induction coil first acts on the upper portion of the ingot melting the material from the top down, causing molten material to cascade around the still-solid ingot and forming a seal before the electromagnetic forces of the induction coil affect the remaining material. The external chamber is evacuated to create an evacuated external chamber wherein the ceramic crucible contains a titanium alloy ingot positioned therein. A pressurized gas is injected into the evacuated external chamber to create a pressurized external chamber. The titanium alloy ingot is melted within the ceramic crucible utilizing induction heating generated by the induction coil positioned around the ceramic crucible, wherein a power for the induction coil is commences at a first power level of 15 kiloWatts and increases to a second power level greater than 50 kiloWatts. The internal chamber is evacuated to create an evacuated internal chamber. The titanium alloy material is completely transferred into the mold from the crucible using a maximum pressure differential created between the external chamber and the internal chamber. The titanium alloy ingot is preferably centered within the ceramic crucible using a centering feature. The centering feature is preferably a plurality of stand-offs in a wall of the ceramic crucible.

[0013] Yet another aspect of the present invention is a method for unit cell casting of titanium or titanium-alloys. The method includes evacuating an external chamber to create an evacuated external chamber wherein a ceramic crucible containing a titanium alloy ingot is positioned therein. The method also includes evacuating the internal chamber to create an evacuated internal chamber having a pressure no greater than 3×10^{-2} atmosphere. The method also includes melting the titanium alloy ingot within the ceramic crucible utilizing induction heating generated by an induction coil wherein a position of the induction coil begins at a upper third of the titanium alloy ingot and during the melting of the titanium alloy ingot the position of the induction coil is lowered relative to the titanium alloy ingot to terminate at a bottom of the titanium alloy ingot. The method also includes injecting a pressurized gas into the evacuated external chamber to create a pressurized external chamber with a pressure in excess of 1 atmosphere, wherein the pressure differential is at a maximum. The method also includes utilizing a high pressure differential between the external chamber and the internal chamber to flow the completely melted titanium alloy material into the mold from the crucible.

[0014] The pressurized gas is preferably argon. The mold is preferably covered in a kaolin wool insulating material. The mold is preferably for a thin-walled golf club head. The mold is alternatively for an article having a wall thickness less than 0.250 inch. The induction melting time preferably ranges from 30 seconds to 90 seconds. The ceramic crucible is preferably composed of two yttria-based primary crucible layers, wherein a first primary crucible layer has a thickness ranging from 0.010 inch to 0.060 inch, and a second primary crucible layer has a thickness ranging from 0.001 inch to 0.020 inch. The ceramic crucible further comprises a silica based backup layer. The induction coil is preferably positioned around a bottom section of the ceramic crucible. The induction coil is alternatively positioned around an upper section of the ceramic crucible.

[0015] Having briefly described the present invention, the above and further objects, features and advantages thereof will be recognized by those skilled in the pertinent art from the following detailed description of the invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0016] FIG. **1** is an illustration of a unit-cell casting system.

[0017] FIG. **2** is an isolated view of an interior chamber, crucible, induction coils and mold of the unit-cell casting system, showing placement of the induction coils at a lower section of the crucible.

[0018] FIG. **2**A is an isolated view of an interior chamber, crucible, induction coils and mold of the unit-cell casting system, showing placement of the induction coils at an upper section of the crucible.

[0019] FIG. **2**B is an isolated view of an interior chamber, crucible, induction coils and mold of the unit-cell casting system, showing an insulation material wrapped around the mold.

[0020] FIG. **3**A is an illustration of a technician preheating a mold in an oven.

[0021] FIG. **3**B is an illustration of a technician attaching the pre-heated mold to a lid of the internal container.

[0022] FIG. **3**C is an illustration of a technician attaching the lid to the internal container.

[0023] FIG. **3**D is an isolated view of the internal container.

[0024] FIG. **3**E is an isolated view of the lid of the internal container.

[0025] FIG. **3**F is an isolated view of the internal chamber of the internal container showing infrared heaters.

[0026] FIG. **4** is an illustration of a unit-cell casting system during an external chamber evacuation step.

[0027] FIG. **4**A is an illustration of a unit-cell casting system during an external chamber pressurization step.

[0028] FIG. **4**B is an illustration of a unit-cell casting system during an ingot melting step.

[0029] FIG. **5** is an illustration of a PLC unit and computer for a unit cell casting system.

[0030] FIG. **6** is a block diagram of a unit cell casting method.

[0031] FIG. **7** is an isolated view of a crucible for a unit cell casting system.

[0032] FIG. **8** is a flow chart of a method for unit cell titanium casting.

[0033] FIG. **9** is a flow chart of a method for unit cell titanium casting.

[0034] FIG. **10** is a flow chart of a method for unit cell titanium casting.

[0035] FIG. **11** is an illustration of a PLC unit, an operator's computer for a unit cell casting system, an internal chamber with monitoring connections.

[0036] FIG. 12 is an illustration of a PLC unit, an operator's computer for a unit cell casting system, an internal chamber with monitoring connections.

DETAILED DESCRIPTION OF THE INVENTION

[0037] Utilizing the two chamber casting system, one of the primary tenets is the use of a crucible in order to contain the target material during melt and prior to evacuation into the pattern mold. In order to accelerate the melting of the target material and reduce cycle times, it is necessary to preheat the crucible to higher temperatures (>500 C). This causes a faster heating and subsequent melting of the target material thus reducing the time necessary to evacuate the material from the crucible into the pattern mold. The accelerated process also reduces the potential for reaction of the target material and may allow for more complete fill of complex geometries.

[0038] Utilizing the two chamber casting system, one of the primary tenets is the use of a crucible in order to contain the target material during melt and prior to evacuation into the pattern mold. In order to ensure uniform heating of the target material it is necessary to have the ingot centered within the crucible. This is achieved by the incorporation of a centering feature (ideally a "seat" in the crucible base, but possible standoffs in the crucible walls) in the crucible itself. This allows for consistent ingot placement resulting in uniform and predictable melting of the target material which in turn results in more consistent final parts.

[0039] Utilizing the two chamber casting system, one of the primary tenets is the use of a crucible in order to contain the target material during melt and prior to evacuation into the pattern mold. In order to reduce operating costs while still allowing the electromagnetic forces from the induction coil to act upon the target material, the crucible should be formed of a molded crucible formed of >90% Yttria. This will allow for the crucible to be reused and also minimize any reaction between the crucible and the target material during melt.

[0040] Utilizing the two chamber casting system, one of the primary tenets is the use of a crucible in order to contain the target material during melt and prior to evacuation into the pattern mold. In order to reduce operating costs while still allowing the electromagnetic forces from the induction coil to act upon the target material, the crucible should be formed of a molded crucible formed of >90% Zirconia. This will allow for the crucible to be reused and reduce overall cost due to crucible usage and materials.

[0041] Utilizing the two chamber casting system, one of the primary tenets is the use of a crucible in order to contain the target material during melt and prior to evacuation into the pattern mold. In order to reduce operating costs while still allowing the electromagnetic forces from the induction coil to act upon the target material, the crucible is preferably formed of a molded crucible formed of Yttria and infused with Barium. This will provide the benefits of a molded Yttria crucible (reusable, low reactivity) with the benefit of the target material being less apt to stick to the surface thus providing better evacuation and higher chance of reuse.

[0042] As shown in FIG. **1**, a unit cell titanium casting system **5** comprises an external container **44**, an internal container **39**, a vacuum mechanism **60**, a crucible **10**, an induction coil **15**, a coil electrical generation mechanism **25**, and a mold **30**. The external container **44** defines an external chamber **45**. The internal container **39** defines an internal chamber **40**. The vacuum mechanism **60** includes a vacuum line **71**, a vacuum connector **70** and pressure gauges **75*a*** and **75*b***. The vacuum mechanism **60** is utilized to evacuate and pressurize the external chamber **45** and the internal chamber **40** in order to create a pressure differential between the internal chamber **40** and the external chamber **45**.

[0043] The crucible **10** is preferably composed of a ceramic material. In a most preferred embodiment, the crucible **10** is composed of a first layer **11*a***, a second layer **11*b*** and a silica based third layer **11*c***, as shown in FIG. **7**. A metal ingot **20** is placed within the interior of the crucible **10**. The metal ingot **20** is preferably a titanium alloy material. The volume of the crucible **10** preferably corresponds to the amount of metal necessary for forming the article. The interior of the crucible **10** preferably has a diameter ranging from 15 centimeters ("cm") to 90 cm, more preferably from 35 cm to 60 cm. A height of the crucible **10** preferably ranges 30 cm to 200 cm, and more preferably from 60 cm to 100 cm.

[0044] A connection nozzle **27** is connected between a bottom opening (not shown) of the crucible **10** and an opening to the mold **30**. The connection nozzle **27** allows the melted metal material from the ingot **20** to flow into the mold **30** for casting of the article. Specifically, the size of connection nozzle **27** is determined based on the size and shape of the cavity of the mold **30**, and is preferably from 5 cm to 100 cm, and more preferably from 15 cm to 50 cm.

[0045] The induction coil **15** is wrapped around the crucible **10**. The induction coil **15** is energized to generate an electromagnetic force to melt the metal ingot **20** (e.g., titanium alloy ingot) within the crucible **10**. The coil electrical generation mechanism **25** provides the electricity to the induction coil **15**. As shown in FIG. **2**, the induction coil **15** is wrapped around a bottom section **10*b*** of the crucible **10**. This melts the bottom of the ingot **20** first. As shown in FIG. **2**A, the induction coil **15** is wrapped around an upper section **10*a*** of the crucible **10**. This melts the top of the ingot **20** first.

[0046] In order to optimize the ability of the target material to seal around the port of a ceramic crucible **10**, the induction coil **15** is preferably centered on the upper third of the ingot **20**. This positioning allows the induction coil **15** to first act on the upper portion of the ingot **20** (melting the material from the top down), causing molten material to cascade around the still-solid ingot **20** and forming a seal before the electromagnetic forces of the induction coil **15** affect the remaining material.

[0047] Alternatively, in order to fully utilize the electromagnetic forces of the induction coil **15**, to include the electromagnetic stirring of the melt, the induction coil **15** is positioned towards the bottom **10*b*** of the ceramic crucible **10**. This positioning allows for a uniform melt as molten material cascades onto itself and also increased homogeneity of the pour as the electromagnetic forces can better act on the molten material prior to it being evacuated from the crucible **10**.

[0048] Melting of the ingot **20** of titanium alloy is carried out in a vacuum condition for induction melting. The induction coil **15** is connected to the coil electrical generation mechanism **25**.

[0049] The ceramic crucible **10** is utilized for vacuum induction melting of the titanium alloy. The ceramic material does not interfere with the fielding effect of the electromagnetic force, and the electro-magnetic induction energy generated by the induction coil **15** is fully focused on melting the ingot of titanium alloy.

[0050] In an embodiment shown in FIG. **2**B, an insulating material **31** is wrapped around the mold **30**. During casting pattern molds are preheated prior to use in order to improve the flow of material into the mold itself and to better allow the mold **30** to fill completely. Due to the nature of titanium materials, and the melting process itself, the more that heat loss is minimized, the greater time the material has to flow and fill the mold **30** prior to solidification. To this end, pattern mold heat is retained through the use of an insulating material **31** (e.g.: Kaolin wool) thereby extending the useful period of the mold **30** prior to the pour and allowing for better fill, including filling of more difficult molds (e.g., thin walled castings).

[0051] As shown in FIGS. **3**A, **3**B, **3**C, **3**D and **3**E, the mold **30** is preheated in an oven **80**. During unit cell casting, pattern molds **30** are preheated prior to use in order to improve the flow of material into the mold **30** itself and to better allow the mold **30** to fill completely. Due to the nature of titanium materials, and the melting process itself, there is a likely correlation between the temperature of the mold **30** and the ability to fill complex and/or thin walled pattern molds **30**. Temperatures testing include 1050° C., 1060° C., 1100° C., 1150° C., 1200° C., 1250° C. and 1260° C. The pre-heated mold is removed from the **80** and attached to a lid **35** of the internal container **39**.

[0052] In an alternative embodiment shown in FIG. **3**F, infrared heaters **50***a* and **50***b* are used to maintain the heat of the mold **30** within the internal chamber **40**. Due to the nature of titanium materials, and the melting process itself, the more that heat loss is minimized, the greater time the material can flow and fill the mold **30** prior to solidification. To this end, pattern mold heat is retained through the use of infrared heaters **50***a* and **50***b* placed within the internal walls of the internal chamber **40** of the internal container **39** in order to minimize pattern mold cool down and improve the ability to cast complex and/or thin-walled parts.

[0053] FIGS. **4**, **4**A and **4**B illustrate the casting process using a pressure differential between the external chamber **45** and the internal chamber **40** to assist in the flow of melted titanium alloy materials into a mold **30**.

[0054] FIG. **5** illustrates a programmable logic computer ("PLC") and operator computer **91** utilized with the unit cell casting system **5**.

[0055] FIG. **6** is a block diagram of a unit cell casting method **600**. At step **601**, an ingot **20** is prepared for casting. The single ingot **20** is utilized to manufacture a single article such as a golf club head **29**. As opposed to manufacturing multiple articles in a single process, which results in the loss of material, the present invention manufactures only a single article in each process. At step **602**, the mold **30** is preheated in an oven. At step **603**, the external chamber **45** is evacuated. At step **604**, the external chamber **45** is pressurized with an argon gas. At step **605**, the internal chamber **40** is evacuated. At step **606**, the induction coil **15** is energized and at step **607** the ingot **20** is melted within the crucible **10**. At the step **608**, the melted material flows into mold **30**. At step **609**, the de-molding process occurs. At step **610**, the article (golf club head) **29** is finished. A frequency generated in the induction coil ranges from 1 kilo-Hertz to 50 kilo-Hertz, and a power ranges from 15 kilo-Watts to 50 kilo-Watts. An atmospheric pressure of the evacuated internal chamber ranges from 3×10^{-2} atmosphere to 9.87×10^{-7} atmosphere. An atmospheric pressure of the evacuated internal chamber ranges from 9.87×10^{-7} atmosphere to 9.87×10^{-13} atmosphere.

[0056] As shown in FIG. **7**, the first layer **11***a* and the second layer **11***b* are preferably composed of yttrium oxide and other materials. Yttrium oxide is highly inert to titanium in a high-temperature environment resulting in no chemical reaction between the two materials. Yttrium oxide also isolates the ceramic material from the titanium during the melting process to prevent reaction between them to ensure the smooth melting of the titanium-alloy. The third layer **11***c* of the crucible **10** is preferably composed of silicon dioxide and other materials. The silicon dioxide resists the metallic expansion and thermal stress during the melting process to ensure strength of the crucible.

[0057] A preferred thickness of the first layer **11***a* is from 0.5 mm to 1.5 mm and the preferred thickness range of the crucible **10** is from 5 mm to 15 mm.

[0058] A method **800** for unit cell casting of titanium or titanium-alloys is shown in FIG. **8**. At block **801**, a pressure of an internal chamber is monitored utilizing a first vacuum gauge. At block **802**, a pressure of an external chamber is monitored utilizing a second vacuum gauge. At block **803**, the pressure of the internal chamber and the pressure of the external chamber are transmitted to a programmable logic controller (PLC). At block **804**, a mold is positioned within the internal chamber. At block **805**, an external chamber is evacuated to create an evacuated external chamber having a pressure no greater than 3×10^{-2} atmosphere, wherein a ceramic crucible containing a titanium alloy ingot is positioned therein. At block **806**, the internal chamber is evacuated to create an evacuated internal chamber having a pressure no greater than 3×10^{-2} atmosphere, wherein the external chamber and the internal chamber have an equal pressurization. At block **807**, the titanium alloy ingot is melted within the ceramic crucible utilizing induction heating generated by an induction coil positioned around the ceramic crucible. At block **808**, the completely melted titanium alloy material is transferred into the mold from the crucible using a pressure equalization between the external chamber and the internal chamber. A pressure equalization is maintained between the external chamber and the internal chamber during the melting of the titanium alloy ingot. The pressure of the internal chamber and the pressure of the external chamber are monitored and communicated to the PLC during the casting process, and wherein the PLC controls the casting process based on the pressure of the internal chamber and the pressure of the external chamber.

[0059] A method **900** for unit cell casting of titanium or titanium-alloys is shown in FIG. **9**. At block **901**, a pressure of an internal chamber is monitored utilizing a first vacuum gauge. At block **902**, a pressure of an external chamber is monitored utilizing a second vacuum gauge. At block **903**, the pressure of the internal chamber and the pressure of the external chamber are transmitted to a programmable logic controller (PLC). At block **904**, a mold is positioned within the internal chamber. At block **905**, an external chamber is evacuated to create an evacuated external chamber having a pressure no greater than 3×10^{-2} atmosphere, wherein a ceramic crucible containing a titanium alloy ingot is positioned therein. At block **906**, the internal chamber is evacuated to create an evacuated internal chamber having a pressure no greater than 3×10^{-2} atmosphere, wherein the external chamber and the internal chamber have an equal pressurization. At block **907**, the titanium alloy ingot is melted within the ceramic crucible utilizing induction heating generated by an induction coil positioned around the ceramic crucible. At block **908**, a pressurized gas is injected into the evacuated external chamber to create a pressurized external chamber with a pressure in excess of 1 atm, wherein the pressure differential between the external chamber and the internal chamber is maximized. At block **909**, the completely melted titanium alloy material is transferred into the mold from the crucible using a pressure equalization between the external chamber and the internal chamber. A high pressure differential in maintained between the external chamber and the internal chamber during the transfer of the melted titanium alloy material. The pressure of the internal chamber and the pressure of the external chamber are monitored and communicated to the PLC during the casting process, and wherein the PLC controls the casting process based on the pressure of the internal chamber and the pressure of the external chamber.

[0060] A method **1000** for unit cell casting of titanium or titanium-alloys is shown in FIG. **10**. At block **1001**, a mold is positioned within an internal chamber of a casting chamber. At block **1002**, an external chamber is evacuated to create an evacuated external chamber wherein a ceramic crucible containing a titanium alloy ingot is positioned therein. At block **1003**, the internal chamber is evacuated to create an evacuated internal chamber having a pressure no greater than 3×10^{-2} atmosphere. At block **1004**, the titanium alloy ingot is melted within the ceramic crucible utilizing induction heating generated by an induction coil positioned around the ceramic crucible, wherein the external chamber and the internal chamber are at an equal pressurization. At block **1005**, a pressurized gas is injected into the evacuated external chamber to create a pressurized external chamber with a pressure in excess of 1 atmosphere. At block **1006**, a high pressure differential is utilized between the external chamber and the internal chamber to flow the completely melted titanium alloy material into the mold from the crucible.

[0061] FIG. **11** illustrates a PLC **90**, an operator's computer **91** and an apparatus **5** for a system for unit cell titanium casting.

[0062] FIG. **12** illustrates a PLC **90**, an operator's computer **91** and an internal chamber with an optical pyrometer for a system for unit cell titanium casting. The optical pyrometer monitors the temperature of the internal chamber.

[0063] Those skilled in the pertinent art will recognize that materials other than titanium and titanium alloy may be cast in the unit cell casting system without departing from the scope and spirit of the present invention.

[0064] From the foregoing it is believed that those skilled in the pertinent art will recognize the meritorious advancement of this invention and will readily understand that while the present invention has been described in association with a preferred embodiment thereof, and other embodiments illustrated in the accompanying drawings, numerous changes, modifications and substitutions of equivalents may be made therein without departing from the spirit and scope of this invention which is intended to be unlimited by the foregoing except as may appear in the following appended claims. Therefore, the embodiments of the invention in which an exclusive property or privilege is claimed are defined in the following appended claims.

We claim as our invention the following:

1. A method for unit cell casting of titanium or titanium-alloys, the method comprising:

positioning a mold within an internal chamber;

evacuating an external chamber to create an evacuated external chamber wherein a ceramic crucible containing a titanium alloy ingot is positioned therein;

evacuating the internal chamber to create an evacuated internal chamber having a pressure no greater than 3×10^{-2} atmosphere;

injecting a pressurized gas into the evacuated external chamber to create a pressurized external chamber with a pressure in excess of 1 atm;

pre-heating the crucible to a temperature greater than 500° C.;

melting the titanium alloy ingot within the ceramic crucible utilizing induction heating generated by an induction coil;

transferring the completely melted titanium alloy material into the mold from the crucible using a pressure differential created between the external chamber and the internal chamber;

wherein a high pressure differential in maintained between the external chamber and the internal chamber during the transfer of the melted titanium alloy material;

wherein the PLC controls power to the induction coil to position the induction coil relative to the titanium alloy ingot;

wherein the pressure of the internal chamber and the pressure of the external chamber are monitored and communicated to the PLC during the casting process, and wherein the PLC controls the casting process based on the pressure of the internal chamber and the pressure of the external chamber;

wherein the preheating of the crucible results in faster heating and subsequent melting of the titanium alloy material thereby reducing the time necessary to evacuate the material from the crucible into the mold.

2. The method according to claim **1** wherein the pressurized gas is argon.

3. The method according to claim **1** wherein a frequency generated in the induction coil ranges from 1 kilo-Hertz to 50 kilo-Hertz.

4. The method according to claim **1** wherein an atmospheric pressure of the evacuated internal chamber ranges from 3×10^{-2} atmosphere to 9.87×10^{-7} atmosphere.

5. The method according to claim **1** wherein the crucible is a single Yttria-based barium infused shell layer having a thickness ranging from 0.015 inch to 0.060 inch, and comprised of a binder with a slurry ratio between 1:1.5 and 1:3.5.

6. The method according to claim **1** wherein a power level to the induction coil is more than 70 kiloWatts.

7. The method according to claim **1** wherein the titanium alloy ingot is centered within the ceramic crucible using a centering feature.

8. The method according to claim **7** wherein the centering feature is a plurality of stand-offs in a wall of the ceramic crucible.

9. The method according to claim **1** wherein an atmospheric pressure of the evacuated internal chamber ranges from 9.87×10^{-7} atmosphere to 9.87×10^{-13} atmosphere

10. A system method for unit cell casting of titanium or titanium-alloys, the system comprising:

an external chamber;

a ceramic crucible positioned within the external chamber;

an induction centered on the upper third of the titanium alloy ingot in the ceramic crucible;

an internal chamber positioned within the external chamber; and

a mold positioned within the internal chamber;

wherein the crucible is preheated to a temperature greater than 500° C.;

wherein the pressure of the internal chamber and the pressure of the external chamber are monitored and communicated to the PLC during the casting process, and wherein the PLC controls the casting process based on the pressure of the internal chamber and the pressure of the external chamber;

wherein the external chamber is evacuated to create an evacuated external chamber wherein the ceramic crucible contains a titanium alloy ingot positioned therein;

wherein a pressurized gas is injected into the evacuated external chamber to create a pressurized external chamber;

wherein the titanium alloy ingot is melted within the ceramic crucible utilizing induction heating generated by the induction coil;

wherein the crucible is composed of Silica and coated with a Yttria based slurry and stucco system;

wherein the internal chamber is evacuated to create an evacuated internal chamber;

wherein the titanium alloy material is completely transferred into the mold from the crucible using a maximum pressure differential created between the external chamber and the internal chamber.

11. A method for unit cell casting of titanium or titanium-alloys, the method comprising:

pre-heating a ceramic crucible to a temperature greater than 500° C.;

evacuating an external chamber to create an evacuated external chamber wherein the ceramic crucible contains a titanium alloy ingot is positioned therein;

evacuating the internal chamber to create an evacuated internal chamber having a pressure no greater than 3×10^{-2} atmosphere;

melting the titanium alloy ingot within the ceramic crucible utilizing induction heating generated by an induction coil wherein a position of the induction coil begins at a upper third of the titanium alloy ingot and during the melting of the titanium alloy ingot the position of the induction coil is lowered relative to the titanium alloy ingot to terminate at a bottom of the titanium alloy ingot;

injecting a pressurized gas into the evacuated external chamber to create a pressurized external chamber with a pressure in excess of 1 atmosphere, wherein the pressure differential is at a maximum; and

utilizing a high pressure differential between the external chamber and the internal chamber to flow the completely melted titanium alloy material into the mold from the crucible.

12. The method according to claim **11** wherein the pressurized gas is argon.

13. The method according to claim **11** wherein a frequency generated in the induction coil ranges from 1 kilo-Hertz to 50 kilo-Hertz.

14. The method according to claim **11** wherein an atmospheric pressure of the evacuated internal chamber ranges from 3×10^{-2} atmosphere to 9.87×10^{-7} atmosphere.

15. The method according to claim **11** wherein the titanium alloy ingot is centered within the ceramic crucible using a centering feature.

16. The method according to claim **11** wherein the internal chamber is preheated at a temperature ranging from 1150° C. to 1250° C.

17. The method according to claim **11** wherein a PLC determines when to melt the titanium alloy based on the pressures of the internal chamber and the external chamber.

18. The method according to claim **11** wherein the PLC determines when to change the pressure of internal chamber and the external chamber.

19. The method according to claim **11** wherein an atmospheric pressure of the evacuated internal chamber ranges from 9.87×10^{-7} atmosphere to 9.87×10^{-13} atmosphere

20. The method according to claim **15** wherein the centering feature is a plurality of stand-offs in a wall of the ceramic crucible.

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