United States Patent [19]

Terkelsen

[11] **3,714,977**

[45] **Feb. 6, 1973**

[54] **METHOD AND APPARATUS FOR THE PRODUCTION OF DIRECTIONALLY SOLIDIFIED CASTINGS**

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[21] Appl. No.: **165,619**

[52] **U.S. Cl.** **164/60,** 164/125, 164/338

[51] **Int. Cl.** **B22d 27/06**

[58] **Field of Search**.....164/60, 125, 136, 338, 348

[56] **References Cited**

UNITED STATES PATENTS

3,532,155	10/1970	Kane et al.	164/60
2,214,976	9/1940	Stockbarger	23/273

OTHER PUBLICATIONS

"Process Speeds Up Directional Solidification," Erickson et al., Metal Progress, March, 1971, pp. 58–60.

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[57] **ABSTRACT**

In making directionally solidified castings, a vertically movable radiation shield is supported in such a way that it may move upwardly with respect to the mold and the mold heater to permit upward movement of the mold and the supporting chill plate into the surrounding heater but upon retraction of the mold from the heater the radiation shield will be supported adjacent to the lower end of the heater and continued downward movement of the mold will withdraw the latter through the shield.

8 Claims, 6 Drawing Figures

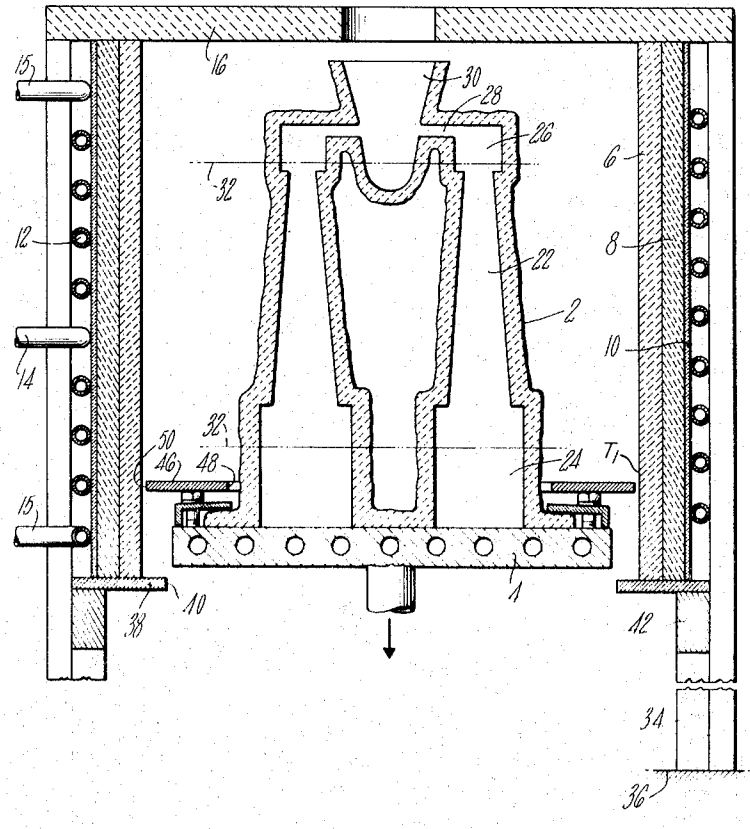
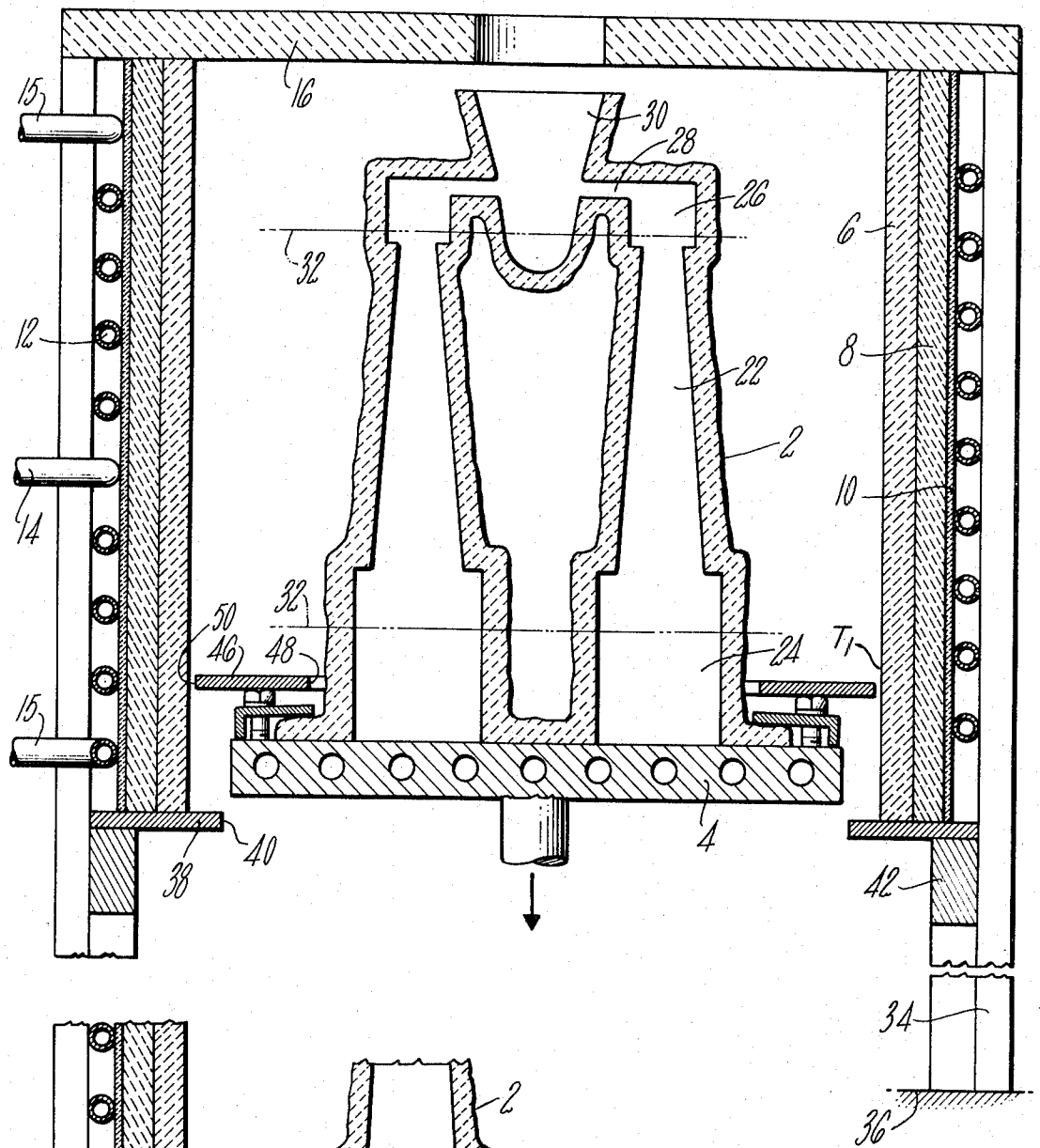


FIG. 1



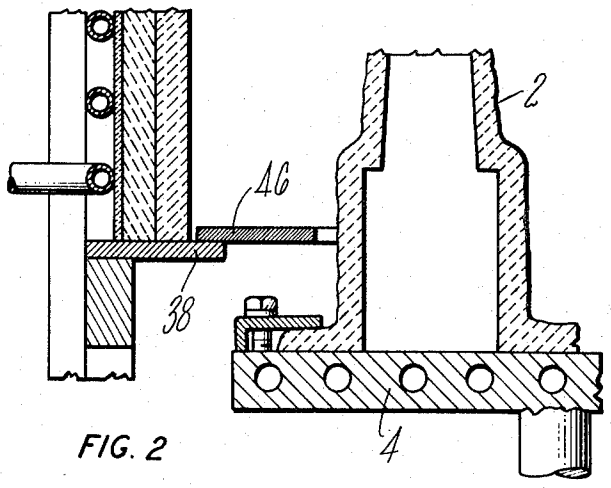


FIG. 2

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FIG. 3

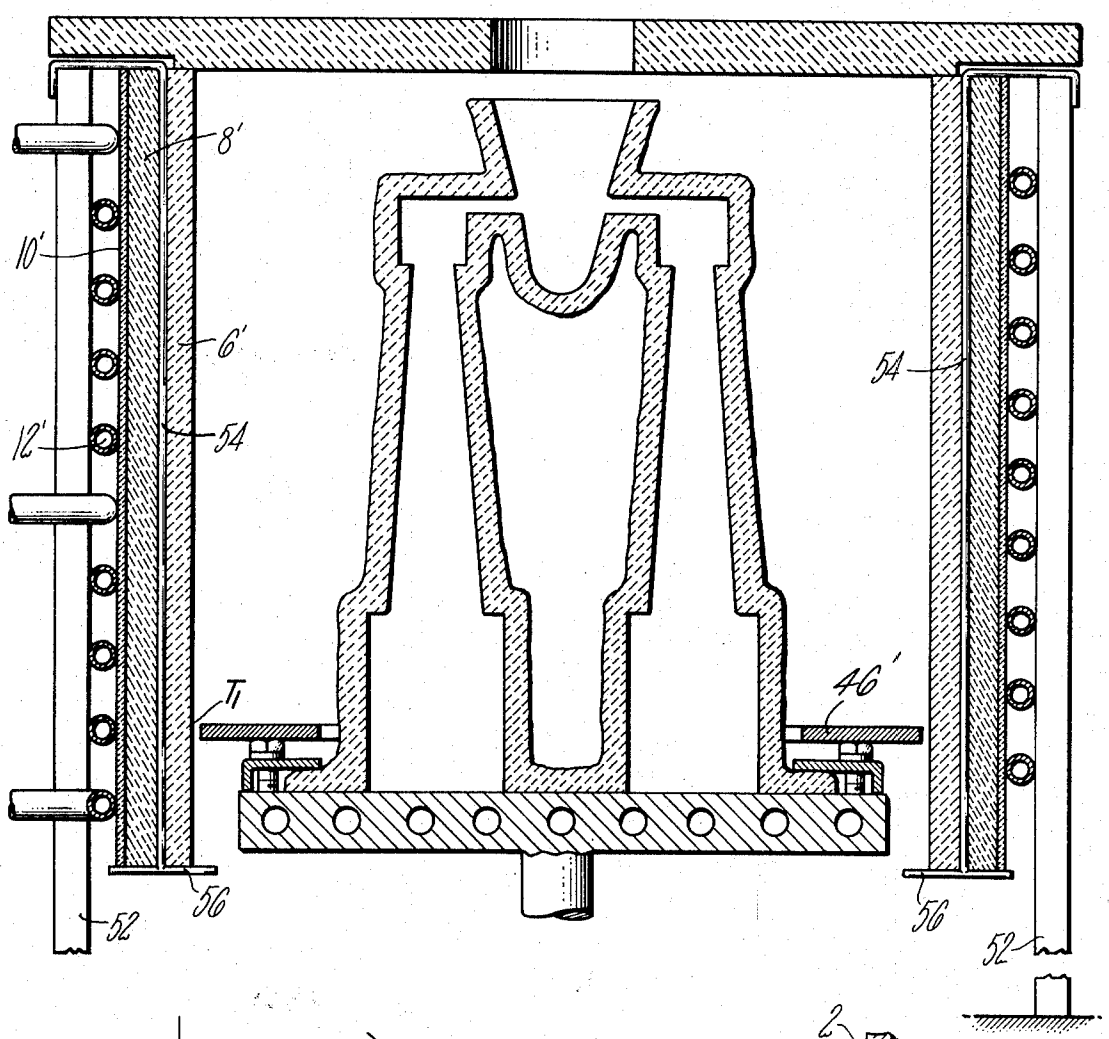
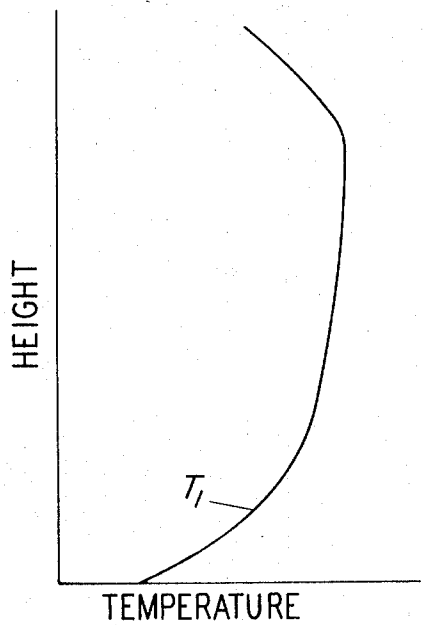


FIG. 4



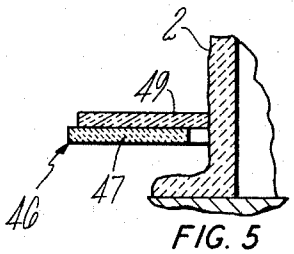


FIG. 5

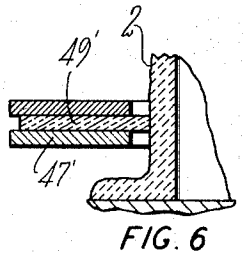


FIG. 6

METHOD AND APPARATUS FOR THE PRODUCTION OF DIRECTIONALLY SOLIDIFIED CASTINGS

SUMMARY OF THE INVENTION

The copending application of Barrow, et al, Ser. No. 63,143 filed Aug. 12, 1970, for PRODUCTION OF DIRECTIONALLY SOLIDIFIED CASTINGS, describes a radiation shield fixed adjacent to the lower end to the mold heater and closely surrounding the mold thereby to provide for the retention of heat above the shield and the removal of heat from the mold below the shield as the mold is withdrawn through the shield during the solidification process. The present invention is in some respects an improvement in that it allows an upward movement of the mold further into the hottest zone of the heater prior to the pouring thereby more effectively heating the portion of the mold adjacent to the chill plate.

One feature of the invention is a vertically movable radiation shield by which to permit the greater movement of the mold within the heater. Another feature is the arrangement for supporting this shield to permit its upward movement into the heater but to terminate the downward movement of the shield at a point close to the bottom end of the heater. Another feature is a process for casting directionally solidified articles utilizing a radiation shield of this movable type.

According to the invention, a radiation shield in the form of a disc with its inner edge closely fitting the mold, is supported against downward movement at a point adjacent to the bottom end of the surrounding mold heater and overlies the chill plate. The shield is so supported that it may move upwardly within the heater so that the mold and supporting chill plate may be moved upwardly into the heater thereby to locate the mold in the hottest part of the heater during the mold heating. In one arrangement the shield supports are located internally of the heater elements so that there are no obstructions below the heater to reduce the effective radiation from portions of the mold below the shield.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a vertical sectional view through an apparatus embodying the invention.

FIG. **2** is a fragmentary view similar to FIG. **1** with the mold in a lower position.

FIG. **3** is a view similar to FIG. **1** of a modification.

FIG. **4** is a plot of the temperature profile within the heater.

FIG. **5** is a fragmentary sectional view of the movable baffle.

FIG. **6** is a fragmentary sectional view of a modified baffle.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring first to FIG. **1**, the mold **2** which is shown as a gang mold for the production of two or more directionally solidified articles at one time, is positioned on a chill plate **4** and is located within a heating means which includes a cylinder in the form of a graphite susceptor **6**, the latter surrounded in turn by one

or more graphite felt sleeves **8** for insulation purposes and a surrounding insulating ceramic cylinder **10** which may be a quartz fiberboard sleeve. Outside of the cylinder **10** is an induction coil **12** which may be tapped as at **14** midway of the ends **15** to permit a separate control of the bottom half of the induction coil. In this way either half or all of the induction coil may be energized at one time for controlling the heat inside the susceptor. A suitable insulating cover **16** may be positioned on the upper end of the susceptor and overlying the cylindrical chamber defined by the susceptor. Suitable means are provided for withdrawing the chill downwardly to move the mold relative to the susceptor so that the mold may be withdrawn more or less out of the cylindrical chamber defined by the susceptor. The means for withdrawing the chill are not shown since any of the conventional actuating means as, for example, a hydraulic device may be utilized.

The particular mold shown is intended for the manufacture of two turbine blades at one time and to this extent the mold has two article forming cavities **22** each having a growth zone **24** projecting therefrom at the lower end and each having a riser **26** at the upper end. The risers are connected by gates **28** to a central filling spout **30**. The portion of the mold that produces the desired cast article, the turbine blade, extends between the dot-dash lines **32** shown on the mold. Mold constructions of this general character are shown, for example, in a patent to Piearcey U.S. Pat. No. 3,485,291. Obviously, other mold assemblies having a greater number of article forming cavities are equally usable.

The apparatus surrounding the mold may be supported as on posts **34** extending upwardly from a support **36**, the latter being, for example, the floor of a vacuum chamber within which the entire apparatus is positioned during the casting operations. A radiation shield **38** in the form of a disc located at the base of the susceptor sleeve **6** and the sleeve **8** and cylinder **10** projects inwardly therefrom and has a central opening **40** therein large enough to permit the upward motion of the chill plate therethrough. This radiation shield may be supported together with the susceptor sleeve and other parts of the apparatus as by heat resistant blocks **42** attached to the posts **34** supporting the baffle **38**, the latter also of suitable heat resistant material. In this way, the radiation shield stays in fixed relation at the bottom of the susceptor sleeve and permits vertical movement of the chill plate through this shield during retraction of the mold while solidification is occurring and also permits upward movement of the chill plate with the mold thereon through the shield for positioning the mold in the selected portion of the heater.

A floating radiation baffle **46** surrounds the mold and has its inner periphery **48** closely adjacent to the mold but of such a diameter that the mold may move therethrough as will be apparent. The outer diameter **50** of this shield is of such a dimension that it will move within the susceptor but will engage and rest upon the radiation shield **38** and be supported in this position during a downward movement of the chill plate and mold within the apparatus. This baffle **46** serves to contain the heat within the susceptor and prevent direct radiation from the susceptor both to the chill plate and to the portions of the mold below this baffle during a downward movement of the mold during this solidifica-

tion process. When the baffle **46** comes to rest on the shield **38** and stays in this position during the remainder of the withdrawal operation, the baffle **46** then serves in the same manner as the fixed baffle described in the copending application above-identified.

The baffle **46** is preferably a laminated structure as shown in FIGS. **5** and **6**. The baffle of FIG. **5** is a layer **47** of shell mold material with an overlying layer **49** of graphite felt. The two layers are suitably attached together and the inner periphery of the felt layer extends inwardly beyond the periphery of the shell mold material substantially into contact with the mold. Since this felt is flexible to a degree, the mold may move freely past the edge of this felt layer, even deforming the latter to some extent if necessary. With such close contact, there is no significant leakage of heat around the inner periphery of this felt layer and also no significant radiation of heat past this baffle. The shell mold disc may be made by the usual dipping process for making shell molds.

Alternatively, the baffle may be made as in FIG. **6** and consists of two discs **47'** of refractory metal or alloy such as tantalum or molybdenum between which is sandwiched a disc **49'** of graphite felt. This arrangement provides a baffle construction that may be readily adapted to different mold constructions as the sheet metal and felt may both be readily cut to the desired configuration. In this arrangement, the felt layer extends inwardly beyond the metal layers and has its inner edge in contact with or closely spaced from the mold surface and is flexible enough to conform to irregularities in the mold surface. The several layers are suitably secured together to function as a unit.

Under certain circumstances, it has been found difficult to maintain or obtain the desired temperature in the mold adjacent to the chill plate by reason of the temperature profile that develops within the mold heater during the heating of the mold. As shown in FIG. **4**, the temperature is relatively low at the bottom of the susceptor and becomes higher a short distance above the bottom of the susceptor. The temperature within the heater then continues to increase slowly to a point adjacent the upper end of the susceptor. Above this point the temperature gradually decreases again to the top of the susceptor. The temperature T_1 represents the desired mold temperature for pouring the alloy.

It is desirable to have the temperature of the mold immediately above the baffle **46** closely approximating the pouring temperature of the alloy. To accomplish this, it is desirable to have the portion of the mold immediately above the baffle **46** positioned high enough within the susceptor so that it is exposed to this temperature within the susceptor as represented by the point T_1 in FIG. **1**. With a floating baffle of the type shown, it is possible to move the mold upwardly within the susceptor into the position shown in FIG. **1**, so that the point T_1 of the susceptor and of FIG. **4** will be almost on the same level as the baffle.

In use, the apparatus is positioned as an entity within a vacuum chamber so that by evacuation of the chamber the entire apparatus shown may be evacuated including the volume defined within the susceptor. When the chamber has been evacuated, the mold is heated while the parts are in the position of FIG. **1** so that the mold itself reaches a temperature effectively above the melting temperature of the alloy to be poured. With the mold and chill plate in the position of FIG. **1**, it is apparent, as above noted, that the portion of the mold immediately above the baffle **46** is in a temperature zone such that this portion of the mold will reach the desired pouring temperature. Positioning of the mold in this location is made possible by the fact that the baffle **46**, being floating, is thereby so arranged that it may move upwardly from the supporting shield **38** to permit the mold, chill plate and baffle all to be moved upwardly into the position shown in this figure. It will be understood that during the heating of the mold, water is circulated through the chill plate to prevent damage to the latter, although the temperature of the mold relatively close to the chill plate is successfully raised to a temperature above that at which the alloy is poured.

The mold is kept in this position while the alloy is poured into the mold, the temperature of the latter being preferably from 200°–300° F above the normal melting temperature. After the alloy is poured into the mold, the chill plate and mold are kept in the position in FIG. **1** for a short time, for example, five minutes, to allow solidification to start upward from the chill plate. At the end of this time interval, withdrawal of the mold is begun in a downward direction at a continuous rate which may, for example, be four inches per hour. As the chill plate and mold are moved downwardly, the radiation shield or baffle **46** moves with them until the baffle engages the shield **38**. Continued downward movement withdraws the mold from within the baffle **46** and during the continued movement the baffle serves to function in the manner of the fixed baffle of the earlier application. This baffle serves to establish a sharp line of demarkation between the heated zone, surrounded by the susceptor and the cooling or radiation zone directly below the baffle. The particular function of making the baffle movable as above described is to permit upward movement of the mold further into the susceptor than would be possible if the baffle were a fixed extension of the shield **38**.

The arrangement of FIG. **3** is similar to the arrangement of FIG. **1** except that the supporting blocks for the baffle **38** have been eliminated and thereby the blockage to the radiation of heat from the mold below the baffle is minimized. To accomplish this result, the induction coil **12'** is supported on posts **52** but hangers **54** extending downwardly from the top of the posts **52** support the susceptor **6'** and the surrounding sleeve **8'** and the insulating sleeve **10'**. These hangers have a bar **56** at the base underlying these sleeves and supporting them in position. This arrangement has the advantage that it permits a sharper line of demarkation between the heated portion of the mold above the baffle **46'** and the cooled portion of the mold below the baffle since radiation of heat from the mold below the baffle is not impeded by the supporting blocks shown in FIG. **1**.

The baffle **46'** is similar to the baffle **46** having an inner periphery closely fitting the mold and an outer periphery to move within the susceptor but to rest on the inner ends of the bars **56** which project inwardly beyond the susceptor **6'** as the mold is withdrawn downwardly. Once the mold begins to be exposed below the baffle **46'** when the latter comes to rest on the bars **56** as the mold is being withdrawn, the mold

will radiate heat therefrom to the surrounding cooled walls of the vacuum chamber at a substantial rate for rapid cooling of the mold while the portion of the mold above the baffle will continue to be heated from the susceptor. In other respects, the functioning of the arrangement of FIG. 3 is the same as that in FIG. 1.

In casting turbine blades, for example, a turbine blade having a length including the root portion of 4 and ½ inches and a growth portion of the bottom end of the mold substantially 1 inch long, the top of the completed cast article would be located at a point five and one-half inches above the chill plate with the gating end of the filling spout positioned thereabove. In making the casting, the alloy is poured into the mold, the latter having been heated to approximately 2750° F. The alloy is poured at a temperature of 2800° F which is about 250° above the melting point of the alloy so that a significant super heat is provided. After pouring, the chill plate is held in the position shown in FIG. 1 for about five minutes, for example, to allow solidification to start upward from the chill plate. At the end of this interval, withdrawal is begun at a continuous rate of 4 inches per hour and continued for 4 minutes. At this time the withdrawal rate is increased to 8 inches per hour. Thirty-eight minutes after pour, the mold is completely withdrawn at the highest rate permitted by the machine to a point where the mold can be removed from the chill plate. It will be understood that the time interval for withdrawing the mold from the heater during the first portion of the withdrawal movement will be determined by the position of the chill plate and mold at the beginning of the casting operation. It will be apparent that only a small amount of radiation cooling of the mold occurs until the floating baffle has moved down into contact with the fixed shield **38** so that portions of the mold will be moved downwardly and exposed below the floating baffle. Prior to this time there is no significant amount of cooling occurring on this part of the mold.

I claim:

1. Casting apparatus for directionally solidified articles including

a cylinder providing an enclosure,

means for heating said cylinder to impart heat to a mold in said enclosure,

a chill plate located at one end of said cylinder on which the mold is positioned,

means for moving said chill plate relative to said cylinder for withdrawing the mold from said cylinder,

a radiation shield extending inwardly from the cylinder at the base thereof and overlying the chill plate, said shield extending inwardly substantially to a mold on said chill plate, and

stop means for limiting the downward movement of the radiation shield beyond a point substantially coinciding with the base of the cylinder, the outer periphery of the shield being slightly spaced from the cylinder to permit upward movement of the shield within said cylinder.

2. Apparatus as in claim **1** in which the inner periphery of the shield conforms closely with the configuration of the mold but slightly spaced therefrom so that the mold may be withdrawn through said shield.

3. Apparatus as in claim **1** in which the cylinder is a susceptor and the heating means is a surrounding induction coil.

4. In the casting of the directionally solidified articles, the steps of

positioning a shell mold for the article on a chill plate,

providing a heating means surrounding said mold for heating said mold to a temperature above the melting point of the alloy to be cast,

cooling the end of the mold resting on the chill plate pouring molten alloy into the mold,

withdrawing the mold partially from the heating means for more rapid cooling of the mold than is accomplished by the chill plate

providing a barrier closely surrounding the mold and movable relative thereto to define, as the mold is withdrawn from the heating means, a dividing line between the cooled and heated portions of the mold,

supporting said barrier on said chill plate so that the latter with the mold thereon may be moved upwardly into the heating means, and

limiting the downward movement of the barrier to a point adjacent the lower end of the heating means as the mold is withdrawn from the heating means.

5. The process of claim **4** including the step of withdrawing the mold past the barrier substantially at the rate of solidification of the alloy.

6. The process of claim **4** including the step of withdrawing the mold past the barrier at such a rate as to maintain a liquid-solid interface at a selected distance above the barrier during the solidification of the alloy.

7. Casting apparatus as in claim **1** in which the radiation shield is a laminated construction with at least one relatively rigid layer, and at least one relatively flexible layer with the inner periphery of the flexible layer extending inwardly beyond the edge of the rigid layer and substantially into contact with the mold surface.

8. Casting apparatus as in claim **7** in which the flexible layer is a graphite felt.

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