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(54) **Method and apparatus for precision casting of titanium or titanium alloy.**

(57) A method for precision casting of titanium or titanium alloy which comprises establish molten metal by induction heating in a assembly formed with water cooled copper segments (2a,2b...2h) disposed circlewise on the inside of an induction coil (5) in a state insulated from each other and casting the molten metal into a permeable mold (21) by vacuum casting. A precision casting method for titanium or titanium alloy which comprises an induction coil (5), an assembly (2) formed with the aforementioned copper segments (2a,2b...2h) and fed with base metal (6) from the under side thereof and a permeable mold for casting the base metal molten in the assembly (21) by means of vacuum casting. According to this invention, it is possible to obtain precision castings of metals having high melting points and high activity such as titanium, titanium alloy or the like.

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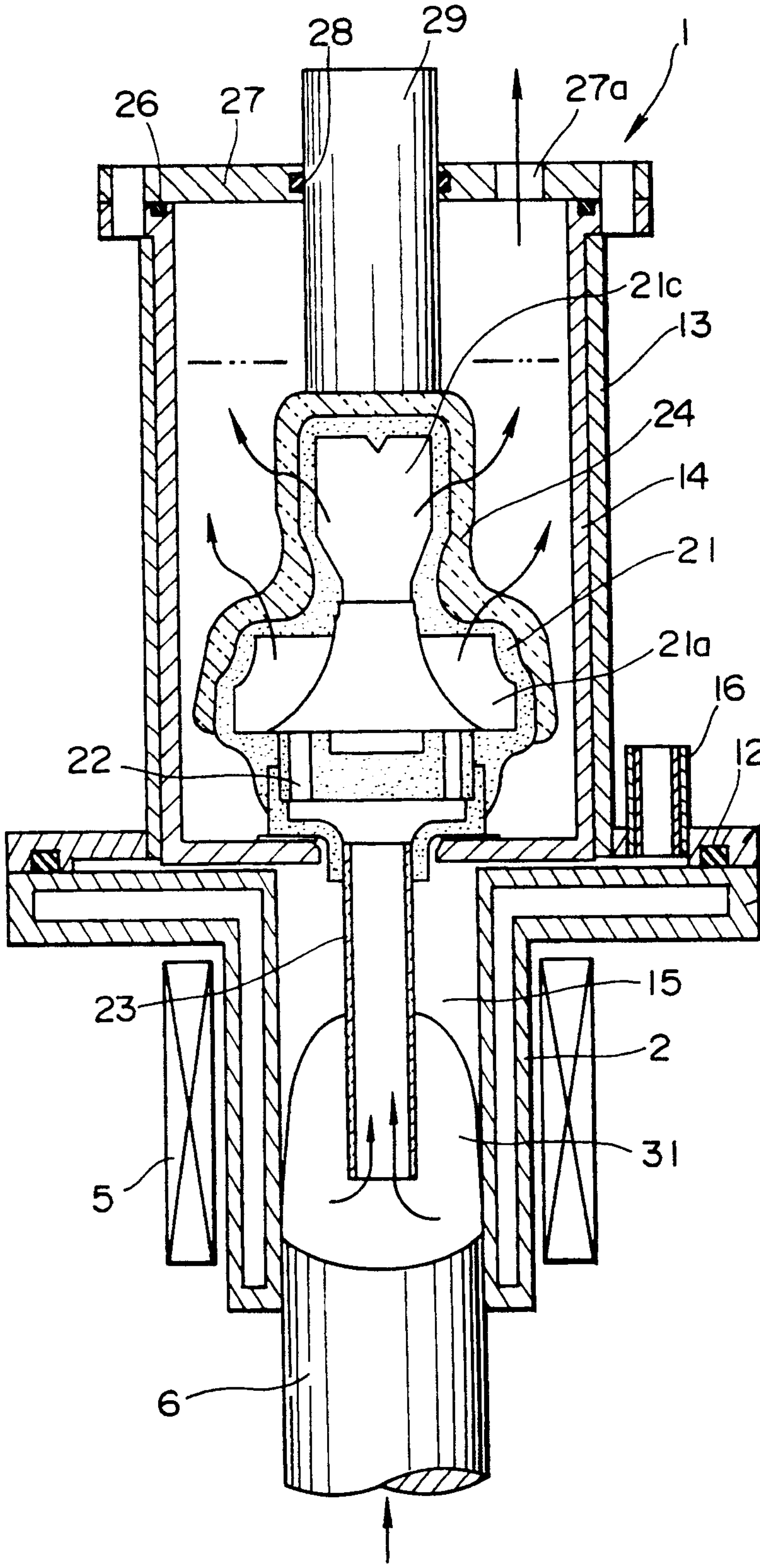
FIG.1



This invention relates to a method and an apparatus for precision castings of titanium or titanium alloy applicable for obtaining precision castings of titanium or titanium alloy which is excellent in heat-resisting property and corrosion resistance in addition to its lightness, and has very high strength.

Titanium and titanium alloy are light and excellent in heat and corrosion resistance, further in mechanical strength, therefore it is expected to obtain useful products which has not been used so far by casting precisely such titanium or titanium alloy.

However, because the titanium or titanium alloy has a melting point higher than 1400°C and is also active, there is a problem in that there are great difficulties in melting and casting the titanium or titanium alloy in the majority of cases.

Namely, when an ordinary ceramic crucible is used in order to melt the titanium or titanium alloy and obtain the quantity and temperature of the molten metal suitable for the casting, there is a problem in that oxide ceramics forming the crucible can be easily reduced by titanium at a high temperature. If a graphite crucible is used, there is another problem in that it is merely possible to carry out the melting in a small quantity for short time from a standpoint of preventing the titanium or titanium alloy from contamination because carbon dissolves into the titanium or titanium alloy. And, in regard to a mold for casting the molten metal of the titanium or titanium alloy thereinto, a reaction sometimes takes place between the mold and the molten metal. In this case, it is necessary to reduce the casting temperature as much as possible, however the molten metal is apt to solidify before the molding cavity is filled sufficiently with the molten metal in such a case and there is a different problem in that misrun of the molten metal is caused in precision castings having thin-walled and complicated shapes.

This invention aims to solve or at least partially to alleviate the above-mentioned problems of the prior art.

The present invention provides a method for precision casting of titanium or titanium alloy which comprises establishing molten base metal of titanium or titanium alloy by induction heating in an assembly formed with a plurality of water cooled copper segments disposed circlewise on the inside of an induction heating coil in a state in which the copper segments are insulated from each other, and casting the molten base metal into a permeable mold disposed above the molten base metal by vaccum casting.

In the preferred aspects according to this invention, the base metal may be molten in an atomosphere of an inert gas such as argon and may be cast into the permeable mold through a tubular sprue, and the base metal of titanium or titanium alloy may be fed continuously into the assembly formed with the water cooled segments from the under side of the assembly.

The present invention also provides a precision casting apparatus for titanium or titanium alloy comprising a induction heating coil, an assembly formed with a plurality of water cooled copper segments disposed circlewise on the inside of the induction heating coil in a state in which the copper segments are insulated from each other, and fed with base metal of titanium or titanium alloy from the under side thereof, and a permeable mold for casting the base metal molten by induction heating on the inside of the assembly formed with the water cooled copper segments by means of vacuum casting.

In the preferred aspects according to this invention, the permeable mold may be provided with a plurality of tubular sprues for conducting the molten base metal thereinto at the time of vacuum casting and a closed feeder head in the upper part thereof, and the permeable mold may be a ceramic shell mold.

Embodiments of the present invention will now be described by way of example only with reference to the accompanying drawings, in which:-

Figure 1 is a vertical sectional side view illustrating the precision casting apparatus according to an embodiment of this invention ; and

Figure 2 is a horizontal sectional view of the assemble formed with the water cooled copper segments in the precision casting apparatus shown in Figure 1.

In the method and the apparatus for precision casting of titanium or titanium alloy according to this invention having the aforementioned construction, eddy currents are formed on the inside of the assembly formed with water cooled copper segments disposed circlewise on the inside of the induction coil in the state insulated from each other at the time of melting the base metal of titanium or titanium alloy in the assembly formed with the water cooled copper segments.

Therefore, the base metal is molten by an eddy current induced in the outer layer thereof by the abovementioned eddy currents which are alternating currents, in this time the molten base metal is detached from the assembly formed with the water cooled copper segments by repelling force caused by currents flowing in the outermost layers of the assembly and the molten metal and having opposite phases each other, and a gap is formed between the molten metal and the inner periphery of the assembly.

Accordingly, thermal transmission from the molten metal to the assembly is suppressed by the formation of the gap, a thick-walled skull (a layer of solidified metal) is scarcely formed differing from the cases of conventional furnaces of a water cooled hearth type such as an arc skull crucible furnace and so on, for example, and the base metal is molten in a better yield. And , it is easy to regulate the temperature of molten metal by controlling electric energy to be supplied to the induction coil, the molten base metal is not contaminated substantially because a ceramic crucible composed of oxides is not used, and precision castings of good quality can be obtained.

A precision casting apparatus which is used in an embodiment of the method for precision casting of titanium or titanium alloy according to this inveniton is shown in Figure 1 and Figure 2. The precision casting apparatus 1 is provided with an assembly 2 in the center part thereof which is formed with a plurality of water cooled copper segments 2a, 2b,...2h disposed circlewise in the state insulated from each other through insulations 7, and the respective water cooled copper segments 2a, 2b,...2h are provided with water pipes 3a, 3b,...3h. The assembly 2 is provided continuously with a magnetic shield 4 on the upper side thereof.

The assembly 2 is disposed with a radio-frequency induction coil 5 on the outside thereof and so designed as to fed base metal 6 of titanium or titanium alloy on the inside from under side thereof.

The magnetic shield 4 is provided with a circlar base 11 through a seal 12 on the upper side thereof and provided with a sleeve 13 on the inside of the circlar base 11, and a mold chamber 14 is provided on the inside of the sleeve 13. And melting space 15 is formed in a part surrounded by the bottom face of the mold chamber 14 and inner peripheries of the assembly 2 and the magnetic shield 4, and it is possible to replace the atomosphere in the melting space 15 with an inert gas by supplying argon through a gas intake 16 provided on the circlar base 11, for example.

A permeable mold 21 which is a ceramic shell mold is disposed in the mold chamber 14, and a turbine wheelshaped molding cavity 21a in the permeable mold 21 and the melting space 15 are connected by a gate 22 formed in the permeable mold 21 and a tubular sprue 23 communicating to the gate 22.

And the permeable mold 21 is provided with a closed feeder head 21c in the upper part thereof, and disposed with a heat insulator 24 having gas permeability on the outer surface thereof.

Further, the mold chamber 14 is provided with an upper plate 27 through a seal 26 on the upper end thereof and the permeable mold 21 is held with a support 29 piercing the upper plate 27 through a seal 28, and the upper plate 27 is provided with a suction hole 27a.

Therefore, in the precision casting apparatus 1 acording to this embodiment and provided with the assembly 2 on the inside of the radio-frequency induction coil 5 as described above, eddy currents are formed on the inside of the assembly 2 by radio frequency induction of the radio-frequency induction coil 5, and the base metal 6 of titanium or titanium alloy is molten by an eddy current induced in the outer layer of the base metal 6 by the eddy currents which are alternating currents. In this time the molten metal 31 of titanium or titanium alloy is slightly separated from the inner periphery of the assembly 2 by repelling force caused by currents flowing in the outermost layers of the assembly 2 and the molten metal 31 and having opposite phases each other, and a gap is formed between the molten metal 31 and the assembly 2

Accordingly, thermal transmission from the molten metal 31 of titanium or titanium alloy to the assembly 2 is suppressed by the formation of the gap. Thereby, a thick-walled skull which is formed in conventional furnaces of a water cooled hearth type such as an arc skull crucible furnace and so on is scarely formed, and it becomes possible to melt the base metal 6 of titanium or titanium alloy in a better yield. And it becomes possible to regulated the temperature of the molten metal 31 of titanium or titanium alloy easily by controlling electric energy to be supplied to the radio-frequency induction coil 5. Furthermore, there is no contamination of the molten 31 practically since the ceramic crucible composed of oxides is not used.

By reducing the pressure in this state through the suction hole 27a provided in the upper plate 27, gas existing in the molding cavity 21a and the feeder head 21c of the permeable mold 21 is discharged in the mold chamber 14 passing through the permeable mold 21 as shown with arrows according to the difference of internal pressures between the mold chamber 14 and the melting space 15, therewith the molten metal 31 of titanium or titanium alloy is sucked and cast into the molding cavity 21a through the tubular sprue 23 and the gate 22. In this time, the molten metal 31 is drawn by suction up to the feeder head 21c and is prepared for shrinkage cavity acompained with solidification shrinkage of the molten metal 31 of titanium or titanium alloy in the molding cavity 21a.

And a casting product is obtained by shakeout after the solidification of the molten metal 31 in the permeable mold 21.

In this embodiment, Ti-Al intermetallic compound which is light and excellent in mechanical strength at high temperature was chosen as base metal 6 of titanium or titanium alloy, and cast into a turbine wheel for turbo charger which is 1200g in finished weight with outside diameter of 140mm.

The high-frequency generator used in this time for supplying high frequency wave to the induction heating coil 5 is a small and simplified type comparatively having capacity of 60kW. And the frequency is high as much as 30kHz, so that it is possible to melt materials with small diameters efficiently.

The turbine wheel has twelve turbine blades and twelve gates 22 having diameters of 8mm were provided near the lower parts of respective turbine blades in total.

The base metal 6 composed of Ti-Al intermetallic compound was fed from the under side of the assembly 2 formed with water cooled copper segments 2a, 2b,...2h, and heated by supplying the high frequency wave of 60 kW with frequency of 30 kHz to the induction heating coil 5. And the base metal 6 was molten by forming eddy currents on the inside of the assembly 2 and inducing an eddy current in the outermost layer of the base metal 6 of Ti-Al alloy.

The casting temperature was determined at 1580°C by making the temperature of the molten metal 31 higher than the melting point 1520°C of the Ti-Al alloy by 60°C (superheat).

The degree of superheat in this time is remarkably low as compared with that of the top poured conventional precision casting (150~50°C), it is effective for inhibiting the reaction between the permeable mold 21 and the molten metal 31.

And by reducing the pressure at the aforementioned casting temperature by pressure of 350mm Hg or so through the suction hole 27a, the gas in the molding cavity 21a was discharged through the permeable mold 21 according to the difference of the internal pressures between the mold chamber 14 and the melting space 15, and the molten metal 31 of Ti-Al alloy was drawn by suction in the molding cavity 21a and the feeder head 21c through the tubular sprue 23 and the gates 22. And then the turbine wheel was obtained by solidifying the molten metal 31 in the molding cavity 21a.

In this time, as the molten metal 31 was drawn in the molding cavity 21a by vacuum casting, the molten metal 31 spreads well every nook and corner of the thinwalled turbine blade, and it was possible to obtain the turbine wheel with high accuracy in shape.

Adopting the method and the apparatus for precision casting according to this invention, it becomes possible to manufacture complicated and large-sized precision casting which has been impossible to be made substantially and the invention will contribute much to further development of the precision casting of titanium or titanium alloy. And in addition to above, it is possible to apply the method and the apparatus to presicion casting of metals or alloys of the metals having high melting points or high activity such as tungsten, molybdenum, vanadium, zirconium, lithium or the like.

As mentioned above, the method for precision casting of titanium or titanium alloy according to this invention comprises the the step of establishing molten base metal of titanium or titanium alloy by induction heating in an assembly formed with a plurality of water cooled copper segments disposed circlewise on the inside of an induction heating coil in a state in which the copper segments are insulated from each other, and casting the molten base metal into a premeable mold disposed above the molten base metal by vacuum casting. Therefore, the molten base metal is deteched from the assembly and a gap is formed between the molten metal and the assembly by repelling force caused by currents flowing in the outermost layers of the assembly and the molten metal and having opposite phases each other because the base metal is molten by an eddy current induced in the outer layer thereof by eddy currents which are alternaing currents at the time of melting the base metal of titanium or titanium alloy. And excellent effects can be obtained in that the yield rate of the base metal is improved remarkably, the control of the temperature of the molten metal is facilitated, it is possible to prevent the molten metal from the contamination and possible to obtain the precision casting of good quality because the thermal transmission from the molten metal to the assembly is suppressed and the solidified metal layer becomes not to be formed between the molten metal and the assembly.

The precision casting apparatus for titanium or titanium alloy according to this invention comprises an induction heating coil, an assembly formed with a plurality of water cooled copper segments disposed circlewise on the inside of said induction heating coil in a state in which the copper segments are insulated from each other, and fed with base metal of titanium or titanium alloy from the under side thereof, and a permeable mold for casting tha base metal molten by induction heating on the inside of the assembly formed with the water cooled copper segments by means of vacuum casting. Therefore, an excellent effect can be obtained since it becomes possible to manufacture the precision castings of titanium or titanium alloy with accuracy in a better yield by enabling execution of the aforementioned method for precision casting of titanium or titanium alloy.

The preferred embodiments of the present invention can Provide a method and an apparatus for precision casting which is possible to obtain precision castings of metals with high melting points or high activity by preventing the molten metal from the contamination in the melting, maintaining the quantity and the temperature of the molten metal required for the casting, and casting the molten metal under the forced casting condition suitable to prevent the misrun of the molten metal even if the molten metal is cast at the low temperature at the time of carring out the precision casting of titanium, titanium alloy or other metals having high melting points or high activities such as tungsten, molybdenum, vanadium, zirconium, lithium or the like.

Claims

1. A method for precision casting of titanium or titanium alloy which comprises :

establishing molten base metal of titanium or titanium alloy by induction heating in an assembly formed with a plurality of water cooled copper segments disposed circlewise on the inside of an induction heating coil in a state in which said copper segments are insulated from each other : and casting said molten base metal into a permeable mold disposed above the molten base metal by vacuum casting.

2. A method for precision casting of titanium or titanium alloy as claimed in claim 1, wherein said base metal of titanium or titanium alloy is molten in an atomosphere of an inert gas such as argon.

3. A method for precision casting of titanium or titanium alloy as claimed in claim 1 or claim 2, wherein said molten base metal is cast into the permeable mold through a tubular sprue.

4. A method for precision casting of titanium or titanium alloy as claimed in any one of claims 1 to 3, wherein said base metal of titanium or titanium alloy is fed continuously into the assembly formed with the water cooled copper segments from the under side of said assembly.

5. A precision casting apparatus for titanium or titanium alloy comprising :

an induction heating coil ;

an assembly formed with a plurality of water cooled copper segments disposed circlewise on the inside of said induction heating coil in a state in which said copper segments are insulated from each other, and fed with base metal of titanium or titanium alloy from the under side thereof ; and

a permeable mold for casting said base metal molten by induction heating on the inside of said assembly formed with the water cooled copper segments by means of vacuum casting.

6. A precision casting apparatus for titanium or titanium alloy as claimed in claim 5, wherein said permeable mold is provided with a plurality of tubular sprue for conducting the molten base metal thereinto at the time of vacuum casting.

7. A precision casting apparatus for titanium or titanium alloy as claimed in claim 5 or claim 6, wherein said permeable mold is provided with a closed feeder head in the upper part thereof.

8. A precision casting apparatus for titanium or titanium alloy as claimed in any one of claims 5 to 7, wherein said permeable mold is a ceramic shell mold.

FIG.1

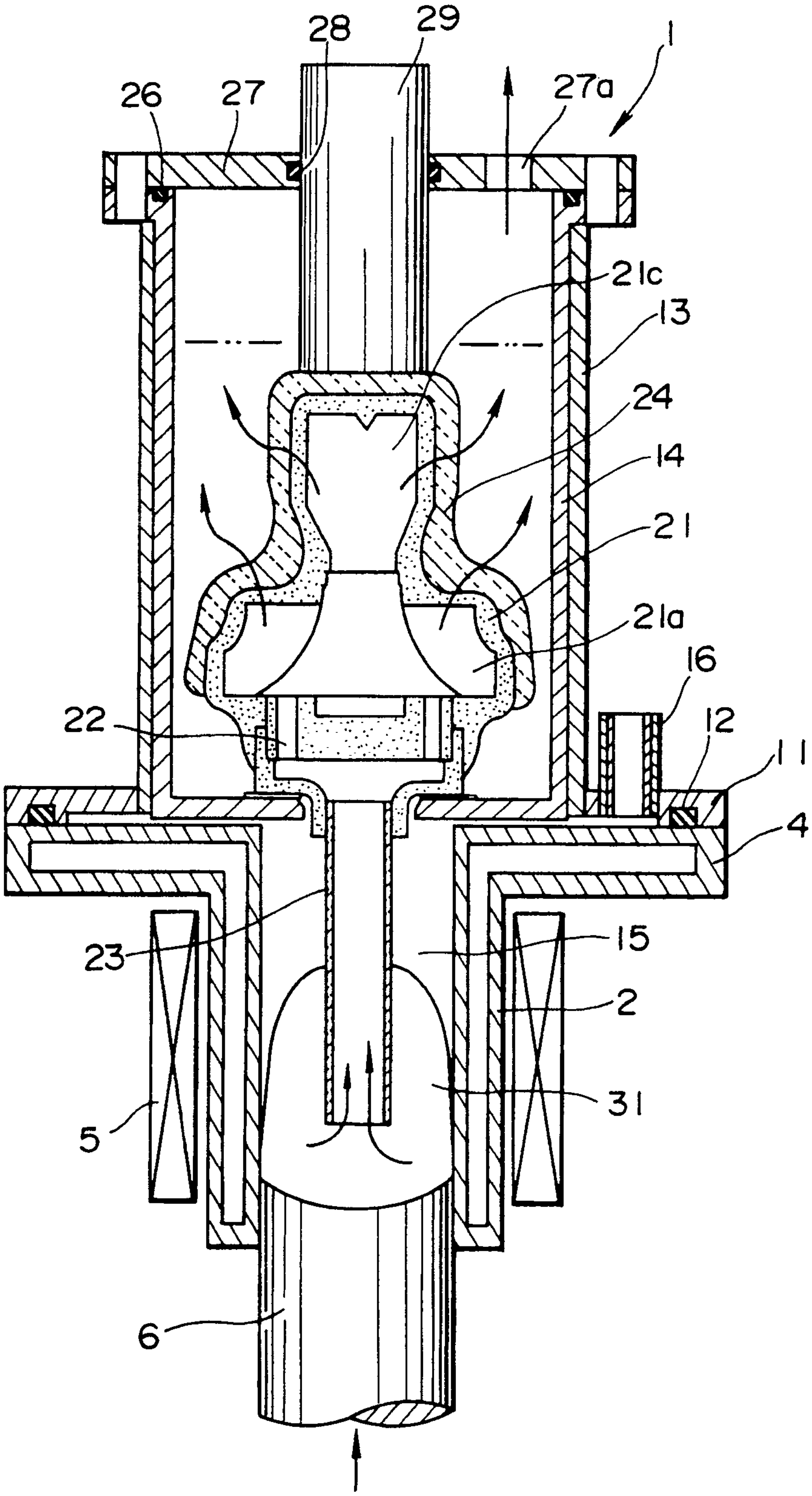
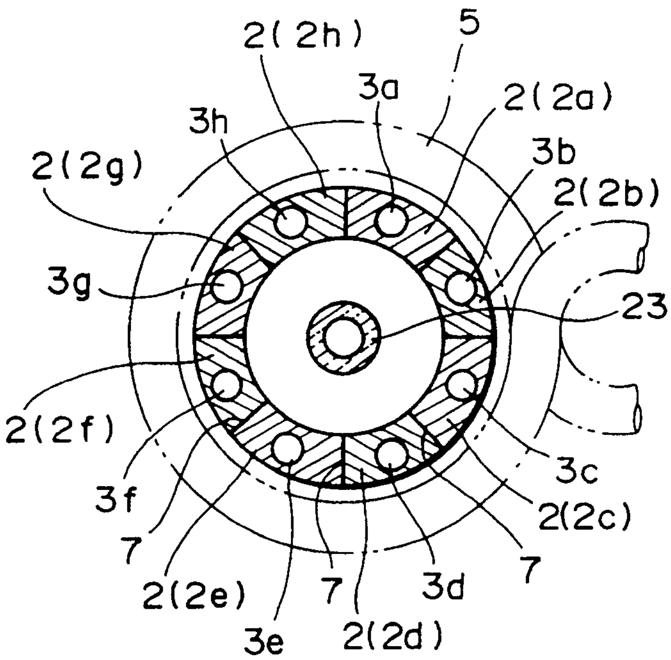


FIG. 2



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EUROPEAN SEARCH REPORT

Application number

EP 91304192.7

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.⁵)
X	GB - A - 2 204 816 (METAL CASTING TECHN. INC.) * Fig. 2; claims 1,4,10,12; page 4, lines 22-27 *	1,2,3, 5,6	B 22 D 18/06 B 22 C 9/04
A	US - A - 4 112 997 (CHANDLEY) * Abstract; fig. 1 *	1,8	
A	DE - A1 - 3 927 998 (OKUDA) * Abstract; fig. 1 *	1,2,5	
A	US - A - 4 196 769 (FEAGIN)		
A	GB - A - 2 035 165 (HITCHINER MANUFACTURING)		

TECHNICAL FIELDS SEARCHED (Int. Cl.⁵)

B 22 D 18/00
B 22 D 21/00
B 22 D 23/00
B 22 D 17/00
B 22 C 9/00

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
VIENNA	09-07-1991	RIEDER

CATEGORY OF CITED DOCUMENTS

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