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(54) Investment casting method and apparatus.

(57) A modified investment casting process is effective to more safely and efficiently produce cast articles. The casting process utilizes a solid, rigid riser tube, in place of a wax tree, upon which heat disposable, positive models of an article to be cast are joined. This assembly is coated with a refractory and after drying of the refractory the heat disposable positive models are removed. Thereafter the ceramic shell is heated and fired and molten casting material is poured into the assembly. The molten casting material flows from the riser tube to fill the cavities formerly occupied by the positive models. Upon cooling and solidification of the casting material, the refractory is fractured and cast parts are removed.

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Background of the Invention

This invention relates to a metal casting process and to apparatuses utilized in such a process. More particularly, the invention relates to investment casting processes.

Various metal casting processes are well known. Investment casting (or lost wax casting) is commonly used to fabricate metal parts. This process requires several steps, the first of which is to fabricate a pattern that is used to form a master mold. The master mold is then used to form solid wax patterns that resemble the part to be manufactured. Typically, several wax patterns are joined together in a wax tree to enable the simultaneous manufacture of several parts. The wax tree is a solid wax tube that has side walls upon which a stem of the solid patterns are joined. Once all solid patterns are joined to the wax tree, the entire assembly is coated with one or more coats of a refractory. Afier drying, the assembly is heated and fired and the solid wax patterns and the wax tree are removed, yielding a shell. Molten metal is then poured into the shell so that it fills each of the cavities formerly occupied by the wax patterns and the wax tree. Upon drying, the refractory is fractured and removed and the metal parts are severed from the metal tree.

Investment casting is advantageous because it facilitates the manufacture of metal parts having complex shapes and accurate dimensions. This type of casting process is particularly useful in manufacturing orthopedic implants.

One of the drawbacks of the investment casting process, as it is currently practiced, is the use of the wax tree which has inherently low structural strength. As a result, the wax tree alone can not adequately support the solid patterns, and several relatively thick coats of refractory are normally required to provide additional structural support. In addition, the application of a greater number of refractory coats requires longer drying periods between coating applications. This in turn leads to significant time increases in the overall casting process.

Further, a wax tree having a relatively large diameter is often required to provide sufficient structural strength to support the solid patterns. Relatively large volumes of molten metal are thus used in each casting run to fill the molds and the space formerly occupied by the large diameter wax tree. This substantially increases the cost of the casting process, particularly when articles are to be cast using expensive metals or metal alloys.

The use of the wax tree also leads to additional processing delays and safety risks in post-casting procedures. The low structural strength of the wax tree necessitates the use of relatively large gates connecting the wax patterns to the wax tree. Following casting, the metal within the gates solidifies and it is generally of such diameter that the cast part cannot be easily separated from the stem. Rather, the part must be cut from the stem using a specialized cutting process. This cutting step obviously requires a significant amount of post-processing time and poses a safety risk to the individuals using the cutting equipment.

There is thus a need for an improved investment casting process that can combine the traditional advantages of investment casting while eliminating some of its disadvantages. Such an improved process would be particularly applicable to the casting of expensive metals and metal alloys such as those used to manufacture orthopedic implants.

Accordingly, an object of the invention is to provide an improved investment casting process that is more cost effective and that requires less time for the production of metal components. It is also an object of the invention to facilitate the production of metal parts in a more cost effective manner. A further object of the invention is to provide an investment casting process that is well suited to the manufacture of orthopedic implants. It is another object of the invention to provide apparatuses that can improve the efficiency and effectiveness of investment casting processes. These and other objects will be apparent from the description that follows.

Summary of the Invention

The present invention relates to an improved investment casting process that enables the production of cast parts with more economical use of metal and with fewer post-casting procedures.

In one embodiment the invention comprises an investment casting process that eliminates the need to use the traditional wax tree. The casting process of the present invention utilizes a hollow, structurally sound riser tube having one or more orifices extending through the wall of the riser tube. The riser tube is typically made from a ceramic material that is able to withstand the temperatures encountered during casting processes.

According to the process of the invention, one or more heat disposable solid patterns of an article to be cast are mounted to the riser tube. The solid patterns are mounted by adhering at least one gate on each solid pattern to a matching orifice on the riser tube to yield a cluster. A refractory is then applied to the cluster in one or more coats to form an investment assembly. The refractory can be applied by a variety of known techniques, including dipping and spraying.

Once the investment assembly is formed, the solid patterns are removed by heating the investment assembly to a temperature sufficient to melt or otherwise destroy of the solid, heat disposable material that forms the solid patterns. In some embodiments, the molten heat disposable material is allowed to flow out of the investment assembly. In other instances the heat disposable material is destroyed by flash firing. Afier melting or destroying the heat disposable material there remains a shell having one or more cavities that represent negatives of the part to be cast. The shell is then filled with a molten casting material, such as a metal or metal alloy, that is poured through the riser tube. The molten casting material fills the cavities in the shell and, after cooling, forms the desired cast articles.

The present invention also provides a novel investment assembly useful in practicing the method of the invention. The investment assembly comprises a hollow, structurally sound, elongate riser tube, heat disposable patterns mounted by their gates to orifices in the side wall of the riser tube, and a refractory that fully coats the riser tube and the adhered patterns. The riser tube preferably is made of ceramic, and can be of any suitable cross sectional shape. In one preferred embodiment the riser tube has a circular cross section.

Brief Description of Drawings

For a fuller understanding of the nature and objects of the invention, reference should be made to the following detailed description and the accompanying drawings, in which:

FIGURES 1A - 1J show successive stages in the casting process in accordance with features of the invention;

FIGURE 2 is a perspective view illustrating the formation of a cluster by attaching heat disposable patterns to a riser tube; and

FIGURE 3 is a perspective view, partly cut away, of an investment assembly.

Detailed Description of the Invention

Referring to Figures 1 through 3, wherein like reference numerals refer to like parts, there is illustrated an investment assembly and successive stages in the casting process in accordance with the features of the invention.

Figures 1A through 1J illustrate sequential steps of a process according to the invention for casting desired articles **62**.

Figure 1A shows a hollow riser tube **10** having one or more orifices **12**. At least one heat disposable solid pattern **14** is mounted to the riser tube **10** by attaching at least one gate **16** of the pattern to a corresponding orifice on the riser tube. The attachment of patterns to the riser tube forms a cluster assembly **18**. Each gate **16** can be secured to the riser tube by inserting it into the orifice **12** where it is held in place by friction between the orifice and stem. More preferably, however, the gate is secured to the orifice by heating the stem until it reaches a molten state and then allowing the gate to solidify and bond to the orifice. It is understood that each pattern may have more than one gate that is used to join the pattern to the riser tube.

Preferably, riser tube **10** has one closed end **22**. In one embodiment, shown in Figure 1B, a plug **20** can be used to close end **22** of the riser tube.

The refractory can be applied to the cluster assembly **18** by a number of known techniques. Figures 1C and 1D illustrate alternative methods of applying a refractory binder material to the cluster assembly **18**. In both methods, the refractory preferably is applied in layers that fully coat the cluster assembly **18**, with drying cycles provided between each application of refractory. As understood by those having ordinary skill in the art, primary layers are typically applied before the application of one or more backup layers of refractory. Primary coats of refractory tend to be finer as they must accurately adhere to the contours of the solid patterns **14**. Backup coats of refractory tend to be more coarse as they are primarily intended to impart structural strength. The application of refractory to the cluster assembly **18** forms an investment assembly **30**.

In the binder application process illustrated in Figure 1C, a dipping apparatus **32** holds cluster **18** over vessel **34** that contains a refractory **36** used in forming primary layers of refractory. The dipping apparatus lowers cluster assembly **18** into vessel **34** until the entire cluster assembly is submerged and fully coated with refractory **36**. The apparatus **34** lifts the cluster from the vessel after the coating process is complete and the applied refractory is allowed to dry and form a primary layer **38**. These steps are repeated until a desired number of primary layers of a desired thickness form on the cluster assembly. A similar apparatus and process can be used to apply backup refractory layers to the cluster.

Figure 1D illustrates an alternative method by which a refractory can be sprayed upon cluster assembly **18** to fully coat the cluster assembly. After spraying, the refractory is allowed to dry and form primary refractory layer **38**. Spray applications can be repeated until the desired number of layers and/or the desired thickness of refractory primary coat forms on the cluster assembly. The cluster assembly can then be sprayed with a refractory backup coat and allowed to dry to form backup layer **40**. These steps can be repeated until the backup layers are present at a desired number of layers and/or at a desired thickness.

Figure 1E illustrates an investment assembly **30** in which a dry refractory **38**, **40** fully coats the riser tube **10** and joined patterns **14**.

After forming the investment assembly **30**, the heat disposable matter **42**, which forms patterns **14**, can be extracted by a number of known techniques. Figure 1F illustrates the extraction of heat disposable matter **42** by placing the investment assembly **30** in a heated, pressurizable chamber or oven **44**. According to known techniques, heat and/or pressure are applied to such a degree that the heat disposable matter **42** forming the solid patterns **14** and the stems **16** melts and flows out of the investment assembly **30**. One preferred embodiment utilizes a steam autoclave, at a temperature in a range of about 315°F to 340°F and at a pressure of about 100 to 150 psi, to extract the heat disposable matter. In some embodiments solid patterns are made from higher melting polymeric materials that are destroyed by flash firing at temperatures sufficient to rapidly vaporize the solid pattern. In one embodiment, flash firing is conducted at temperatures of about 1900°F.

Removal or destruction of the heat disposable matter from investment assembly **30** yields a shell **46** having cavities **48** formerly occupied by the heat disposable patterns. The cavities **48** form the negative image of the desired articles to be manufactured.

Shell **46** can be heated and fired, as illustrated in Figure 1G, to impart increased strength to the shell and to remove any residual heat disposable matter. The shell **46** preferably is fired at a temperature typically in the range of about 1,400°F to 2,000°F for approximately one-half hour or more. The shell **46** is then ready to accept molten casting material **50**, which is poured into shell **46**, as illustrated in Figure 1H, to form solid, cast articles. Preferably, molten casting material **50**, such as a metal or metal alloy, is poured from a container **52** into the shell through opening **22** in riser tube **10**. The metal fills the riser tube **10** and passes through orifices **12** and gates **16** to fill cavities **48**. Once the cavities are filled, the molten metal is allowed to cool and solidify. Thereafter, the refractory shell **46** is fractured and removed, as illustrated in Figure 1I, leaving behind riser tube **10** with gates **60** extending from orifices **12** and the desired solid, cast articles **62** attached to the end of the gates opposite the orifices. As illustrated in Figure 1J, the cast articles **62** can be removed from the gates **60** simply by manually fracturing the stems.

Figure 2 illustrates an exemplary riser tube **10**, elongated along a vertical axis **11**, that is useful with the casting process of the invention. The riser tube **10** is hollow and has an outer wall **13** that defines an interior space **15**. One end of the riser tube, preferably top end **23**, remains open to allow communication of molten metal to the riser tube's interior space **15**. The other end **22** remains closed. The riser tube **10** contains one or more orifices **12** that extend through the wall **13** to which heat disposable solid patterns **14** are secured. Riser tube **10** can have a variety of suitable cross sectional shapes, including circular, ovoid, triangular, and square.

Figure 3 illustrates an investment assembly **30** having a ceramic riser tube **10**, heat disposable patterns **14** joined to orifices **12** by gates **16**, and refractory binder material **38**, **40**.

The riser tube is manufactured from virtually any inert, solid, rigid material that is able to withstand contact with molten metal and temperatures in excess of about 3200°F. Suitable materials include high purity alumina, magnesium oxide, ceramic refractory, and silica.

The dimensions of riser tube **10** depend upon the identify of articles to be cast and the number of articles to be formed in a single casting operation. The inner diameter or dimensions of riser tube **10** need only be large enough to accommodate the flow of molten material during a casting process. These dimensions can be as small as 0.0625 inch or less. Generally, the range of the inner dimensions (e.g., diameter) of riser tube **10** is approximately 0.0625 inch to 2 inches. Riser tubes with smaller interior dimensions are preferred whenever possible so as to conserve the amount of casting material used in a casting process. The outer diameter or dimension of the riser tube **10** is not critical and it can be varied depending upon the structural strength required of the riser tube.

The use of solid, heat disposable patterns is well known in the art of investment casting. Suitable materials that can be used to form heat disposable patterns are those that are solid at room temperature and melt at elevated temperatures (e.g., about 150°F and higher). Suitable heat disposable materials include known casting waxes and polymers. Exemplary polymers include polystyrene as well as photocurable polymers such as a blend of epoxy resin and acrylate ester. An exemplary, commercially available photocurable polymer is sold by Ciba-Geigy Corporation, Los Angeles, CA, as product name XB 5170. Casting waxes tend to melt in the range of about 150 - 160 °F while photocurable polymers have a much higher melting range. Photocurable polymers normally must be extracted by flash firing at temperatures of about 1900 °F to rapidly vaporize the solid polymer.

A variety of refractory materials well known for use in investment casting processes can be used with the process of the present invention. Examples of suitable refractory materials include those that utilize colloidal silica binder, alcohol based binder, latex binder additive, and colloidal silica binder with a latex additive. A preferred primary refractory is a fine stucco with a high percentage of zircon. Preferred backup coats are generally more coarse than the primary coat and typically use colloidal silica binder with fused silica.

By way of example, a ceramic riser tube can be used in a process to cast femoral components of artificial knee joints. A single riser tube can be used to cast from one to as many as about seventy two knee femoral components. Preferably, twelve knee femoral components are cast using a single riser tube. A riser tube suitable for casting twelve knee femoral components typically has a length of about 12 inches, an outside diameter of about 0.75 inch, and an inside diameter of about 0.375 inch. Further, the riser tube preferably has two orifices per article representing a positive model of the article to be cast. Each orifice may be circular in shape having a diameter of about 0.375 inch.

It is understood that riser tubes used according to the present invention, and the components thereof, may have shapes and sizes other than those recited in this exemplary description. For example, the size and shape of the orifices may vary depending upon the requirements of a given casting operation.

The use of the solid, rigid riser tube according to the present casting process has several advantages over the traditional wax trees that these riser tubes replace. The riser tube used according to the invention has sufficient rigidity and structural strength to enable its inside diameter to be substantially smaller than the diameters typically required of a wax tree used for a similar casting operation. This enables a smaller volume of molten metal to be used in casting processes, thus achieving significant cost savings and improved filling of the investment assembly. Further, the structural strength of the riser tube enables the gates used with the riser tube to be substantially smaller than gates used with wax trees. This provides an important safety advantage as the cast articles can simply be snapped away from the riser tube; they do not have to be mechanically sawed as do the gates that are formed through a casting process that utilizes a wax tree.

The riser tube of the invention is also advantageous because it possesses good thermal insulation properties. An investment assembly formed in a casting process using the riser tube of the present invention derives insulation from the riser tube itself as well as from the refractory. When molten material flows into the cavities from the riser tube, the molten material immediately undergoes progressive solidification. The metal first forms a skin corresponding to exterior regions of the article, and solidification progresses thereafter from the exterior regions of the article to interior regions. Due to the insulating properties of the riser tube, casting material (e.g., metal) within the riser tube remains in its molten state longer than the material within the mold cavities. This feature contributes to better mold filling properties during the casting process.

A further unexpected advantage achieved through the use of riser tubes accordingly to the present invention is a significant reduction in material waste. Investment casting processes that use wax trees tend to have yields of about 36%. That is, a given casting operation will utilize 36% of the casting material (e.g., metal) to form castings and 64% of the casting material will be waste that forms in the gates and the area once occupied by the wax tree. In contrast, the process of the present invention, utilizing a solid riser tube, achieves as much as about a 93% yield. That is, 93% of the casting material forms castings while only 7% of the casting material represents waste components.

The present invention is applicable to the manufacture of virtually any article that can be cast. The cast article can be made from materials that are typically used in casting processes. Such materials include metals, metal alloys, stainless steel, ferrous alloys, and non-ferrous alloys.

EXAMPLE

Metal usage was compared between casting processes using the solid riser tube of the invention and the conventional wax tree system. In both processes thirty-six 10 ounce knee femorals were cast. The actual metal usage for both processes together with the casting yield are illustrated below in Table 1.

TABLE 1

Method	Actual Metal Usage	Metal Usage per Cast Part	Casting Yield
Casting with Solid Riser Tube	27 lbs	12 ounces	83%
Casting with Wax Tree	63 lbs	28 ounces	36%

The data illustrated above indicates the improved efficiency of the present casting process. This improved efficiency translates to a substantial cost savings as a great deal of metal can be conserved using the process of this invention.

The foregoing description of methods of manufacture and the illustrative embodiment is presented to indicate the range of constructions to which the invention applies. Variations in the casting process of the invention and the materials to be used in the casting process of the invention will be readily apparent to those having ordinary skill in the art. Such variations are considered to be within the scope of the invention in which patent rights are asserted, as set forth in the claims appended hereto.

Claims

1. A lost-wax casting process, comprising the steps of:

   providing a hollow riser tube that is closed at one end, the riser tube having a plurality of orifices extending through the wall thereof;

   mounting one or more heat disposable solid patterns of an article to be cast directly to the riser tube to form a cluster, the solid patterns being mounted by adhering at least one gate on each solid pattern to at least one orifice of the riser tube;

   building a shell around the cluster by applying one or more coatings of a refractory to the cluster to form, upon drying, an investment assembly;

   removing the solid patterns from the investment assembly by heating the investment assembly to a temperature sufficient to melt or destroy the solid patterns such that a material from which the solid patterns are made vacates the investment assembly leaving a shell having one or more cavities; and

   filing the shell through the riser tube, with a molten casting material such that the molten casting material fills the cavities in the shell to form, upon cooling, solid cast articles.

2. The process of claim 1 further comprising, prior to the step of filing the shell, the step of heating and firing the shell at a temperature and for a duration sufficient to remove any residual material from which the solid patterns are made, and to add fired strength to the shell.

3. The process of claim 2 wherein the step of heating and firing the shell is conducted at a temperature in the range of about 1400 °F to 2000 °F for approximately one-half hour or more.

4. The process of any one of claims 1 to 3 wherein the patterns are mounted to the riser tube by melting the gates of the solid patterns, adhering the molten gates to the orifices, and allowing the gates to solidify and bond to the orifices.

5. The process of any one of claims 1 to 4 wherein the investment assembly is formed by multiple applications to the cluster of a refractory.

6. The process of claim 5 wherein one or more applications of the refractory is a primary coat.

7. The process of claim 5 or claim 6 wherein at least one application of the refractory comprises a backup coat.

8. The process of any one of claims 1 to 7 wherein the step of removing the solid patterns is conducted with heat and/or pressure.

9. The process of any one of claims 1 to 8 wherein the shell is formed around the cluster by dipping the cluster in the refractory or by spraying the refractory on the cluster.

10. The process of any one of claims 1 to 9 wherein the step of removing the solid patterns is conducted in a steam autoclave at a temperature in the range of about 315°F to 340°F and at a pressure in the range of about 100 to 150 psi.

11. The process of any one of claims 1 to 9 wherein the step of removing the solid patterns is conducted by flash firing at a temperature of about 1900°F.

12. The process of any one of claims 1 to 11 wherein the casting material is a metal or metal alloy.

13. The process of any one of claims 1 to 12 wherein the solid cast articles are implantable bone prostheses.

14. The process of any one of claims 1 to 13 further comprising the step of removing the solid cast articles from the shell following completion of the step of filling the shell.

15. The process of any one of claims 1 to 14 wherein the inside diameter of the riser tube is in the range of about 0.0625 inch to 2 inches.

16. The process of any one of claims 1 to 15 wherein said riser tube has a circular or square cross sectional shape.

17. An investment assembly, for use in an investment casting process, comprising:
a hollow riser tube having one or more orifices extending through a wall thereof;
one or more heat disposable solid patterns mounted to the orifices within the riser tube; and
one or more coats of refractory fully enveloping the riser tube and solid patterns.

FIG.1A

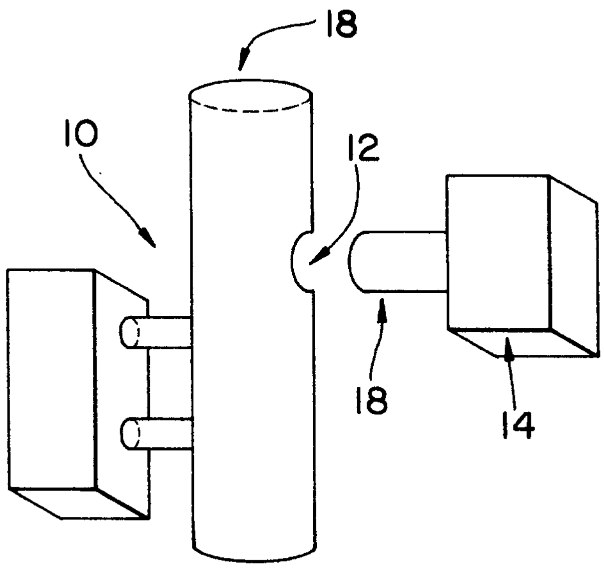

FIG.1B

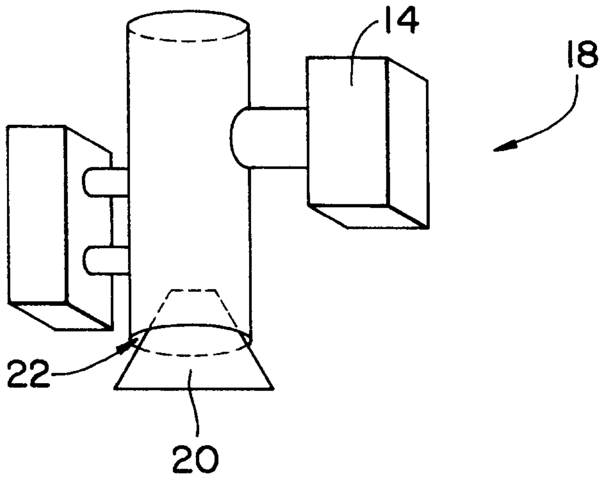

FIG.1C

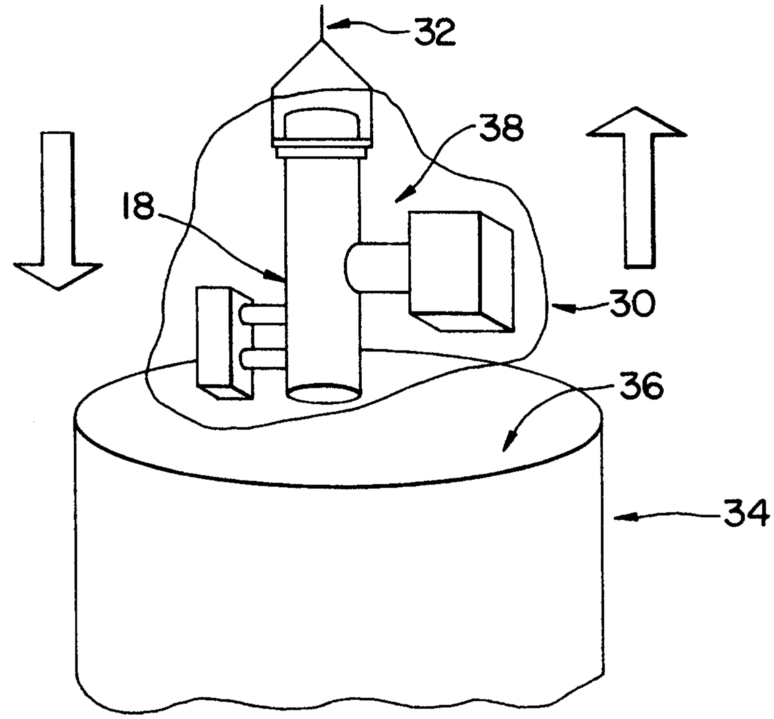

FIG.1D

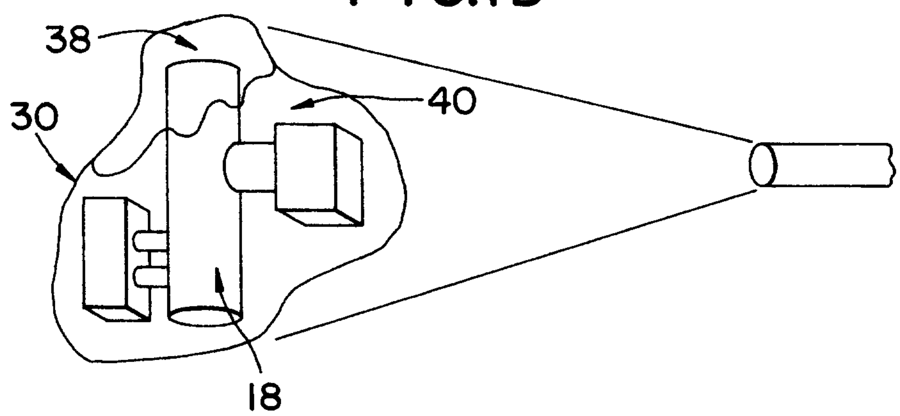

FIG.1E

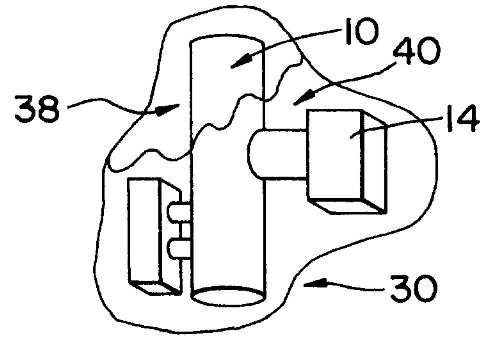

FIG.1F

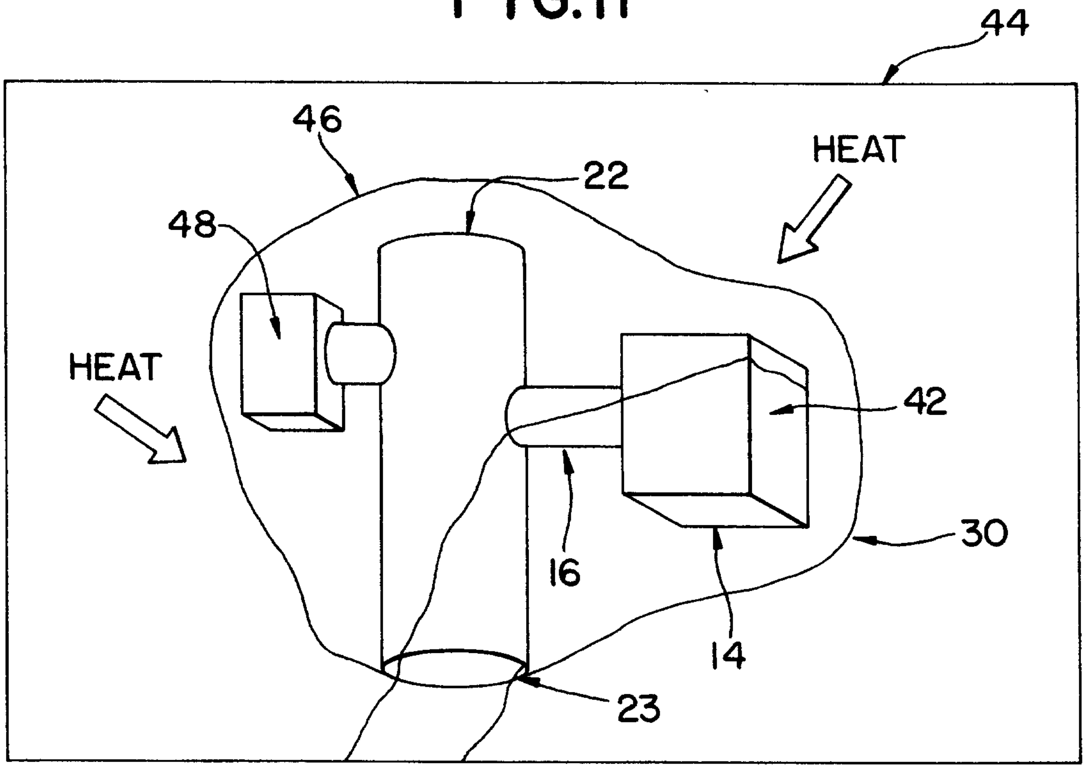

FIG.1G

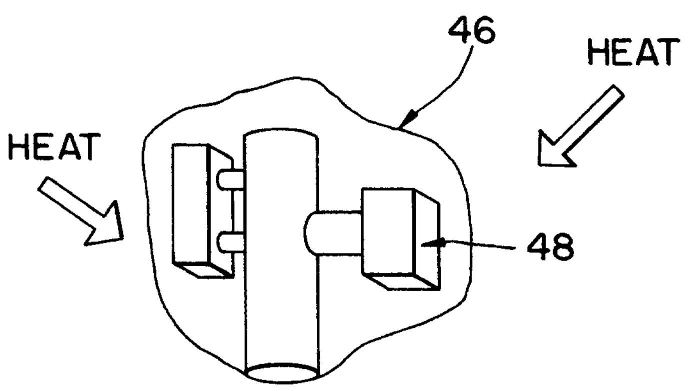

FIG.1H

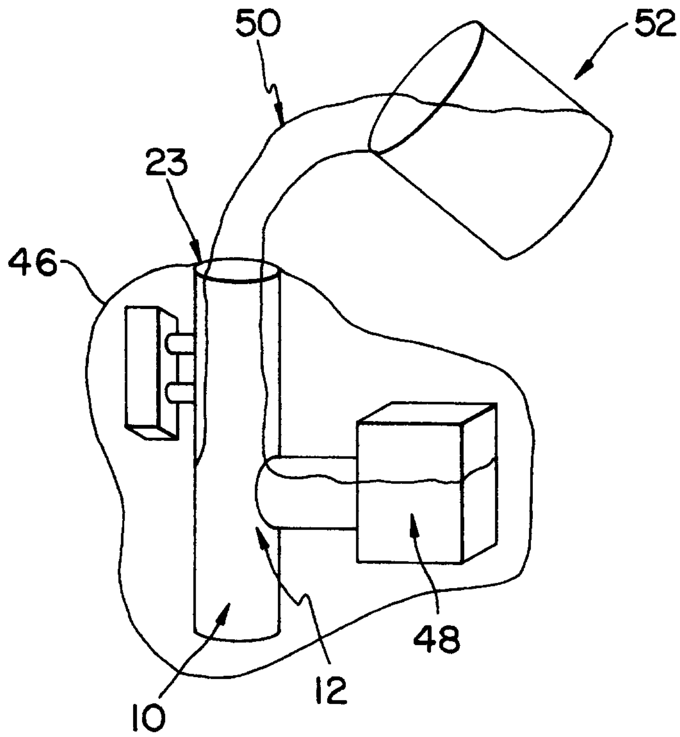

FIG.1I

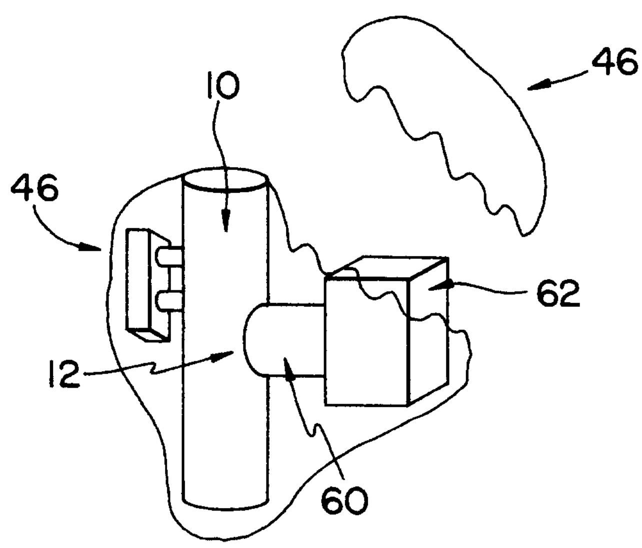

FIG.1J

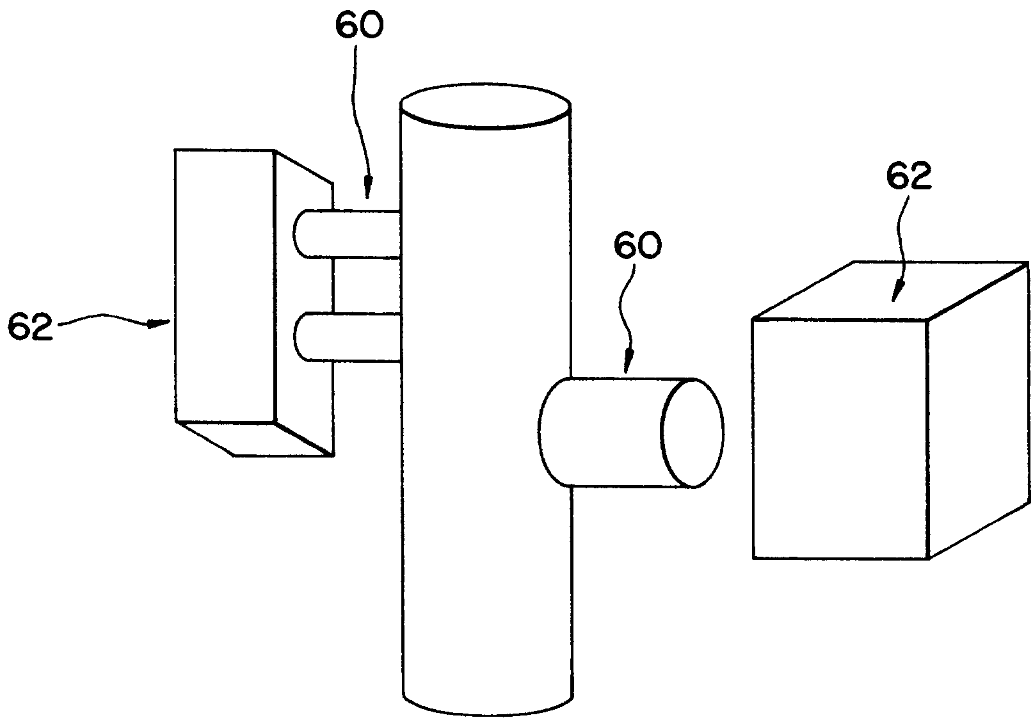

FIG.2

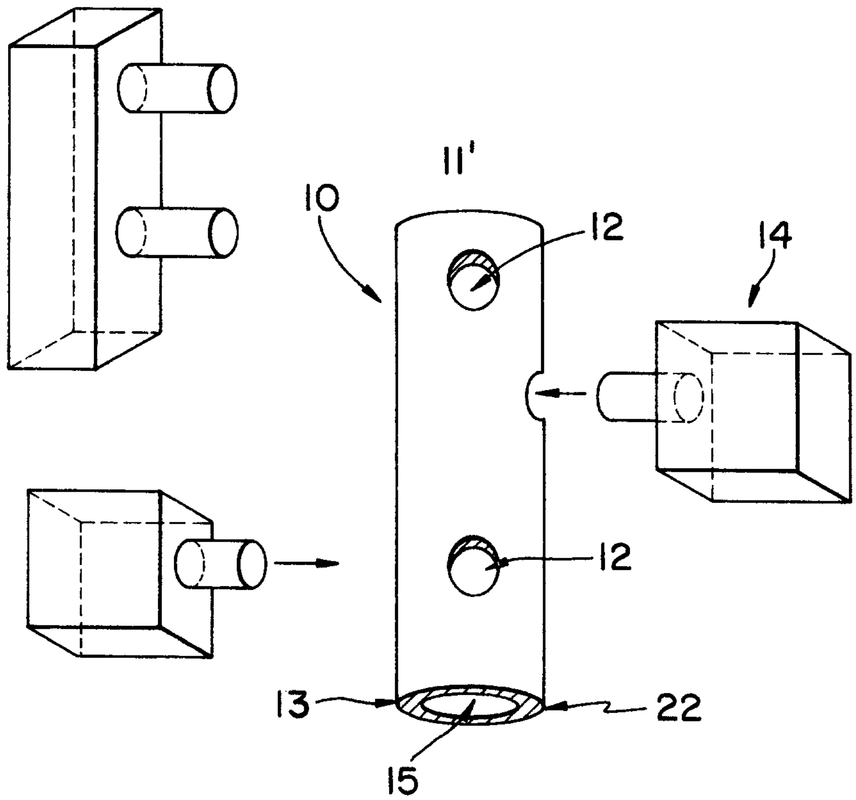

FIG.3