

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
28 May 2009 (28.05.2009)

PCT

(10) International Publication Number
WO 2009/067512 A1

(51) International Patent Classification:
C22C 19/05 (2006.01)

(21) International Application Number:
PCT/US2008/084034

(22) International Filing Date:
19 November 2008 (19.11.2008)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/989,321 20 November 2007 (20.11.2007) US
60/989,330 20 November 2007 (20.11.2007) US

(71) Applicant (for all designated States except US): **BUHLERPRINCE, INC.** [US/US]; 670 Windcrest Drive, Holland, Michigan 49423 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **YURKO, James A.** [US/US]; 3040 Jamesway Avenue, Holland, Michigan 49424 (US). **MCINERNEY, Robert J.** [US/US]; 634 Sleepy Hollow Lane, Holland, Michigan 49423 (US). **BROWER, Rodger W.** [US/US]; 7415 Warner Street,

Allendale, Michigan 49401 (US). **KOZACHIK, David** [US/US]; 6266 Walton Heath Drive, Hudsonville, Michigan 49426 (US).

(74) Agent: **DOLCE, Marcus P.**; Price, Heneveld, Cooper, DeWitt & Litton, LLP, 695 Kenmoor, S.E., P.O. Box 2567, Grand Rapids, Michigan 49501-2567 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL,

[Continued on next page]

(54) Title: VACUUM DIE CASTING MACHINE AND PROCESS

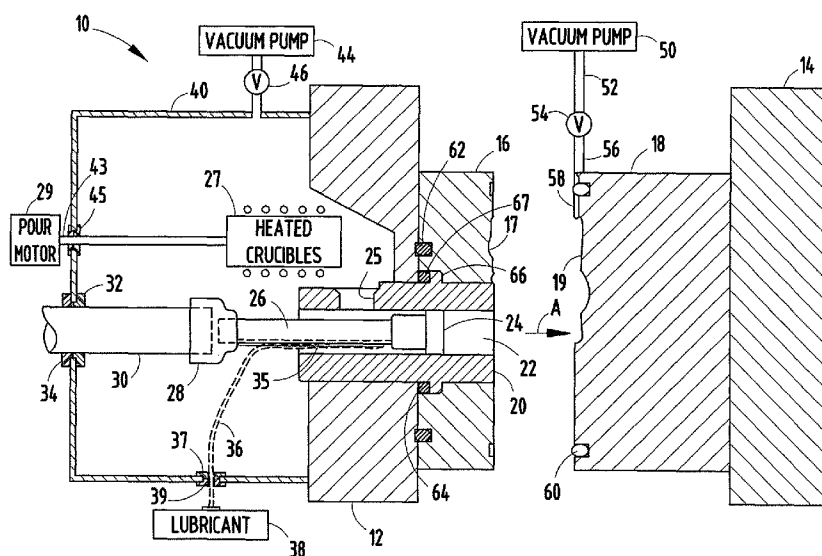


FIG. 1

(57) Abstract: A vacuum die and process for casting alloys includes a cold chamber having a bore and molten alloy inlet. A vacuum chamber encloses the cold chamber to provide a vacuum at the inlet. A plunger rod has a plunger tip which seals the bore and moves for forcing molten metal into a die cavity. The plunger tip in one embodiment has a first section facing the die cavity for sealing to the bore and a second reduced diameter section remote from the die cavity. In other embodiments, the plunger tip includes a sealing ring, the sections are reversed, or an inert gas floods the tip area. A vacuum source is coupled to the die cavity and is selectively coupled to the vacuum chamber through the molten alloy inlet of the cold chamber when the plunger tip moves to a side of the inlet remote from the die.

WO 2009/067512 A1



NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG,
CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

— *as to the applicant's entitlement to claim the priority of the
earlier application (Rule 4.17(iii))*

Declarations under Rule 4.17:

— *as to applicant's entitlement to apply for and be granted a
patent (Rule 4.17(ii))*

Published:

— *with international search report*
— *with amended claims*

VACUUM DIE CASTING MACHINE AND PROCESS**CROSS-REFERENCE TO RELATED APPLICATIONS**

[0001] This application claims priority under 35 U.S.C. § 119(e) on U.S. Provisional Application Nos. 60/989,321 entitled **VACUUM DIE FOR CASTING BULK METALLIC GLASS ALLOYS**, filed on November 20, 2007, and 60/989,330 entitled **VACUUM DIE CASTING PROCESS AND MACHINE FOR CASTING BULK METALLIC GLASS ALLOYS**, filed on November 20, 2007, the entire disclosures of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

[0002] The present invention relates to a die casting machine and process particularly used in vacuum casting metal alloys.

[0003] Recent advances in materials technology has led to the development of metallic glass alloys that are formed with the die casting process. These alloys have significant mechanical properties that make them advantageous for a number of applications because of their high strength, hardness, cosmetic appearance, and ability to fill very thin part geometries. Certain metallic glass alloys must be melted and cast under vacuum conditions to avoid oxidation of the alloy which prevents formation of the necessary glassy microstructure.

[0004] Also other aluminum and magnesium die casting processes utilize a vacuum to evacuate air from the mold prior to the filling of the die cavity. Typically the injection end (shot-end) of the die casting machine is at atmospheric pressure. After the molten metal enters the shot sleeve through the pour hole, the plunger tip advances to a position where the pour hole is closed, thus sealing the die from atmosphere and vacuum evacuation begins. The plunger continues to advance and evacuation proceeds for a short duration until the plunger position corresponds to the advancement of the metal flow front into the die cavity. The duration between the plunger tip closing the pour hole and the plunger tip advancing the metal into the mold is typically less than 1 – 2 seconds.

[0005] In such a system a series of vacuum runners are coupled to the die cavity and to a vacuum source. Initially, each cavity is at atmosphere, but after a control vacuum valve is actuated, each cavity's pressure is reduced. The vacuum runners are connected to a

location in the part cavity that typically corresponds to the final place to fill in the cavity, often opposite the side from the gate. Each cavity is connected to a vacuum runner, to maintain the cavity pressures at the same level. The use of vacuum with multiple cavities is challenging because of the need for multiple vacuum runners, which increases tooling costs, limits die design, and requires more metal to be cast each cycle.

[0006] Some metal alloys including bulk metallic glasses require melting and holding of the alloy in a molten state within a vacuum. This requires the die casting machine injection-end to be enclosed within a vacuum chamber, as well as the die. U.S. Patents 6,021,840 and 6,070,643 both of which are incorporated herein by reference, disclose die casting machines and processes for casting a bulk metallic glass. In their operation, each cycle, after the die closes, a vacuum pump evacuates both the vacuum chamber and the die. In this vacuum die casting process, the die is evacuated through the pour hole of the cold chamber (shot sleeve), thus, the die must be sealed to prevent leaking. O-rings are added to the parting line of the die, the cover die/platen interface, as well as sealing of the ejector pins or bumper pins.

[0007] There are several disadvantages to this process. Each cycle, the melting process cannot begin until the die is closed and evacuated, drastically increasing cycle time. All metal that is melted must be cast in one single cycle. If the crucible is also made of reactive material that oxidizes, the mold and chamber cannot be vented to atmosphere until the crucible has cooled to a non-oxidizing temperature. The addition of an additional vacuum chamber for melting the metal such that the metal only enters the main vacuum chamber through a gate valve for pouring into the shot sleeve has been employed. This process eliminates the cycle-time challenges of waiting for the metal to melt or the crucible to cool. It is still necessary that the main chamber must be evacuated each cycle, requiring significant energy usage and a large vacuum pump. Vacuum gate valves that are large enough (> 100 mm diameter) for such a system are very expensive.

[0008] There remains a need for a vacuum die casting machine and process for casting alloys including bulk metallic glasses that decreases cycle time, minimizes vacuum pumping time and capacity, and decreases manufacturing cost relative to previous casting techniques. Unlike the previously mentioned process, the die must prevent

leaking of air into the vacuum chamber of the die casting machine, which is continuously at vacuum.

SUMMARY OF THE INVENTION

[0009] The machine and process of the present invention satisfy these goals by providing a uniquely sealed die chamber and shot plunger tip design and sequence of operation that allows the use of a single vacuum chamber which is coupled to the cold chamber and a vacuum runner which is coupled to the die and actuated immediately upon closing of the die. The resulting operation of the system is faster producing better results while the cost of the die casting machine is reduced.

[0010] A vacuum die for use in casting alloys, according to one aspect of the present invention, includes a cold chamber having an injection bore and a molten alloy inlet. A vacuum chamber sealably encloses the cold chamber to provide a vacuum at the inlet of the cold chamber. A plunger rod has a plunger tip which is movably positioned in the cold chamber bore for forcing molten metal into a die cavity. The plunger tip has a first section facing the die cavity and a second reduced diameter section remote from the die cavity. In other embodiments, the plunger tip includes a sealing ring, the sections are reversed, or an inert gas floods the tip area. A vacuum source is coupled to the die cavity and is selectively coupled to the vacuum chamber through the molten alloy inlet of the cold chamber when the plunger tip moves to a side of the inlet remote from the die.

[0011] The invention also includes a method of vacuum die casting a part in a die cavity between dies including the steps of sealably coupling a vacuum chamber to a fixed platen which includes a cold chamber with a bore and an inlet for a molten alloy. Subsequently, positioning a plunger tip in the bore between the inlet and the die cavity while drawing a vacuum on the die cavity while the dies are closed. Next, the plunger tip is moved to a side of the inlet distal from the die cavity and introducing molten alloy into the bore through said inlet. Finally, the plunger tip is advanced to fill the die cavity.

[0012] These and other features, objects and advantages of the present invention will become apparent upon reading the following description thereof together with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

- [0013] Fig. 1 is a schematic illustration of a die casting machine embodying the present invention;
- [0014] Fig. 2 is a greatly enlarged side elevational view of the plunger rod and tip employed in the machine shown in Fig. 1;
- [0015] Fig. 3 is a greatly enlarged view of the circled area III in Fig. 2;
- [0016] Fig. 4 is a right side elevational view of the assembly shown in Fig. 2;
- [0017] Fig. 5 is a front elevational view of the cold chamber;
- [0018] Fig. 6 is a right side elevational view of the cold chamber;
- [0019] Fig. 7 is a front elevational view of the face of one of the dies taken in the direction of arrow A in Fig. 1;
- [0020] Fig. 8 is a schematic view of the machine shown in a second position with the dies closed prior to the introduction of molten metal into the cold chamber;
- [0021] Fig. 9 is a schematic view of the machine shown with the plunger tip retracted to the left of the port in the cold chamber to allow a crucible to pour molten metal into the cold chamber;
- [0022] Fig. 10 is a schematic view of the machine shown with the plunger tip moving from left to right to inject molten material into the die space;
- [0023] Fig. 11 is a schematic view of the machine showing the plunger tip partially extended from the surface of the fixed die for ejecting parts therefrom while sealing the vacuum chamber from the atmospheric pressure of the open dies;
- [0024] Fig. 12 is a greatly enlarged side elevational view of an alternative embodiment of the plunger rod and tip which can be employed in the machine shown in Fig. 1;
- [0025] Fig. 13 is a greatly enlarged side elevational view of another alternative embodiment of the plunger rod and tip which can be employed in the machine shown in Fig. 1;
- [0026] Fig. 14 is a schematic illustration of a die casting machine of yet another embodiment of the present invention; and
- [0027] Fig. 15 is a front elevational view of an alternative embodiment of a cold chamber which can be employed in the machine of Fig. 1.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0028] Referring initially to Fig. 1, there is shown a die cast machine 10 embodying the present invention, which includes a fixed platen 12 and a movable platen 14 typically coupled to one another by tie bars and closing and clamping cylinders mounted on a base frame. The general construction of such die casting machines is well known and can generally be of a commercially available type, such as Model No. 225CCA from BuhlerPrince of Holland, Michigan. Published patent application 2003/0217829, the disclosure of which is incorporated herein by reference, shows another die casting machine with these universal components. Sealably mounted to the fixed platen 12 is a fixed or cover die 16 with a die cavity 17 formed therein. Coupled to the movable platen 14 is a movable or ejector die 18 with a corresponding mold cavity 19 which mates with cavity 17 when the dies are closed and molten metal alloy is injected into the die space to form multiple die cast articles. Coupled to the fixed platen and communicating with the die cavities 17 and 19 is a cold chamber 20 (also frequently referred to as the shot sleeve) having a cylindrical bore 22 which injects molten metal into die cavities 17 and 19 as described below. The cold chamber 20 receives a plunger tip 24 coupled to a plunger rod 26, in turn, coupled by means of a coupling 28 to a piston rod 30, which sealably extends through the walls of a vacuum chamber 40 by means of seals 32 and 34. Piston rod 30 is coupled to a shot cylinder piston for injecting the molten metal from cold chamber 20 into die cavities 17 and 19.

[0029] A vacuum chamber 40 encloses the opposite end of the cold chamber 20, which includes a pour hole 25 for receiving molten metal from one or more independently movable inductively heated crucibles represented by the schematic block 27. An external servo motor 29 is coupled by shaft 43 and seals 45 to the heated crucibles to fill the cold chamber during an initial part of a cycle of operation as described below. The crucibles are coupled by conventional gate valves and troughs for alternately receiving ingots, which are heated to a temperature, depending upon the particular alloy, to provide molten alloy for the continuous casting operation of machine 10. When a zirconium, copper, nickel, beryllium alloy forming a bulk metallic glass is employed as the molten material, the crucible temperature is approximately 2000°F. Other materials, such as stainless steel, aluminum, aluminum-titanium, etc., may have different crucible

temperatures for melting the alloy ingots as necessary. Also, other forms of material, such as pellets, powder, etc. may be used.

[0030] In addition to these basic components, the end of plunger rod 26 is lubricated during a portion of the stroke by means of a lubricating conduit 35 coupled by a flexible hose 36 to a source 38 of pressurized lubricant through seals 37 and 39 in vacuum chamber 40. A vacuum pump 50 is coupled to the die cavities 17 and 19 by a conduit 52, vacuum valve 54, and a conduit 56 leading to die cavities 17 and 19 through a runner 58. The dies 16 and 18 are sealably coupled by an O-ring seal 60 when closed to allow the vacuum to be drawn on the die space when valve 54 is opened. The fixed die 16 is sealably coupled to fixed platen 12 by a first O-ring seal 62 surrounding the cold chamber in radially spaced relationship thereto and a second O-ring seal 64, which engages the interface between fixed platen and die 16 by means of a collar 66, to compress O-ring 64 when the annular shoulder 67 of the cover die 16 is bolted to the fixed platen 12 in a conventional manner. Vacuum chamber 40 is evacuated by a vacuum pump 44 coupled to chamber 40 by valve 46 when the die is in a closed position and plunger tip 24 is retracted to the left (in Fig. 1) of pour hole 25, as described in greater detail below.

[0031] Machine 10 of the present invention maintains the vacuum chamber 40 at a vacuum throughout the casting process by utilization of a very close tolerance, specially configured plunger tip 24 to provide a seal between the vacuum chamber 40 when the die is opened, as illustrated in Fig. 1, and allow the vacuum pump 50, when valve 54 is opened and dies 16 and 18 are closed, to maintain the vacuum chamber at the desired reduced pressure of from about .1 to 50 TORR depending upon the material being molded. Cylindrical plunger tip 24 comprises a first or end section 21 having a diameter represented by dimension D (Fig. 2) and a length L, which is substantially 75% of the diameter D. Thus, $L = .75D$ in the preferred embodiment and the diameter has a tolerance with respect to the inner diameter of wall 22' in cold chamber 20 of approximately .0005 inches, which is significantly tighter than existing plunger tip tolerances. The effective sealing is also achieved by a reduced diameter second integral section 23 of tip 24 behind section 21 and coupled to plunger rod 26. The diameter of section 23, which is integrally machined with section 21 of plunger tip 24, is approximately .020 inches smaller than D. This allows the plunger tip to operate

effectively with the closer tolerances without galling the inner cylindrical surface of cold chamber 20 during operation. In one embodiment of the invention, the diameter D of the plunger tip was approximately 1-3/8 inches and the overall length was 4 inches with the first section 21 having a length L of 1 inch and section 23 having a length of approximately 3 inches for a 220 ton machine. The vacuum tank in such embodiment had dimensions of approximately 1-1/2 feet by 2 feet by 3 feet to enclose the crucibles at the end of the cold chamber and other components shown in Fig. 1.

[0032] Also, the circular edge 31 of the plunger tip section 21 is a knife edge and, as shown in Fig. 3, is at an angle α of precisely 90° around the circular edge 31. This sharp edge serves as a wiper for pushing the molten metal into the die cavities 17 and 19 during the injection process and also pushes externally solidified particles (esp) out of the bore 22 of the cold chamber without scoring the surface 22' of the cold chamber. This extremely tight tolerance of the diameters of section 21 of plunger tip 24 and bore 22 is effective in handling metallic glass alloys, which is somewhat thinner than other molten metals which may be employed. The knife edge 31 of plunger tip 24 and particularly the first section 21 of plunger tip 24 is important in handling the molten metal alloy, and particularly metallic glass alloys, while the tighter tolerance of the plunger tip facilitates the vacuum sealing of the chamber from the atmosphere when the dies are open. Cold chamber 20, shown in Figs. 5 and 6, includes a central cylindrical bore 22 having an inner cylindrical surface 22' which is machined to a dimension which provides the tolerance of about .0005 inches between the outer cylindrical surface 21' of plunger tip section 21 and the inner surface 22' of cold chamber bore 22.

[0033] In addition to the uniquely shaped plunger tip and its close tolerance configuration, the sealing and smooth operation of the plunger tip during the injection process is further facilitated by the injection of a lubricant from source 38 through flexible hose 36 and injection tube 35. Tube 35 fits within a trough 42 (Figs. 2 and 3) formed longitudinally along plunger rod 26 for receiving therein the tube 35 which is coupled to the source 38 of pressurized lubricant, as shown in Fig. 1. The lubrication employed typically will be a mineral-based oil or, in some instance, it can be a graphite lubricant. The lubricant injection system can be a commercially available type, such as a System 138 available from the Rimrock Corporation of Columbus, Ohio. The lubricant is injected, as noted in the sequence diagrams below, as the plunger tip starts to

retract from the fully extended position through fixed die 16. The wiping of the lubricant by the plunger tip first section 21 serves not only to prevent scoring or galling of the bore 22 (*i.e.*, the inner surface 22' of cold chamber 20) but, more importantly, enhances the seal between the vacuum chamber 40 and the now opened die space, as seen in Fig. 1.

[0034] The unique sealing ability provided by the plunger tip configuration, as well as the lubrication method, allows the vacuum valve 54 (Fig. 1) to be actuated substantially immediately upon closure of the dies. This typically allows several seconds of evacuation and, therefore, no need to draw vacuum on each part cavity greatly simplifying the die configuration, as shown in Fig. 7. As seen in Fig. 7, which is the face of movable die 18, the vacuum runner 58 communicates through a T-shaped branch 59 with legs 61 and 63, which provide a pathway for the vacuum applied to the part cavities 19a-19d, in the example four-part mold seen in Fig. 7. Between the molds 19a, 19b and 19c, 19d is a runner 65 and the usual mold biscuit 69. Thus, instead of actuating the vacuum valve 54 only after the plunger tip has moved to close the pour hole 25, in the present invention, the vacuum can be applied to the dies substantially immediately upon closing and sealing of the two dies, thereby greatly decreasing the cycle time of operation of the machine 10.

[0035] With the present invention, the vacuum chamber 40 remains at a vacuum throughout the entire cycle of operation of the system as opposed to previous vacuum die casting systems in which the melting chamber must be evacuated during each casting cycle, which required a separate, relatively large vacuum chamber and valving to quickly reduce the pressure in the melting chamber. Vacuum chamber 40 of this system remains at a vacuum throughout a cycle of operation, which is now explained in connection with a description of Figs. 8-11. In these figures, details of the seals and other parts shown in Fig. 1 are eliminated for simplifying an explanation of the cycle of operation.

[0036] In Fig. 8, dies 16 and 18 are closed and valve 54 opened immediately to begin evacuating the die as the plunger moves in the direction to the left, as shown by arrow B in Fig. 8. The shot cylinder rod 30 continues to move the plunger rod 26 and plunger tip 24 to the left until it clears the pour hole 25 within the cold chamber as shown in the position of Fig. 9. At this time, one of the multiple heated crucibles is actuated by pour

motor 29 to pour the molten alloy (shown as element 70) into the bore 22 of cold chamber 20. The plunger rod 26 and plunger tip 24 are then advanced in the direction indicated by arrow C in Fig. 10 to inject the molten metal into the closed, now evacuated die space 17 and 19 (*i.e.*, die cavities 19a-19d) between dies 16 and 18, respectively. The molten metal flows through the biscuit area 69 and the runner 65 and into the parts cavities 19a-19d until the molten metal 70 substantially fills these cavities, as seen in Fig. 10. Suitable mechanism is provided to prevent the molten metal from entering the vacuum runner 58 in a conventional manner, such as by providing cooling of the die in this area so that the material solidifies or by controlling the injection time and pressure so that the die substantially fills without overflowing into vacuum outlet 58.

[0037] Upon solidification of the molten metal in the dies 16 and 18, the dies are opened and the plunger tip 24 advanced, as shown by arrow D in Fig. 11, to a position to eject any parts which remain in die 16 but remaining within the bore 22 of cold chamber 20, thereby sealing the vacuum chamber 40 as the dies are opened and the cast parts removed therefrom. The cycle is then repeated by retracting the plunger tip to the midpoint position shown in Fig. 1 and preparing the dies, if necessary, for the next shot while ingots enter through the vacuum valve and trough system to the previously empty crucible within the vacuum chamber 40. The controlling of the various cylinders for operation of the movable platen, lock-up cylinders, injection cylinders, as well as the vacuum valves 47 and 54 and motor 29, is controlled by an electro/pneumatic/hydraulic control system which can be of conventional design and of the type used in commercially available machines. The timing sequence can be shortened, however, with the improved process and machine of the present invention to provide shorter cycle times for die casting parts with the machine of the present invention.

[0038] Instead of configuring the plunger tip 24 as seen and described in connection with Fig. 2, other techniques to seal the plunger tip and cold chamber bore 22 could be employed as seen in Figs. 12-15. Examples of other sealing techniques include use of a sealing ring on the outer diameter of the plunger tip; utilizing a piston with two heads, one piston pushes the molten metal and the second piston serves as the sealing member, potentially with a sealing ring; bleeding of argon or some other inert gas around the plunger tip clearance from the die space to minimize oxygen contamination; or covering the shot sleeve opening the die space with a sealing member when the die is open.

[0039] Fig. 12 illustrates the first approach in which, instead of a very close tolerance provided in the embodiment shown in Figs. 2-4, one or more collapsible sealing rings 125, such as a typical split piston ring employed in internal combustion engines, are provided on the tip 121 of plunger 124 to provide a seal. Sealing rings 125 (one shown) fit within annular grooves formed in the outer surface 126 of plunger tip 121 in a conventional manner to provide a substantially airtight seal between the plunger 124 and bore 22 of the cold chamber, which is otherwise identical to the system shown in Fig. 1.

[0040] Fig. 13 is an alternative embodiment of a plunger 224 having a tip end 221, which does not have as tight a tolerance as a backup plunger head 223, both of which are integrally formed with a space 227 therebetween. The diameter of plunger section 223 is selected to backup and seal plunger tip 221 and has a configuration and tight tolerance similar to that of tip 21 in the preferred embodiment of the invention. In some embodiments, head 223 may also receive one or more split sealing rings, such as ring 125 shown in Fig. 12.

[0041] In yet another embodiment, as seen in Fig. 14, an inert gas supply 300, such as argon or other inert gas, is coupled to the fixed die through conduits 302, valve 303, and internal conduit 304 in die 16 which extends through conduit 306 in cold chamber 20 to provide an inert gas shield by flooding the area in front of plunger 24, *i.e.*, the bore 22 adjacent plunger 24. Only inert gas may pass beyond plunger 24 and into the vacuum chamber 40 through pour hole 25. This minimizes oxygen contamination of the molten metal in the heated crucibles, and plunger 24 need not have as close a tolerance as in the first embodiment.

[0042] Finally, as shown in Fig. 15, vacuum chamber 40 can be sealed from the open dies, as seen in Figs. 1 and 14, by the use of a sealing plate 400 coupled to an actuator cylinder 402 having a rod 404 which moves the sealing plate in a direction indicated by arrow D in Fig. 15 to engage an O-ring seal 406 around the mouth of pour hole 25 to seal the pour hole from the vacuum chamber 40 when the dies are in an open position, as illustrated in Fig. 1.

[0043] It will become apparent to those skilled in the art that these and various other modifications to the preferred embodiments of the invention as described herein can be made without departing from the spirit or scope of the invention as defined by the appended claims.

The invention claimed is:

1. A vacuum die casting machine for use in casting alloys comprising:
 - a fixed platen;
 - a fixed die including a molten alloy inlet, said fixed die sealably coupled to said fixed platen;
 - a movable die;
 - a seal between said fixed and movable dies for vacuum sealing said dies when in a closed position, said dies defining a die cavity for molding a part;
 - a cold chamber with a bore and molten alloy inlet communicating with said bore, said cold chamber communicating with said inlet of said fixed die and sealably coupled to said fixed platen;
 - a vacuum chamber sealably coupled to said fixed platen and enclosing said molten alloy inlet;
 - a plunger rod positioned in said cold chamber, said plunger rod including a plunger tip for forcing molten metal into said die cavity within said dies, said tip having a first section facing said fixed die and a second reduced diameter section remote from said fixed die; and
 - a vacuum source coupled to said dies and selectively coupled to said vacuum chamber through said molten alloy inlet of said cold chamber.
2. The machine as defined in claim 1 wherein said vacuum source communicates with said vacuum chamber through said inlet of said cold chamber when said dies are closed and said plunger tip is on a side of said inlet opposite said fixed die.
3. The machine as defined in claim 2 wherein said vacuum source includes a vacuum pump coupled to a mold cavity between said fixed and movable dies and a valve for selectively coupling said vacuum pump to said mold cavity.
4. The machine as defined in claim 1 wherein said molten alloy is a metallic glass alloy.

5. The machine as defined in claim 1 wherein said first section of said plunger tip has a diameter D and a length L and wherein L is about .75D.
6. The machine as defined in claim 5 wherein said second section of said plunger tip has a diameter of D less about .020 inches.
7. The machine as defined in claim 1 wherein said plunger tip has a circular edge facing said fixed die and wherein said edge is a sharp knife edge forming an angle α between the cylindrical side of said first section and the circular face of said first section of 90° .
8. A vacuum die for use in casting alloys comprising:
a cold chamber including a bore and a molten alloy inlet;
a vacuum chamber sealably enclosing said cold chamber to provide a vacuum at said inlet;
a plunger rod positioned in said cold chamber, said plunger rod including a plunger tip for forcing molten metal into a die cavity, said tip having a first section sealing said bore and facing said die cavity and a second reduced diameter section remote from said die cavity; and
a vacuum source coupled to said die cavity and selectively coupled to said vacuum chamber through said molten alloy inlet of said cold chamber.
9. The vacuum die as defined in claim 8 wherein said first section of said plunger tip has a diameter D and a length L and wherein L is about .75D.
10. The vacuum die as defined in claim 9 wherein said second section of said plunger tip has a diameter of D less about .020 inches.
11. The vacuum die as defined in claim 10 wherein said plunger tip has a circular edge facing said fixed die and wherein said edge is a sharp knife edge forming an angle α between the cylindrical side of said first section and the circular face of said first section of 90° .

12. The vacuum die as defined in claim 11 wherein said vacuum source includes a vacuum pump and a valve for selectively coupling said vacuum pump to said die cavity.

13. The vacuum die as defined in claim 12 wherein said die is used for molding articles of a metallic glass alloy.

14. A vacuum die for use in casting alloys comprising:

- a cold chamber including an injection bore and a molten alloy inlet communicating with said injection bore;

- a vacuum chamber sealably enclosing said cold chamber to provide a vacuum at said inlet;

- a plunger rod positioned in said bore of said cold chamber, said plunger rod including a plunger tip for forcing molten metal into a die cavity, said tip having at least one sealing ring circumscribing said tip to seal the plunger tip to said bore; and

- a vacuum source coupled to said die cavity and selectively coupled to said vacuum chamber through said molten alloy inlet of said cold chamber as said plunger tip moves within said bore.

15. A vacuum die for use in casting alloys comprising:

- a cold chamber including an injection bore and a molten alloy inlet communicating with said injection bore;

- a vacuum chamber sealably enclosing said cold chamber to provide a vacuum at said inlet;

- a plunger rod positioned in said bore of said cold chamber, said plunger rod including a plunger tip for forcing molten metal into a die cavity, said tip having first and second sections, wherein said first section faces said die cavity and said second section is remote from said die cavity and has a diameter greater than said first section to movably seal said second section to said bore; and

- a vacuum source coupled to said die cavity and selectively coupled to said vacuum chamber through said molten alloy inlet of said cold chamber as said plunger tip moves within said bore.

16. The vacuum die as defined in claim 15 wherein said second section of said plunger tip includes a sealing ring.

17. A vacuum die for use in casting alloys comprising:

a cold chamber including an injection bore and a molten alloy inlet communicating with said injection bore;

a vacuum chamber sealably enclosing said cold chamber to provide a vacuum at said inlet;

a plunger rod positioned in said bore of said cold chamber for forcing molten metal into a die cavity, said plunger rod including a plunger tip;

a source of inert gas communicating with an end of said bore adjacent said plunger tip; and

a vacuum source coupled to said die cavity and selectively coupled to said vacuum chamber through said molten alloy inlet of said cold chamber.

18. The vacuum die as defined in claim 17 wherein said source of inert gas provides argon to said bore.

19. A vacuum die for use in casting alloys comprising:

a cold chamber including an injection bore and a molten alloy inlet communicating with said injection bore;

a vacuum chamber sealably enclosing said cold chamber to provide a vacuum at said inlet;

a plunger rod positioned in said cold chamber, said plunger rod including a plunger tip for forcing molten metal into a die cavity;

a vacuum source coupled to said die cavity and selectively coupled to said vacuum chamber through said molten alloy inlet of said cold chamber; and

a sealing valve selectively sealably closing said inlet when the die is open and exposed to atmospheric pressure.

20. The vacuum die as defined in claim 19 wherein said valve is a sliding gate valve.

21. A method of vacuum die casting a part in a die cavity between dies comprising the steps of:

sealably coupling a vacuum chamber to a fixed platen which includes a cold chamber with a bore and an inlet for a molten alloy;

positioning a plunger tip in sealed relationship in said bore between the inlet and the die cavity;

drawing a vacuum on the die cavity while the dies are closed;

moving the plunger tip to a side of the inlet distal from the die cavity;

introducing molten alloy into the bore through the inlet; and

advancing said plunger tip to fill the die cavity.

22. The method as defined in claim 21 wherein said drawing step comprises providing a vacuum pump and valve for selectively drawing said vacuum on said die cavity.

23. The method as defined in claim 22 and further including closing the valve, sealing the vacuum chamber, and opening said die cavity to remove a molded article.

24. The method as defined in claim 23 wherein said sealing step comprises moving said plunger tip to a position between said die cavity and said inlet.

25. The method as defined in claim 24 wherein the introducing step comprises introducing a metallic glass alloy.

26. A method of vacuum die casting a part in a die cavity between dies comprising the steps of:

sealably coupling a vacuum chamber to a fixed platen which includes a cold chamber with a bore and an inlet for a molten alloy;

positioning a plunger tip in said bore between the inlet and the die cavity;

drawing a vacuum on the die cavity while the dies are closed;

moving the plunger tip to a side of the inlet distal from the die cavity;

introducing molten alloy into the bore through the inlet;
advancing said plunger tip to fill the die cavity; and
flooding the bore with an inert gas when the die cavity is open to the atmosphere.

27. The method as defined in claim 26 wherein said flooding step comprises providing argon gas to the bore.

28. A method of vacuum die casting a part in a die cavity between dies comprising the steps of:

sealably coupling a vacuum chamber to a fixed platen which includes a cold chamber with an inlet for a molten alloy;

positioning a plunger tip in said bore between the inlet and the die cavity;

sealing said plunger tip in said bore by at least one sealing ring on said plunger tip;

drawing a vacuum on the die cavity while the dies are closed;

moving the plunger tip to a side of the inlet distal from the die cavity;

introducing molten alloy into the bore through the inlet; and

advancing said plunger tip to fill the die cavity.

AMENDED CLAIMS**received by the International Bureau on 23 February 2009 (23.02.2009)**

1. A vacuum die casting machine for use in casting alloys comprising:
 - a fixed platen;
 - a fixed die including a molten alloy inlet, said fixed die sealably coupled to said fixed platen;
 - a movable die;
 - a seal between said fixed and movable dies for vacuum sealing said dies when in a closed position, said dies defining a die cavity for molding a part;
 - a cold chamber with a bore and molten alloy inlet communicating with said bore, said cold chamber communicating with said inlet of said fixed die and sealably coupled to said fixed platen;
 - a single vacuum chamber sealably coupled to said fixed platen and enclosing said molten alloy inlet;
 - a plunger rod positioned in said cold chamber, said plunger rod including a plunger tip for forcing molten metal into said die cavity within said dies, said tip having a first section facing said fixed die and sealably engaging said bore of said cold chamber and a second reduced diameter section remote from said fixed die; and
 - at least one vacuum source coupled to said dies and to said single vacuum chamber.
2. The machine as defined in claim 1 and further including a lubricant injector extending through said cold chamber to inject a lubricant near said tip of said plunger rod.
3. The machine as defined in claim 1 wherein said vacuum source includes a vacuum pump coupled to a mold cavity between said fixed and movable dies and a valve for selectively coupling said vacuum pump to said mold cavity.
4. The machine as defined in claim 1 wherein said molten alloy is a metallic glass alloy.

5. The machine as defined in claim 1 wherein said first section of said plunger tip has a diameter D and a length L and wherein L is about .75D.

6. The machine as defined in claim 5 wherein said second section of said plunger tip has a diameter of D less about .020 inches.

7. A vacuum die casting machine for use in casting alloys comprising:
a fixed platen;
a fixed die including a molten alloy inlet, said fixed die sealably coupled to said fixed platen;
a movable die;
a seal between said fixed and movable dies for vacuum sealing said dies when in a closed position, said dies defining a die cavity for molding a part;
a cold chamber with a bore and molten alloy inlet communicating with said bore, said cold chamber communicating with said inlet of said fixed die and sealably coupled to said fixed platen;
a single vacuum chamber sealably coupled to said fixed platen and enclosing said molten alloy inlet;
a plunger rod positioned in said cold chamber, said plunger rod including a plunger tip for forcing molten metal into said die cavity within said dies, said tip having a first section facing said fixed die and sealably engaging said bore of said cold chamber and a second reduced diameter section remote from said fixed die;
at least one vacuum source coupled to said dies and to said single vacuum chamber; and
wherein said plunger tip has a circular edge facing said fixed die and wherein said edge is a sharp knife edge forming an angle α between the cylindrical side of said first section and the circular face of said first section of 90° .

8. A vacuum die for use in casting alloys comprising:
a cold chamber including a bore and a molten alloy inlet;
a vacuum chamber sealably enclosing said cold chamber to provide a vacuum at said inlet;

a plunger rod positioned in said cold chamber, said plunger rod including a plunger tip for forcing molten metal into a die cavity, said tip having a first section sealing said bore and facing said die cavity and including a sealing ring for sealably engaging said bore of said cold chamber and a second reduced diameter section remote from said die cavity; and

a vacuum source coupled to said die cavity and selectively coupled to said vacuum chamber through said molten alloy inlet of said cold chamber.

9. The vacuum die as defined in claim 8 wherein said first section of said plunger tip has a diameter D and a length L and wherein L is about $.75D$.

10. The vacuum die as defined in claim 9 wherein said second section of said plunger tip has a diameter of D less about .020 inches.

11. A vacuum die casting machine for use in casting alloys comprising:

a fixed platen;

a fixed die including a molten alloy inlet, said fixed die sealably coupled to said fixed platen;

a movable die;

a seal between said fixed and movable dies for vacuum sealing said dies when in a closed position, said dies defining a die cavity for molding a part;

a cold chamber with a bore and molten alloy inlet communicating with said bore, said cold chamber communicating with said inlet of said fixed die and sealably coupled to said fixed platen;

a single vacuum chamber sealably coupled to said fixed platen and enclosing said molten alloy inlet;

a plunger rod positioned in said cold chamber, said plunger rod including a plunger tip for forcing molten metal into said die cavity within said dies, said tip having a first section facing said fixed die and sealably engaging said bore of said cold chamber and a second reduced diameter section remote from said fixed die;

at least one vacuum source coupled to said dies and to said single vacuum chamber; and

wherein said plunger tip has a circular edge facing said fixed die and wherein said edge is a sharp knife edge forming an angle α between the cylindrical side of said first section and the circular face of said first section of 90° .

12. The vacuum die as defined in claim 11 wherein said vacuum source includes a vacuum pump and a valve for selectively coupling said vacuum pump to said die cavity.

13. The vacuum die as defined in claim 12 wherein said die is used for molding articles of a metallic glass alloy.

14. A vacuum die for use in casting alloys comprising:

- a cold chamber including an injection bore and a molten alloy inlet communicating with said injection bore;

- a vacuum chamber sealably enclosing said cold chamber to provide a vacuum at said inlet;

- a plunger rod positioned in said bore of said cold chamber, said plunger rod including a plunger tip for forcing molten metal into a die cavity, said tip having at least one sealing ring circumscribing said tip to seal the plunger tip to said bore, said tip including a reduced diameter section on a side of said tip toward said plunger rod; and

- at least one vacuum source coupled to said die cavity and to said vacuum chamber.

15. A vacuum die for use in casting alloys comprising:

- a cold chamber including an injection bore and a molten alloy inlet communicating with said injection bore;

- a vacuum chamber sealably enclosing said cold chamber to provide a vacuum at said inlet;

- a plunger rod positioned in said bore of said cold chamber, said plunger rod including a plunger tip for forcing molten metal into a die cavity, said tip having integral first and second sections, wherein said first section faces said die cavity and said second section is remote from said die cavity and has a diameter greater than said first section to movably seal said second section to said bore; and

a vacuum source coupled to said die cavity and selectively coupled to said vacuum chamber through said molten alloy inlet of said cold chamber as said plunger tip moves within said bore.

16. The vacuum die as defined in claim 15 wherein said second section of said plunger tip includes a sealing ring.

17. A vacuum die for use in casting alloys comprising:

a cold chamber including an injection bore and a molten alloy inlet communicating with said injection bore;

a vacuum chamber sealably enclosing said cold chamber to provide a vacuum at said inlet;

a plunger rod positioned in said bore of said cold chamber for forcing molten metal into a die cavity, said plunger rod including a plunger tip;

a source of inert gas communicating with an end of said bore adjacent said plunger tip; and

a vacuum source coupled to said die cavity and selectively coupled to said vacuum chamber through said molten alloy inlet of said cold chamber.

18. The vacuum die as defined in claim 17 wherein said source of inert gas provides argon to said bore.

19. A vacuum die for use in casting alloys comprising:

a cold chamber including an injection bore and a molten alloy inlet communicating with said injection bore;

a single vacuum chamber sealably enclosing said cold chamber and a molten metal crucible to provide a vacuum at said inlet;

a plunger rod sealably positioned in said cold chamber for selectively sealing said vacuum chamber from a die cavity, said plunger rod forcing molten metal into a die cavity;

at least one vacuum source coupled to said die cavity and to said vacuum chamber; and

a sealing valve comprising a tip on said plunger rod for selectively sealably closing said inlet when the die is open and exposed to atmospheric pressure.

20. The vacuum die as defined in claim 19 wherein said plunger rod tip has a larger diameter end facing said die cavity to define said sealing valve.

21. A method of vacuum die casting a part in a die cavity between dies comprising the steps of:

sealably coupling a single vacuum chamber to a fixed platen which includes a melting crucible, a cold chamber with a bore, and an inlet for a molten alloy;

positioning a plunger tip in sealed relationship in said bore between the inlet and the die cavity;

drawing a vacuum on the die cavity while the dies are closed;

moving the plunger tip to a side of the inlet distal from the die cavity;

introducing molten alloy from a crucible into the bore through the inlet;

advancing said plunger tip to fill the die cavity; and

leaving the plunger tip in the advanced position to sealably separate the die cavity from the vacuum chamber when the die cavity is opened.

22. The method as defined in claim 21 wherein said drawing step comprises providing a vacuum pump and valve for selectively drawing said vacuum on said die cavity.

23. The method as defined in claim 22 and further including closing the valve, sealing the vacuum chamber, and opening said die cavity to remove a molded article.

24. The method as defined in claim 23 wherein said leaving step comprises moving said plunger tip to a position between said die cavity and said inlet.

25. The method as defined in claim 24 wherein the introducing step comprises introducing a metallic glass alloy.

26. A method of vacuum die casting a part in a die cavity between dies comprising the steps of:

sealably coupling a vacuum chamber to a fixed platen which includes a cold chamber with a bore and an inlet for a molten alloy;

positioning a plunger tip in sealed relationship in said bore between the inlet and the die cavity;

drawing a vacuum on the die cavity while the dies are closed;

moving the plunger tip to a side of the inlet distal from the die cavity;

introducing molten alloy into the bore through the inlet;

advancing said plunger tip to fill the die cavity; and

flooding the bore with an inert gas when the die cavity is open to the atmosphere.

27. The method as defined in claim 26 wherein said flooding step comprises providing argon gas to the bore.

28. A method of vacuum die casting a part in a die cavity between dies comprising the steps of:

sealably coupling a vacuum chamber to a fixed platen which includes a cold chamber with an inlet for a molten alloy;

positioning a plunger tip in sealed relationship in said bore between the inlet and the die cavity;

sealing said plunger tip in said bore by at least one sealing ring on said plunger tip;

drawing a vacuum on the die cavity while the dies are closed;

moving the plunger tip to a side of the inlet distal from the die cavity;

introducing molten alloy into the bore through the inlet; and

advancing said plunger tip to fill the die cavity.

1/6

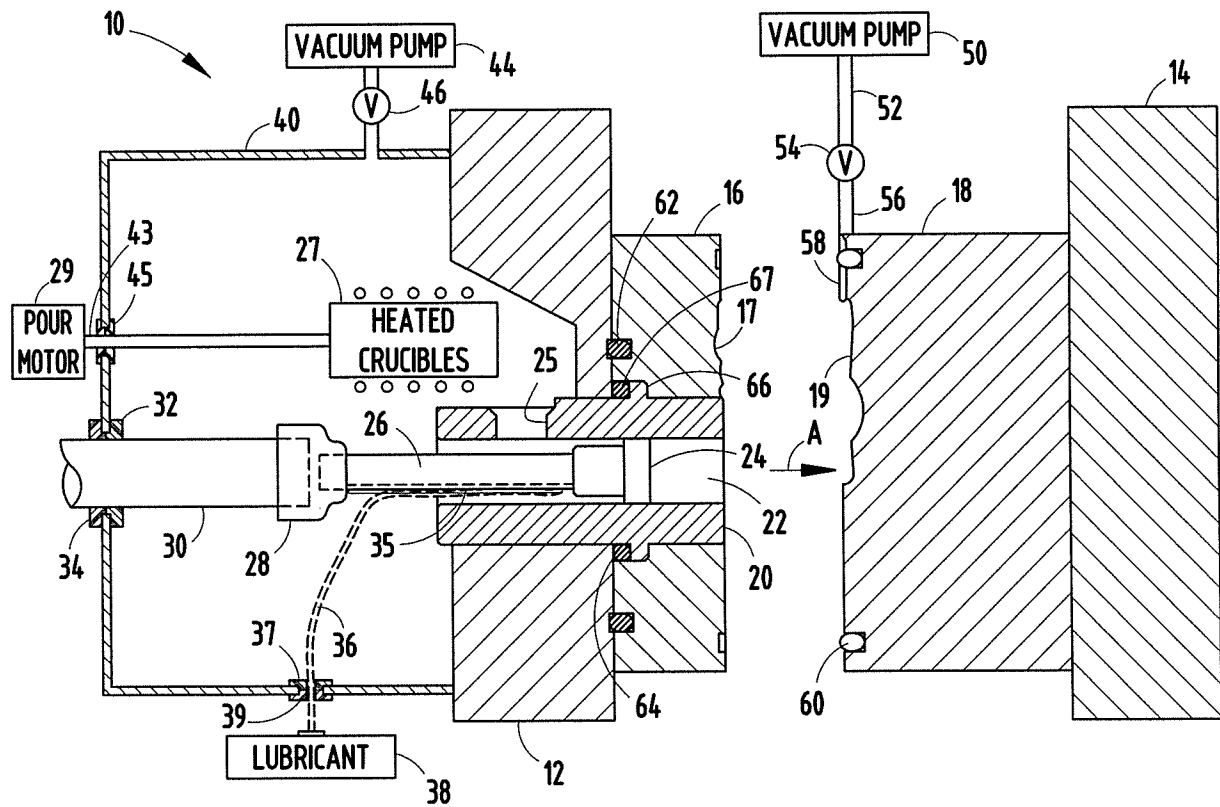


FIG. 1

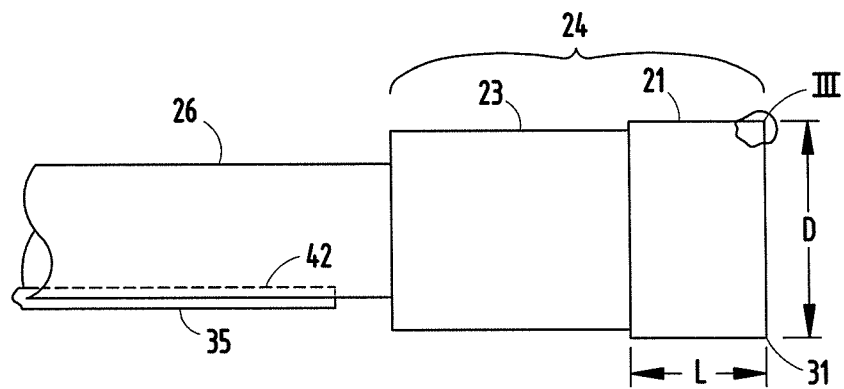


FIG. 2

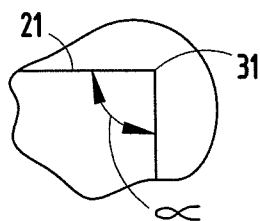


FIG. 3

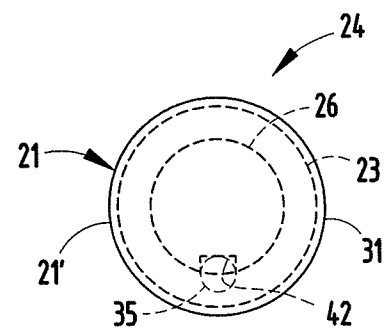


FIG. 4

2/6

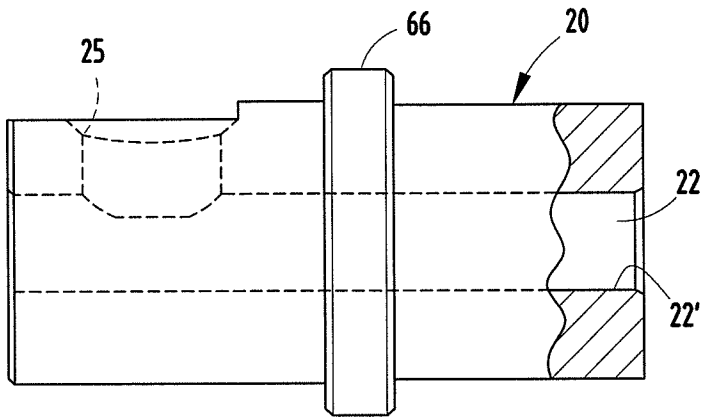


FIG. 5

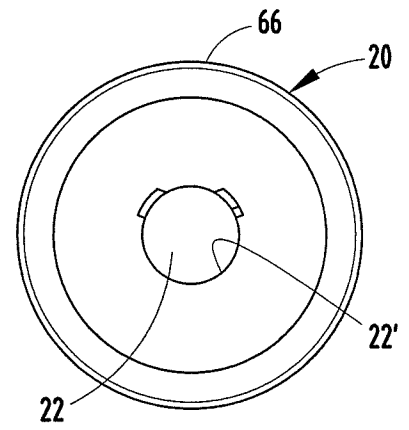


FIG. 6

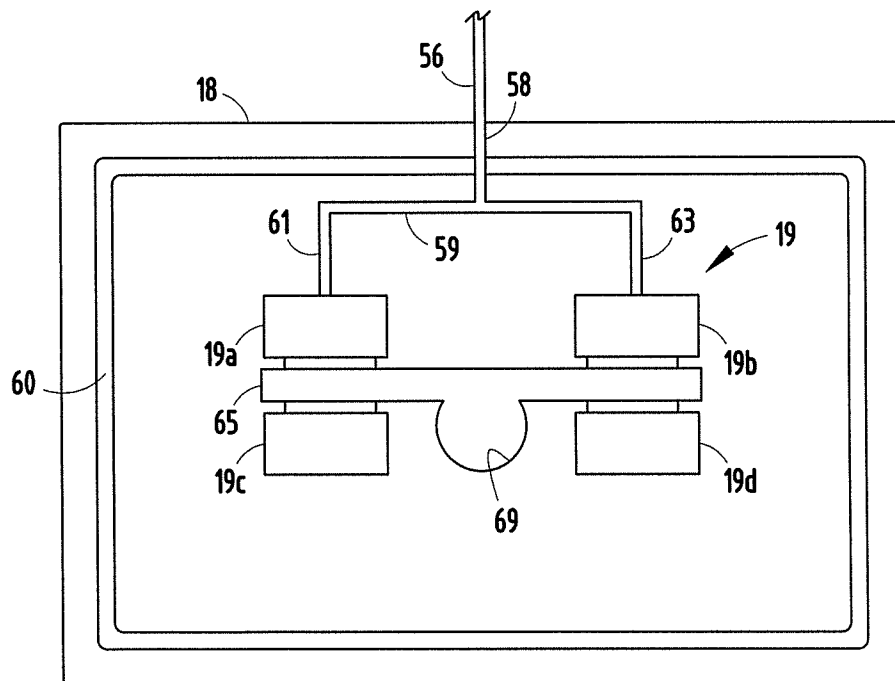
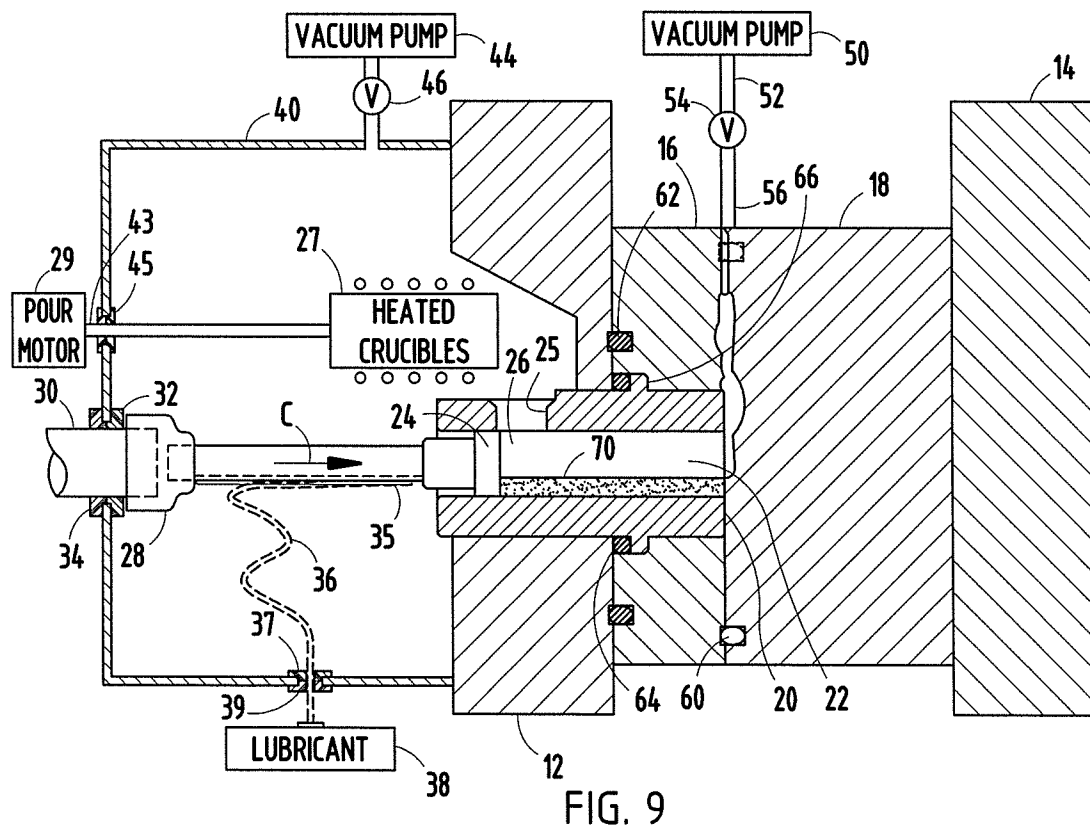
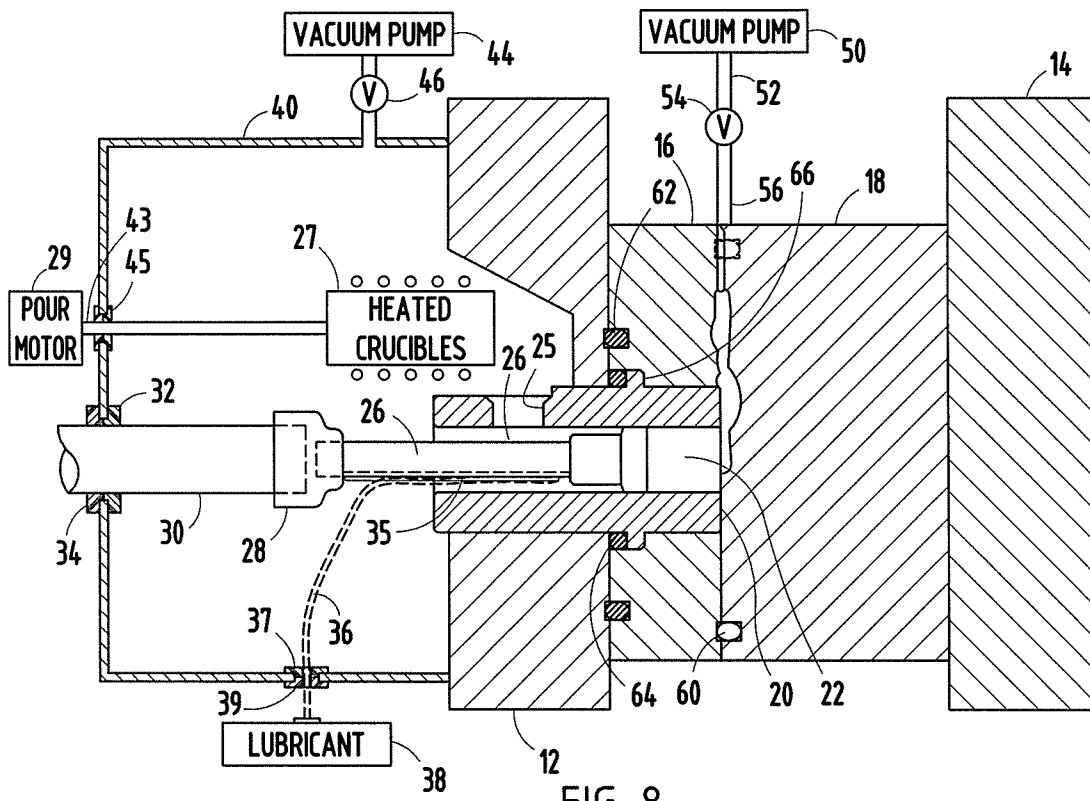
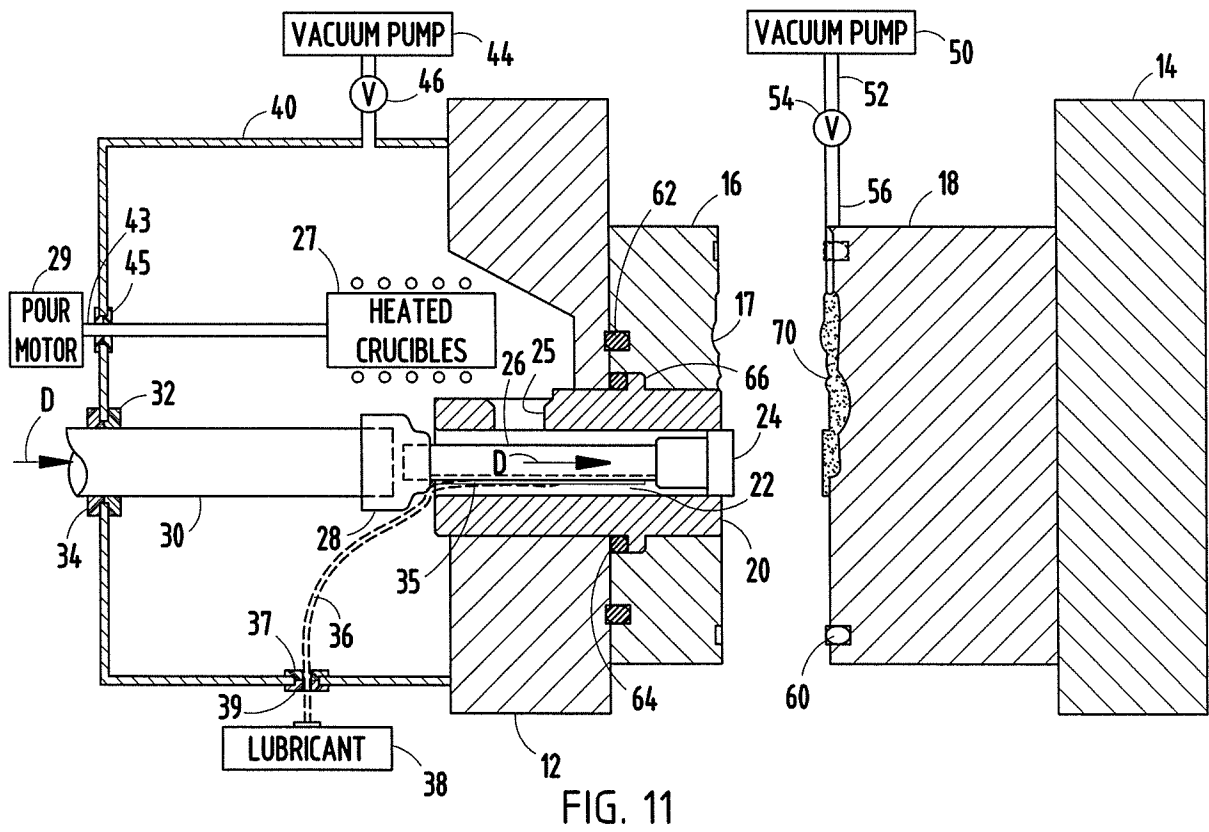
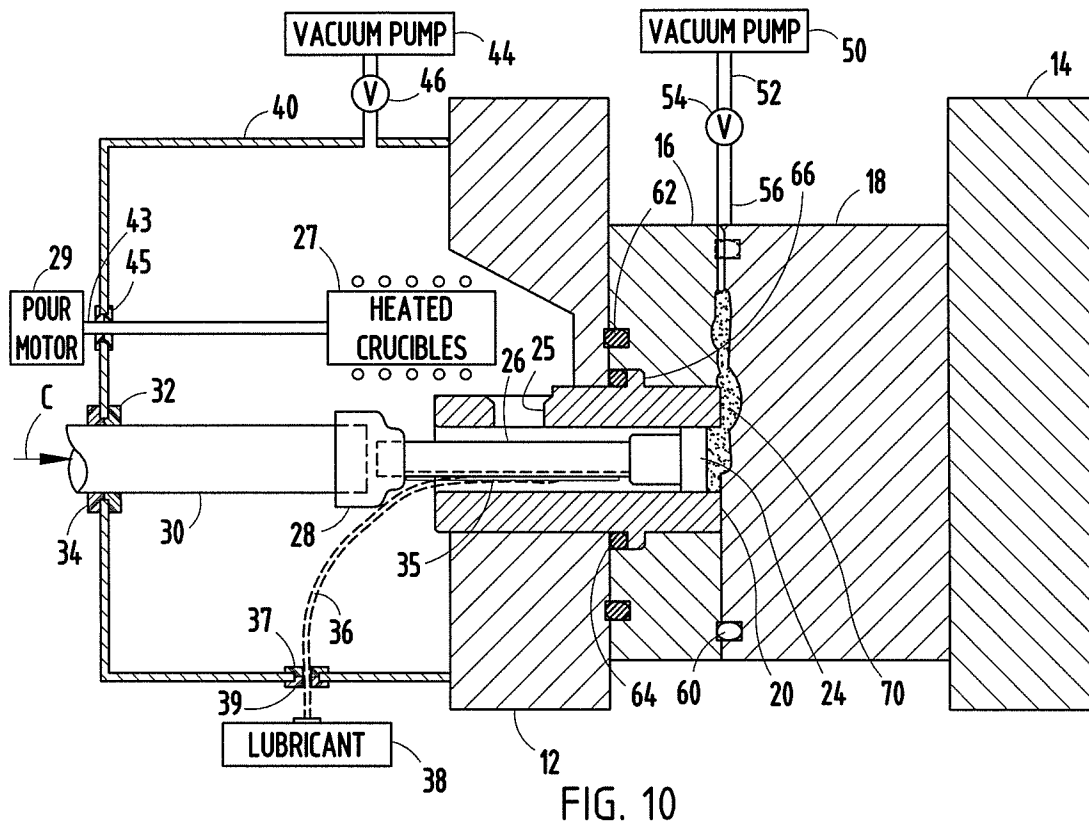


FIG. 7

3/6



4/6



5/6

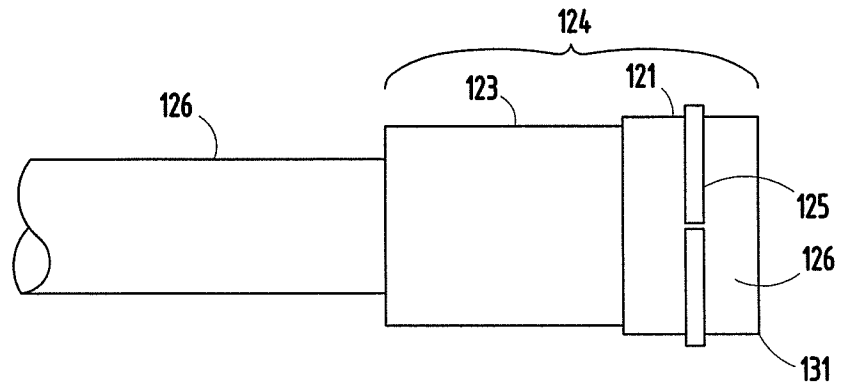


FIG. 12

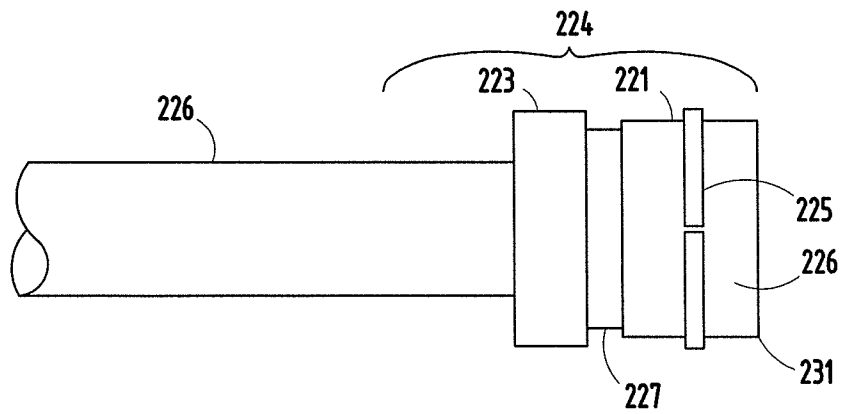


FIG. 13

6/6

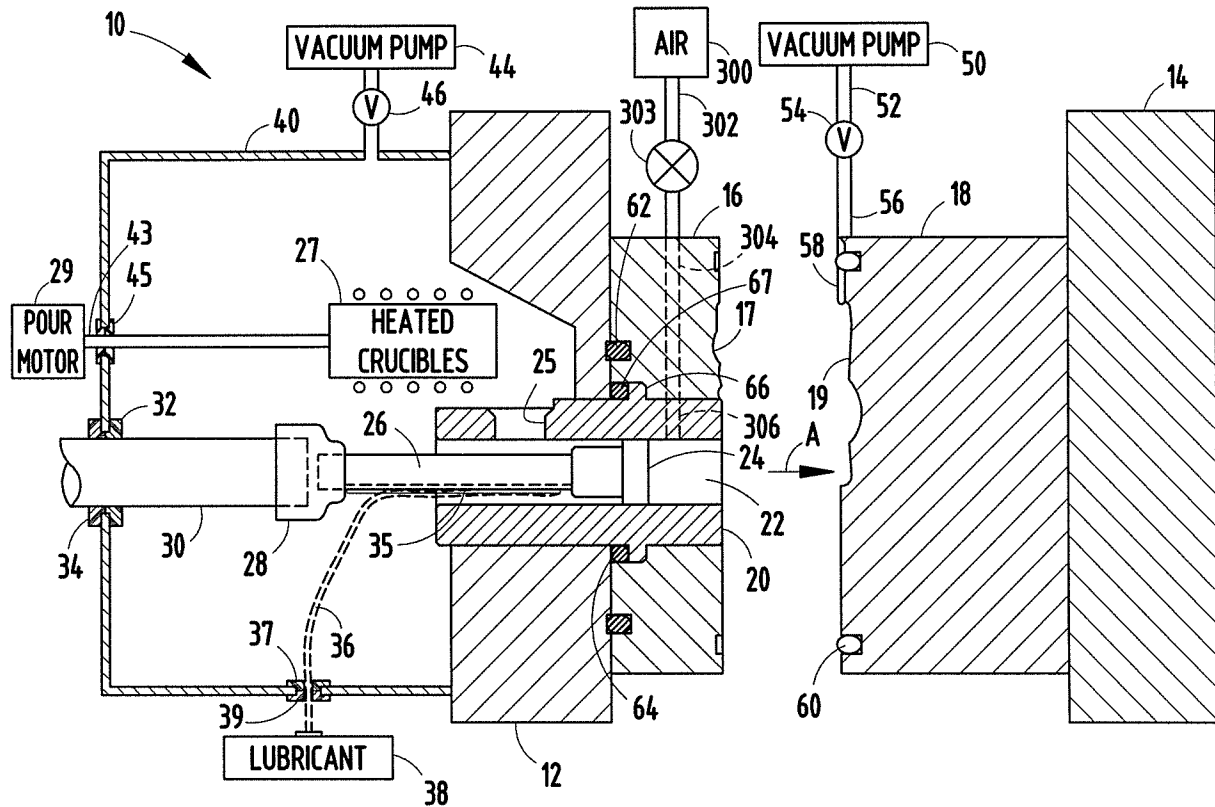


FIG. 14

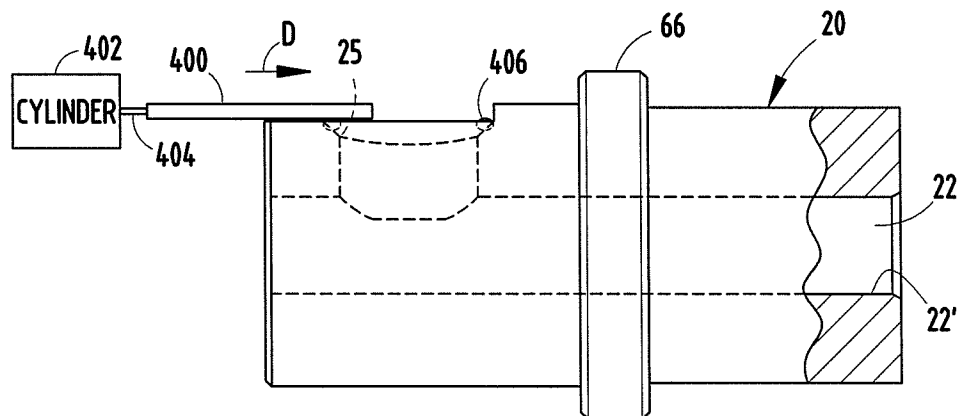


FIG. 15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2008/084034

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - C22C 19/05 (2009.01)

USPC - 148/428

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - C22C 10/05, 19/05 (2009.01)

USPC - 148/428; 164/154.8, 457

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

PubWEST(USPT,PGPB,EPAB,JPAB); Google Scholar

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X ----- Y	US 2002/0005233 A1 (SCHIRRA et al) 17 January 2002 (17.01.2002) entire document	19-21 ----- 1-6, 8-10, 14-18, 22-28
Y	US 4,899,804 A (HAMMERER) 13 February 1990 (13.02.1990) entire document	1-6, 8-10, 14-16, 28
Y	US 2006/0254747 A1 (ISHIDA et al) 16 November 2006 (16.11.2006) entire document	3, 4, 17, 18, 22-27
A	US 2008/0164002 A1 (YURKO et al) 10 July 2008 (10.07.2008) entire document	1-28

☐ Further documents are listed in the continuation of Box C.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T"

later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X"

document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y"

document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&"

document member of the same patent family

Date of the actual completion of the international search

02 January 2008

Date of mailing of the international search report

09 JAN 2009

Name and mailing address of the ISA/US

Mail Stop PCT, Attn: ISA/US, Commissioner for Patents

P.O. Box 1450, Alexandria, Virginia 22313-1450

Facsimile No. 571-273-3201

Authorized officer:

Blaine H. Copenhaver

PCT Helpdesk: 571-272-4300

PCT OSP: 571-272-7774