

Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to directional solidification apparatus and processes wherein heat is removed in a unidirectional manner from a metallic melt in a mold to form a columnar grain or single crystal casting.

BACKGROUND OF THE INVENTION

[0002] In the manufacture of components, such as nickel base superalloy turbine blades and vanes, for gas turbine engines, directional solidification (DS) investment casting techniques have been employed in the past to produce columnar grain and single crystal casting microstructures having improved mechanical properties at high temperatures encountered in the turbine section of the engine.

[0003] In the manufacture of turbine blades and vanes using the well known DS casting "withdrawal" technique where a melt-filled investment mold residing on a chill plate is withdrawn from a casting furnace, a stationary thermal baffle has been used proximate the bottom of the casting furnace to improve the unidirectional thermal gradient present in the molten metal or alloy as the investment mold is withdrawn from the casting furnace. The baffle reduces heat loss by radiation from the furnace and the melt-filled mold as the mold is withdrawn from the casting furnace.

[0004] Attempts to improve the thermal gradient have included introducing a cooling gas below the stationary thermal baffle of the casting furnace to extract heat from the mold and/or withdrawing the hot melt-filled investment mold from the furnace into a bath of liquid cooling metal, such as liquid tin, positioned below the furnace.

[0005] The low heat capacity of cooling gas creates a disadvantage in that large gas quantities are needed to effect cooling and in that the presence of the cooling gas below the baffle has a negative impact on the thermal profile of the mold heater in the casting furnace due to a chimney effect. The large quantities of cooling gas require complex and expensive vacuum pumping and recycling systems associated with the casting apparatus as well as more complex heat shielding and cooling of the casting furnace equipment.

[0006] Use of a liquid metal cooling bath adds significantly to complexity of the mold design and withdrawal apparatus since the mold must be lowered into a hot circulating cooling media. Complex bath circulation and level control systems are needed. In addition, the liquid metal cooling bath can be subject to contamination and reactions should a prior cast investment mold experience a leak or significant run-out of molten metal into the bath.

SUMMARY OF THE INVENTION

[0007] The present invention provides in an embodiment a method and apparatus for DS casting wherein a liquid cooling medium is sprayed directly on exterior surfaces of a melt-filled ceramic investment mold as it is withdrawn from an end of a DS casting furnace by relative movement therebetween so as to extract heat from the mold and improve the thermal gradient in the melt residing in the mold. The liquid cooling medium preferably is collected for reuse after it impinges on the exterior mold surfaces.

[0008] In an illustrative embodiment of the invention, a plurality of spray nozzles are disposed beneath a thermal baffle at a lower end of the DS casting furnace. The nozzles are spaced about a baffle opening through which the investment mold is withdrawn downwardly out of the casting furnace. The spray nozzles are oriented to spray a liquid metallic cooling medium in directions transverse to the path of mold withdrawal through the opening so that the sprays impinge directly on the exterior mold surfaces as the mold is withdrawn from the casting furnace by relative movement therebetween.

[0009] The invention provides a high heat extraction capability from the melt-filled mold without the disadvantages described above associated with use of a cooling gas and/or liquid metal cooling bath in which a mold is immersed. The invention will be described in more detail below in connection with the following drawings.

DESCRIPTION OF THE DRAWINGS

[0010]

Figure 1 is a schematic cross-sectional view of a DS casting apparatus in accordance with an embodiment of the invention.

Figure 1A is a partial schematic cross-sectional view of the DS casting furnace of another embodiment where the nozzles are oriented at an upward angle relative to horizontal.

Figure 2 is a schematic view taken along lines 2-2 of Figure 1 of the bottom of the thermal baffle showing spray nozzles disposed about the baffle opening as well as liquid metal supply piping. The mold is schematically and partially shown in cross-section for convenience.

Figure 3 and 4 are a schematic cross-sectional views of DS casting apparatus in accordance with other embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

[0011] The present invention provides a DS casting method and apparatus especially useful, although not

limited, to casting of nickel, cobalt and iron base superalloys to produce a columnar grain or a single crystal cast microstructure. Referring to Figure 1, casting apparatus in accordance with an illustrative embodiment of the invention for DS casting nickel, cobalt and iron base superalloys to produce columnar grain or a single crystal cast microstructure includes a vacuum casting chamber 10 having a casting furnace 12 disposed therein in conventional manner. Thermal insulation members 13a, 13b form a furnace enclosure. Positioned within the tubular thermal insulation member 13a is an inner solid graphite tubular member 15 forming a susceptor that is heated by energization of the induction coil 18. The thermal insulation member 13b includes an aperture 13c through which molten metal or alloy (metallic melt), such as a molten superalloy, can be introduced into the mold 20 from a crucible (not shown) residing in the chamber 10 above the casting furnace 12 in conventional manner.

[0012] Induction coil 18 disposed about the susceptor 15 is energized by a conventional electrical power source (not shown). The induction coil 18 heats tubular graphite susceptor 15 disposed interiorly thereof. After the empty mold 20 is positioned in the furnace 12, the mold is preheated to a suitable casting temperature for receiving the metallic melt by the heat provided by the susceptor 15.

[0013] The mold 20 typically comprises a conventional ceramic investment shell gang or cluster mold formed by the well known lost wax process to include a pour cup 20a that receives the melt from the crucible and that communicates via sprues 20b to a plurality of shell molds 21 each having a mold cavity 22 in the shape of the article to be cast. Although two shell molds 21 are illustrated in Figure 1, four or more shell molds 21 can be disposed around the center post 20d. Each mold cavity 22 communicates to a chill plate 26 at an open bottom end of each mold cavity in conventional manner to provide unidirectional heat removal from the metallic melt residing in the mold and thus a thermal gradient in the metallic melt M in the mold extending along the longitudinal axis of the mold. In casting single crystal components, a seed or crystal selector (not shown), such as pigtail passage, will be incorporated into the mold above the open lower end thereof to select a single crystal for propagation through the metallic melt, all as is well known. The invention is not limited to use with a gang or cluster mold 20 having a plurality of shell molds 21 and can be practiced with any type of refractory shell mold having one or more mold cavities.

[0014] In one embodiment of the invention, the mold 20 is formed with an integral mold base 20c and central support post 20d that rest on the chill plate 26 as shown. The base 20c can be clamped thereto in conventional manner if desired. The chill plate resides on a ram 28 raised and lowered by a fluid actuator (not shown) to move the mold 20 into and out of the casting furnace 12. Alternately, the invention envisions using any relative

movement between mold 20 and casting furnace 12 to effect withdrawal of the melt-filled mold 20 from the end of the furnace 12. For example, in another embodiment, the mold 20 on chill plate 26 and collection vessel 50 can be disposed in a fixed position, while the casting furnace 12 and nozzles 40 are moved together to effect withdrawal of the melt-filled mold 20 from the end of the furnace 12.

[0015] In the DS casting of gas turbine engine blades or vanes, each mold cavity 22 will have a root region 22a corresponding to a root of the blade or vane and a relatively large platform cavity 22b corresponding to the platform portion of the blade or vane to be cast. Each mold cavity 22 also will have a relatively smaller or narrower airfoil cavity region 22c corresponding to the airfoil portion of the blade or vane to be cast.

[0016] A stationary thermal baffle 30 is disposed at the lower end of the casting furnace 12 and is connected in conventional manner to the walls W of the vacuum chamber 10. The baffle 30 includes an opening 30a oriented perpendicular to the mold withdrawal direction (vertical direction in Figure 1) and having a cross-sectional configuration selected to accommodate movement of the relatively large platform region or profile of the melt-filled molds 21 therewith with only a small gap (e.g. 1/2 inch) present between the platform region 22b and the inner periphery of the baffle 30. The baffle 30 typically is made of graphite material, although other refractory materials can be used.

[0017] In accordance with an illustrative embodiment of the invention, a plurality of spray nozzles 40 are disposed beneath thermal baffle 30 at the lower end of the DS casting furnace 12. The nozzles 40 are spaced about the periphery of baffle opening 30a through which the metallic melt-filled investment mold 20 is withdrawn downwardly out of the casting furnace. The spray nozzles 40 are oriented to spray a liquid cooling medium as a plurality of liquid cooling sprays S in generally horizontal directions transverse to the downward vertical path of mold withdrawal through the opening 30a so that the sprays S impinge directly on and around the exterior surfaces of shell molds 21 as the mold 20 is withdrawn from the casting furnace. In Figure 1, the nozzles 40 are shown horizontally oriented to provide spray coverage of the exterior surfaces of the mold. Alternately, each nozzle 40 can be mounted on a bracket 41 to angle the nozzle 40 at an upward angle relative to horizontal as shown in Figure 1A to this end. The nozzles 40 are mounted by any suitable mounting means on the structural frame F that supports the casting furnace 12 in vacuum casting chamber 10.

[0018] The spray nozzles 40 preferably are of the type that produce a flat fan-shaped spray of the liquid cooling medium to provide the sharpest temperature transition and to minimize the number of nozzles needed to cool the mold surfaces. The nozzles can be made of any suitable material that can withstand prolonged contact with the cooling medium, such as for example a liquid tin

cooling medium.

[0019] The sprays S each can comprise a relatively low melting point, relatively high heat capacity liquid metal or alloy, or other liquid material such as a molten salt or oxide, that is compatible with the shell mold material so as not to react adversely therewith. For purposes of illustration and not limitation, molten tin, molten aluminum, or any other suitable liquid cooling metal or alloy may be used. The relatively low melting point of the liquid cooling metal or alloy is with respect to the melting point of the metal or alloy to be cast and directionally solidified in the molds 21. The relatively high heat capacity of the liquid cooling metal or alloy is with respect to the heat capacity provided by a cooling gas, such as Ar or other inert gas, used in the past to cool molds.

[0020] If liquid tin is used as the sprayed liquid cooling medium, the liquid tin temperature is typically in the range of 300 to 500 degrees F, whereas for purposes of illustration, the temperature of a molten nickel base superalloy residing in the molds 21 is typically in the range of 2800 to 2300 degrees F. If liquid aluminum is used as the sprayed liquid cooling medium, the liquid aluminum temperature is typically in the range of 900 to 1400 degrees F.

[0021] The nozzles 40 are supplied with the liquid cooling medium via a common distribution or manifold pipe 42 connected to a pump 44, Figure 2. The pump 44 is connected to a heated storage tank 46 containing the liquid cooling metal or alloy. The tank 46 can comprise a conventional metal (e.g. steel) or ceramic tank used to heat the liquid metal or alloy, such as molten tin or aluminum, to desired use temperature and store it for use. The pump 46 provides the liquid cooling metal or alloy under pressure to the nozzles 40 to generate sprays S. A typical pressure range of the liquid cooling metal or alloy supplied to the nozzles 40 will depend on the type of nozzle 40 selected for use and typically can be in the range of 40 to 250 psi. The pump 44 and tank 46 are disposed outside the vacuum chamber 10 and are connected to the nozzles 40 by the piping 43 that supplies the liquid cooling metal or alloy to the distribution or manifold pipe 42.

[0022] After the liquid cooling medium impinges on the shell molds 21 as they are withdrawn from baffle opening 30a, the still liquid cooling medium, such as still liquid tin or aluminum, falls by gravity from the mold 20 into a collection vessel 50 in vacuum chamber 10. The liquid cooling medium then is returned via piping 51 and pump 52 back to tank 46 for conditioning and reuse in closed loop manner. The tank 46 can be effective to thermally condition the liquid cooling medium to an appropriate temperature as well as filter or separate out any contaminants therein that might plug the nozzles 40.

[0023] In operation, an empty mold 20 is positioned in the furnace 12 by upward movement of the ram 28. The induction coil 18 is energized to preheat via susceptor 15 the mold 20 to a suitable casting temperature,

such as above 2500 degrees F for casting nickel base superalloys. The mold is filled with molten metal or alloy to be cast from a crucible above the furnace. Then, the metallic melt-filled mold 20 is withdrawn downwardly past baffle 30 out of the furnace 12 for example by lowering of the ram 28 (or any relative movement between furnace 12 and mold 20) at a controlled withdrawal rate to establish a thermal gradient in the melt to achieve a solidification front that progresses upwardly through the melt residing in the shell molds 21 during withdrawal to form either a columnar grain or a single crystal microstructure, if a single crystal selector or seed is present in the mold.

[0024] Shortly after the mold 20 begins downward withdrawal, the nozzles 40 are supplied with the liquid cooling medium, such as a liquid metallic cooling medium, to generate cooling sprays S that impinge on the exterior surfaces of the shell molds 21 as they past the baffle 30 out of the furnace 12. The liquid cooling metal or alloy of relatively high heat capacity and relatively low temperature impinges on and around the hot mold exterior surfaces to extract heat and improve the thermal gradient in the melt residing in the molds 21 above the solidification front progressing through the melt. After the liquid cooling metal or alloy impinges on the shell molds 21, the still liquid cooling metal or alloy is collected in vacuum chamber 10 in vessel 50 and returned by pump 56 to tank 46 for conditioning and reuse.

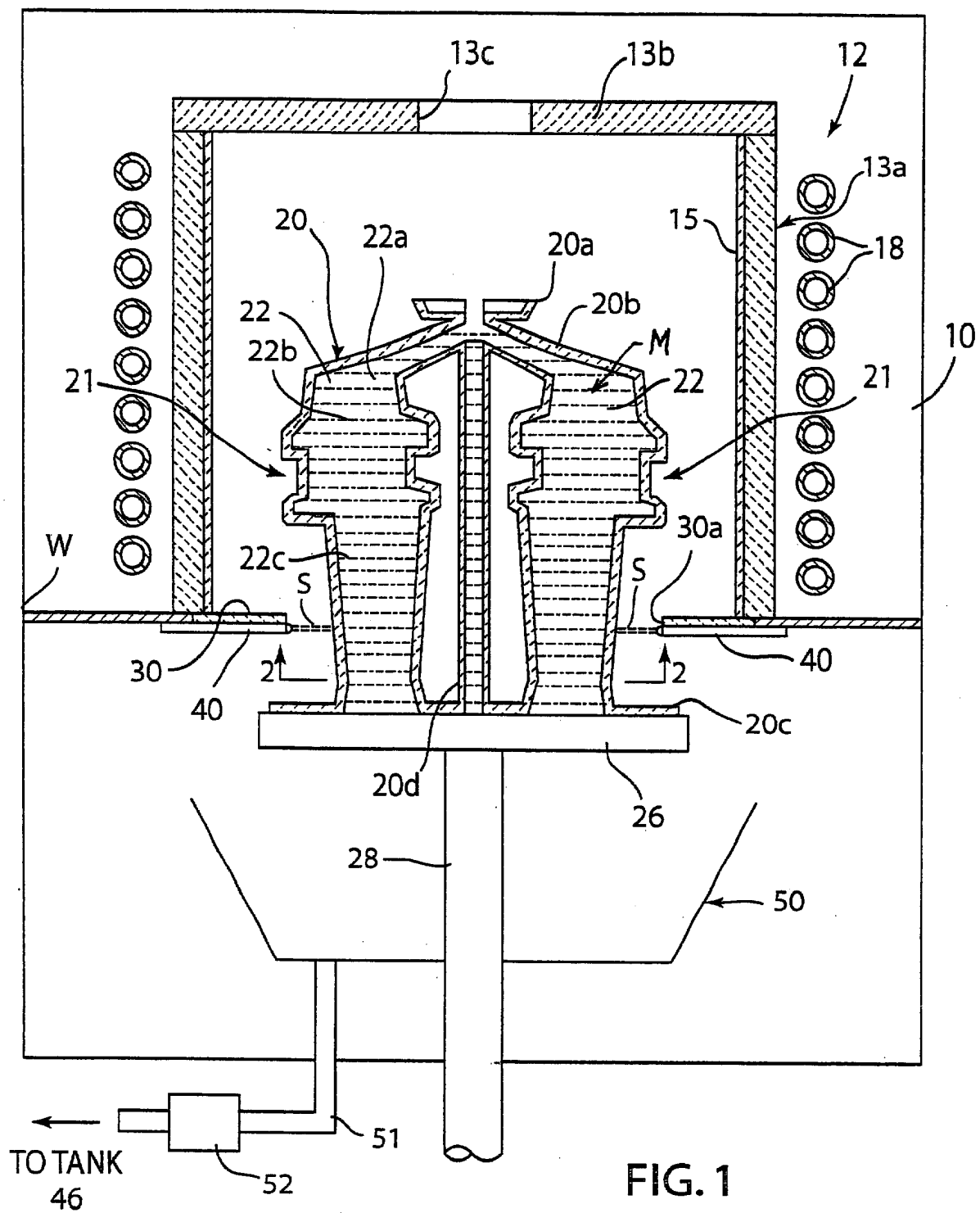
[0025] In lieu of using a plurality of individual nozzles 40 as described above, the invention envisions using other nozzle or orifice arrangements to generate one or more sprays S of the liquid cooling medium to impinge on the exterior mold surfaces. For example, as illustrated in Figure 3, the invention envisions using a manifold pipe 42' that has a plurality of individual orifices 42a' spaced about its inner periphery facing the mold 20 to generate the sprays S. Also, as shown in Figure 4, a manifold pipe 42" may be provided with an annular slit or slot orifice 42a" on its inner periphery facing the mold 20 to generate a spray S in the form an annulus or other suitable shape to impinge on the exterior mold surfaces.

[0026] Moreover, it is to be understood that the invention has been described with respect to certain specific embodiments thereof for purposes of illustration and not limitation. The present invention envisions that modifications, changes, and the like can be made therein without departing from the spirit and scope of the invention as set forth in the following claims.

Claims

1. Method of casting, comprising relatively moving a metallic melt-filled mold and a casting furnace to withdraw said metallic melt-filled mold from an end of a casting furnace and spraying a liquid cooling medium to impinge on exterior surfaces of said mold as said mold is withdrawn.

2. The method of claim 1 including disposing a plurality of spray nozzles below a thermal baffle at said end to discharge sprays of said cooling medium to impinge on said exterior surfaces.
3. The method of claim 1 or 2 including collecting said cooling medium after it impinges on said exterior mold surfaces and reusing it.
4. The method of one of the preceding claims wherein the cooling medium is selected from the group consisting of molten tin and molten aluminum.
5. The method of one of the preceding claims wherein said mold is withdrawn from said end of said casting furnace by moving a chill member on which said mold rests.
6. Method of directional solidification, comprising withdrawing a melt-filled mold from an end of a casting furnace disposed in a vacuum chamber by relative movement therebetween, spraying a liquid cooling medium to impinge on exterior surfaces of said mold as said mold is withdrawn, and collecting said cooling medium in said vacuum chamber after it impinges on said exterior mold surfaces.
7. The method of claim 6 including disposing a plurality of spray nozzles below a thermal baffle at said end to discharge sprays of said cooling medium to impinge on said exterior surfaces.
8. The method of claim 6 or 7 including reusing the collected cooling medium.
9. The method of one of claims 6 to 8 wherein the cooling medium is selected from the group consisting of molten tin and molten aluminum.
10. Directional solidification casting apparatus, comprising a casting furnace (12) having an open lower end, a metallic melt-filled mold (20), said furnace (12) and said metallic melt-filled mold (20) being relatively movable to withdraw said melt-filled mold (20) through said end out of said furnace (12), and means (40, 42, 44) for spraying a liquid cooling medium to impinge on exterior surfaces of said mold (20) as said mold (20) is moved out of said furnace (12).
11. The apparatus of claim 10 including a thermal baffle (30) at said lower end, said means (40, 42, 44) being disposed below said baffle.
12. The apparatus of claim 10 or 11 wherein said means (40, 42, 44) comprises a plurality of spray nozzles (40) disposed below a thermal baffle (30) at said end to discharge sprays of said cooling medium to impinge on said exterior surfaces.
13. The apparatus of one of claims 10 to 12 wherein said means (40, 42, 44) comprises an annular pipe (42) disposed below a thermal baffle (30) at said end and having one or more orifices to discharge one or more sprays of said cooling medium to impinge on said exterior surfaces.
14. The apparatus of one of claims 10 to 13 including means (50) for collecting said cooling medium after it impinges on said exterior mold surfaces.
15. The apparatus of one of claims 10 to 14 wherein the cooling medium is selected from the group consisting of molten tin and molten aluminum.
16. The apparatus of one of claims 10 to 15 including a chill member (26) on which said mold (20) is disposed and moved out of said end of said casting furnace (12) by moving said chill member (26) relative to said furnace (12).



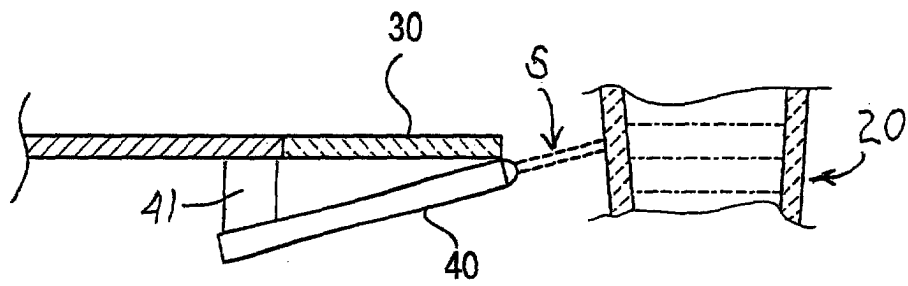


FIG. 1A

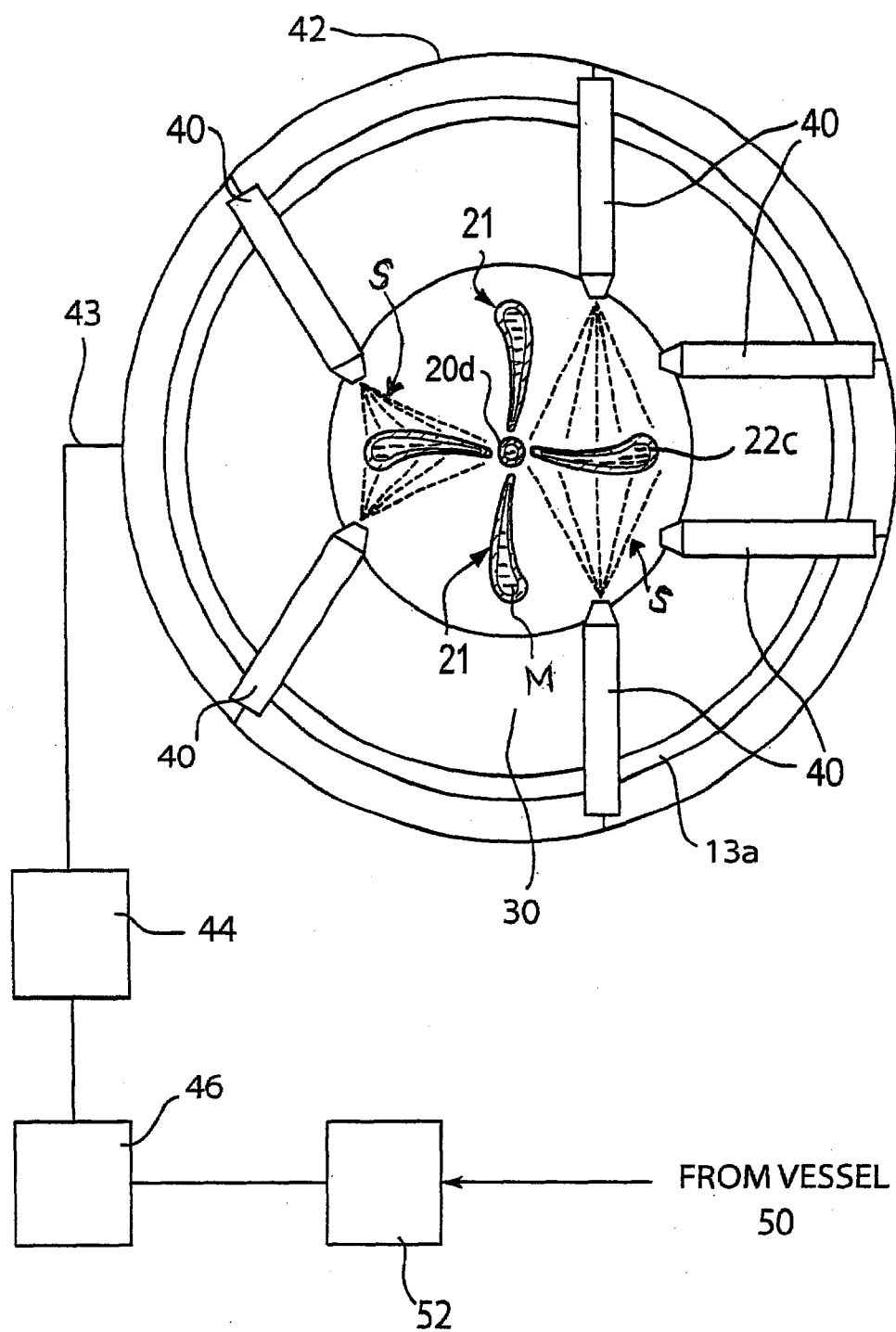


FIG. 2

