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(54) **HORIZONTAL DIRECT CHILL CASTING APPARATUS AND METHOD**

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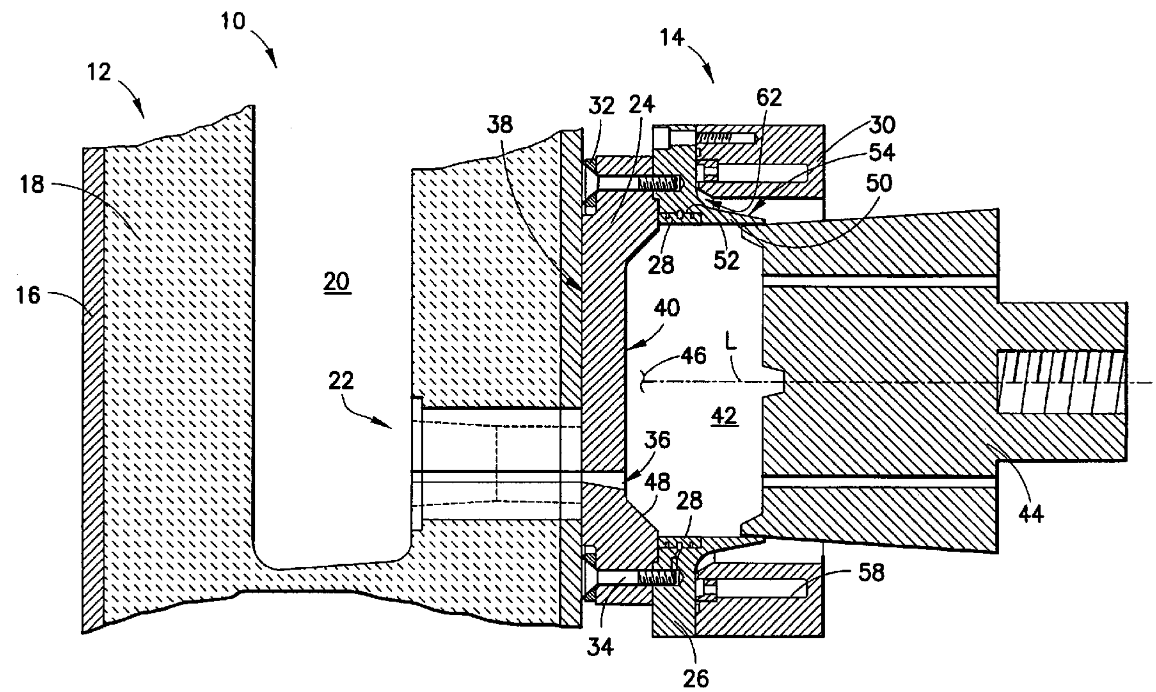
(57) **ABSTRACT**

A casting apparatus (**10**) for direct chill casting metal includes a tundish (**12**) containing a supply of molten metal, a casting mold (**14**), and a starter block (**44**) associated with the casting mold (**14**). The casting mold (**14**) is in fluid communication with the tundish (**12**) through a passage (**22**) defined in the tundish wall. The casting mold (**14**) includes a header plate (**24**), a casting ring (**26**), and a feed ring (**28**). The header plate (**24**) defines an arcuate shaped opening (**36**) connected to the passage (**22**). The header plate (**24**) has an upstream side (**38**) and a downstream side (**40**). The casting ring (**26**) is connected to the downstream side (**40**) of the header plate (**24**) and defines a groove (**52**) proximate to the sidewall (**48**) of the header plate (**24**). The feed ring (**28**) is disposed in the groove.



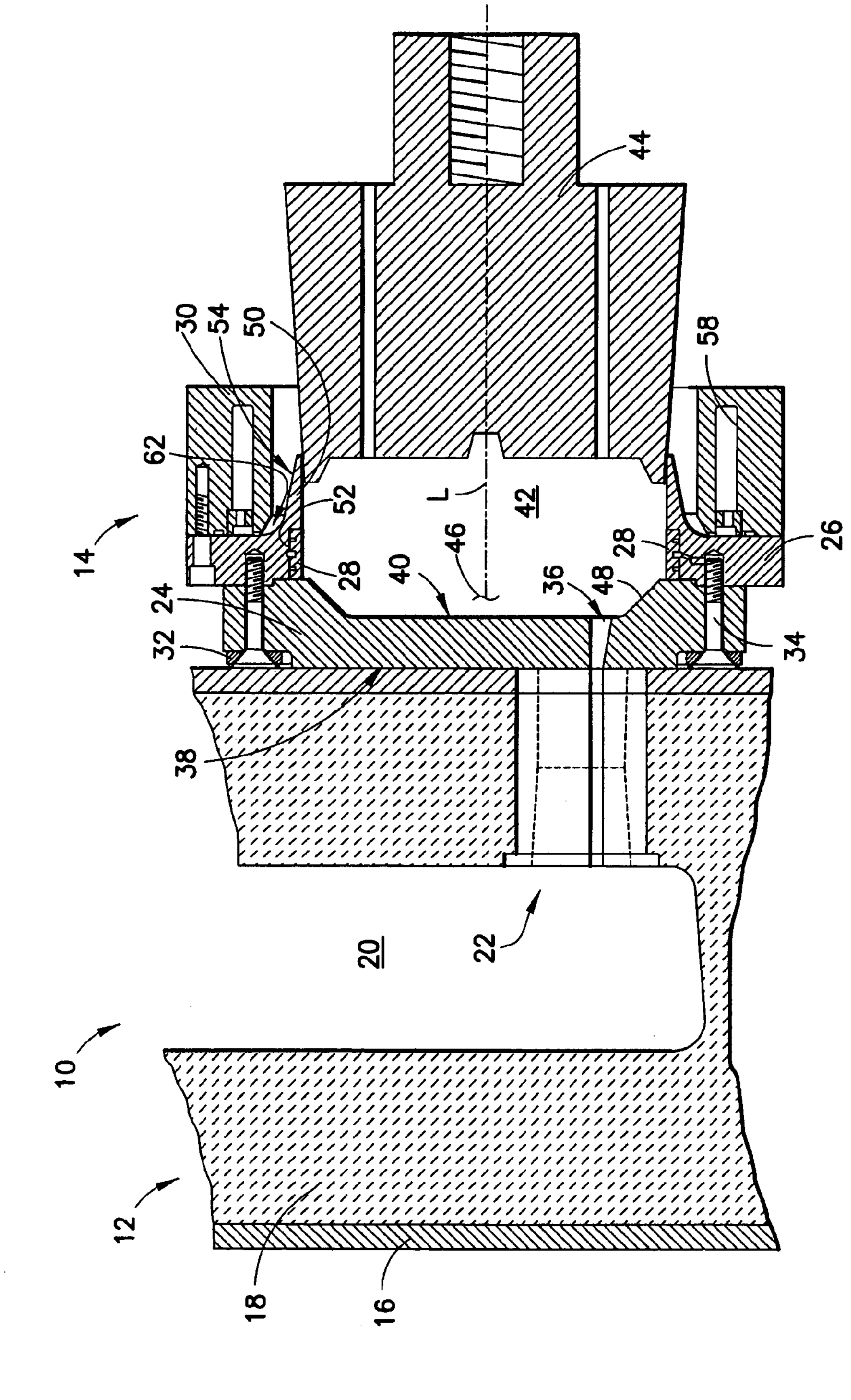

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FIG. 1

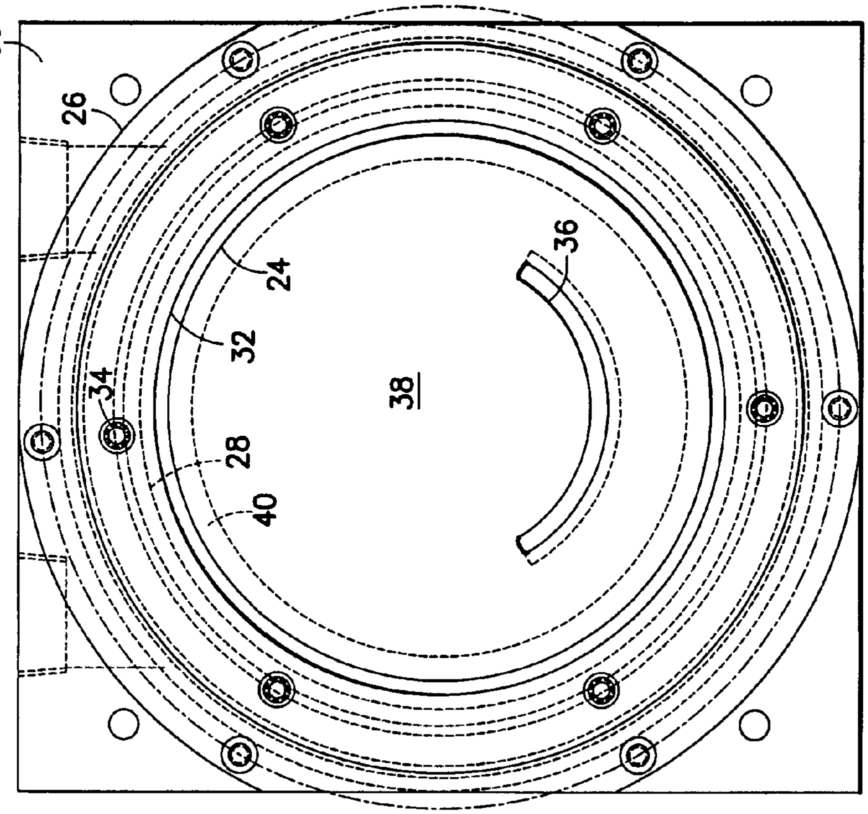
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FIG.3

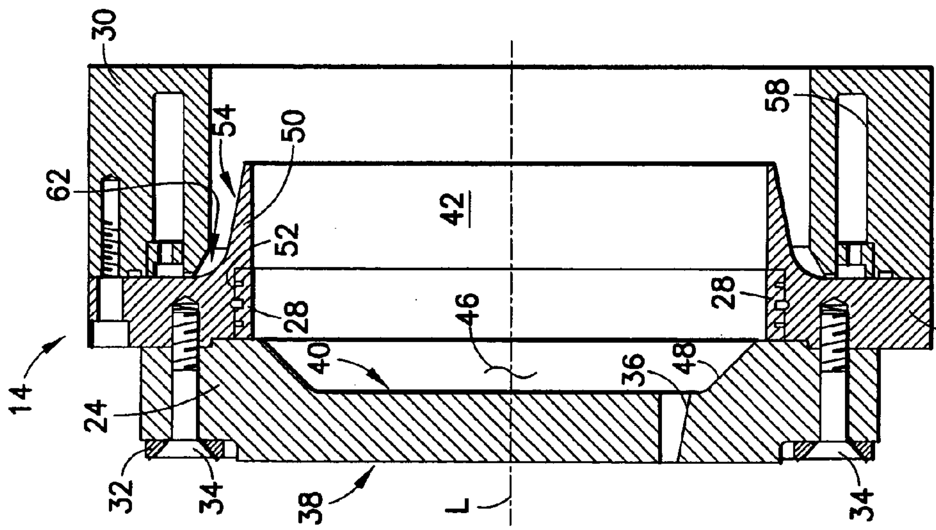
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FIG.2

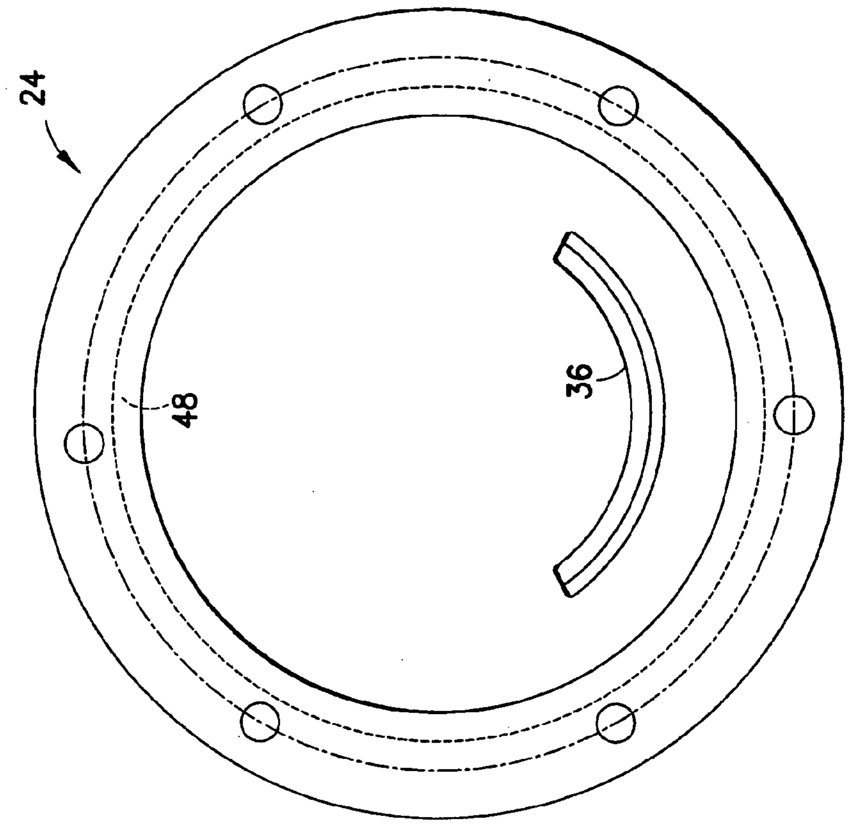

FIG.5

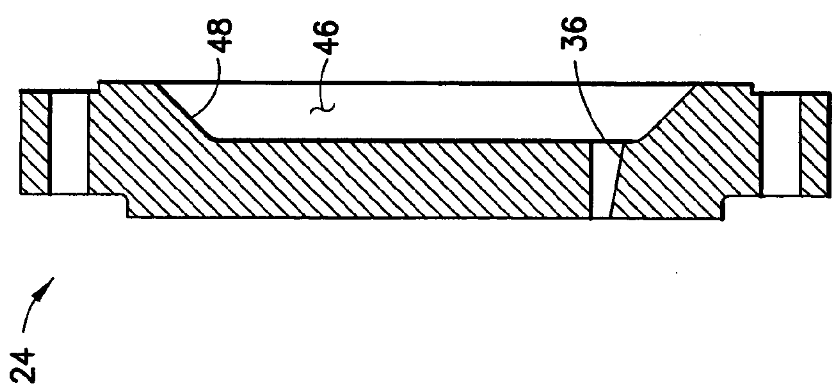

FIG.4

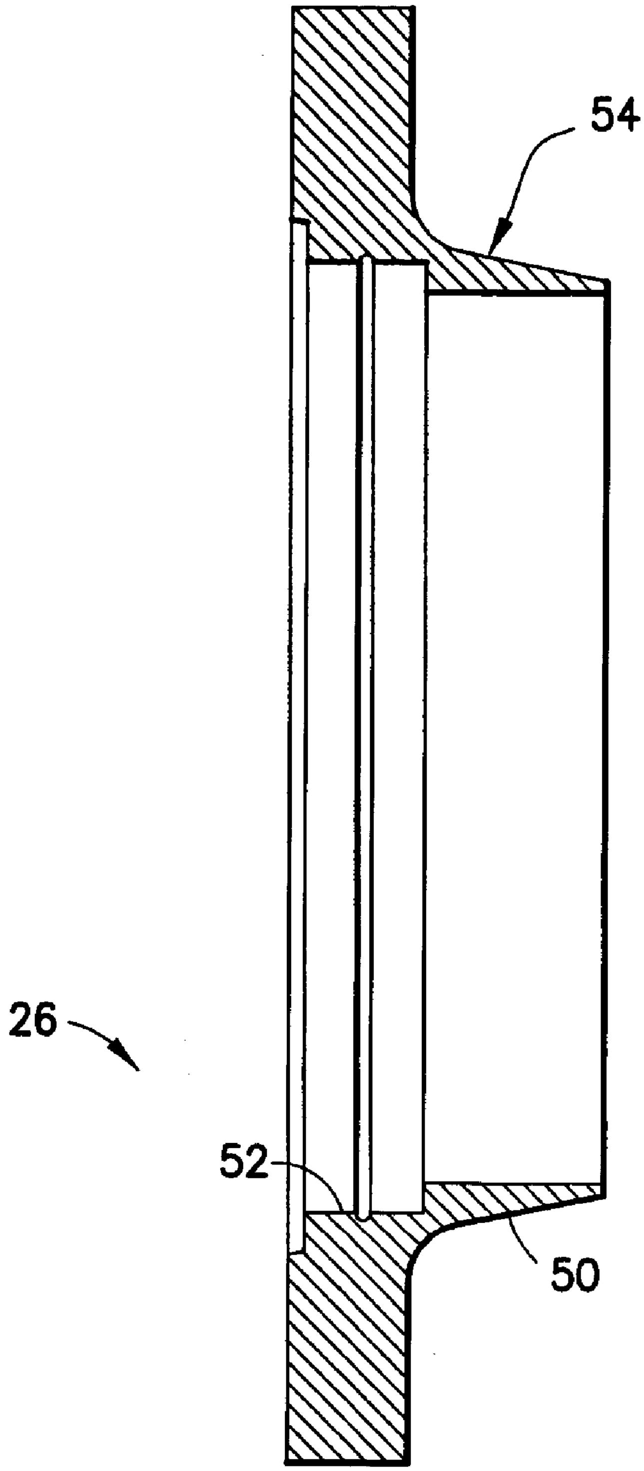

FIG.6

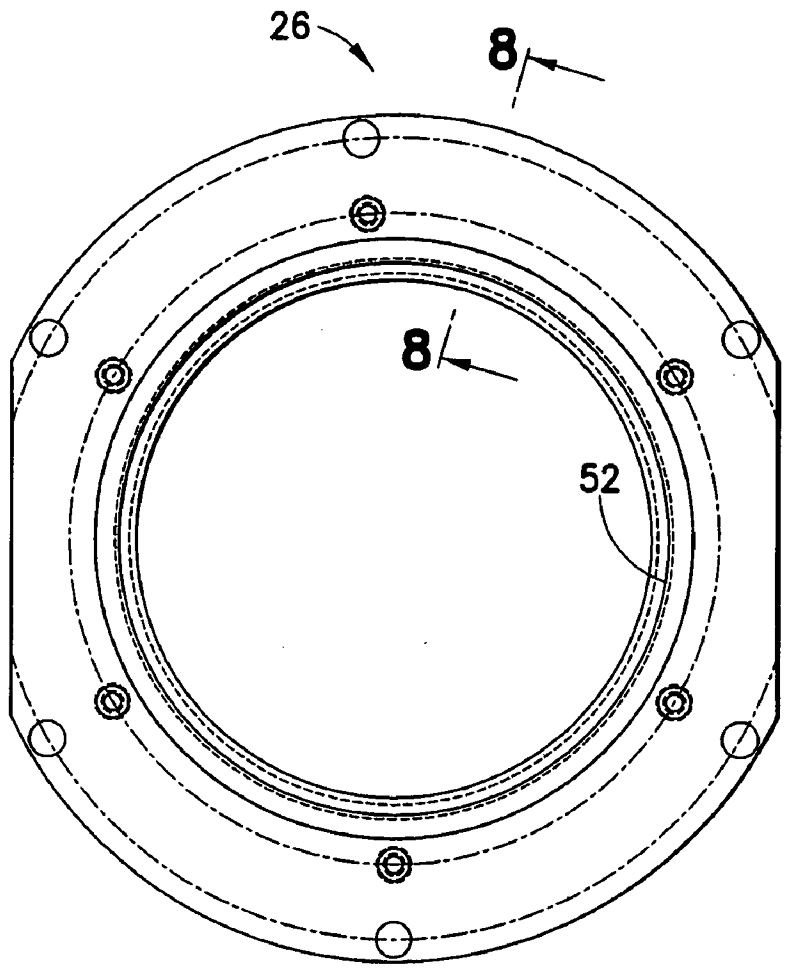

FIG.7

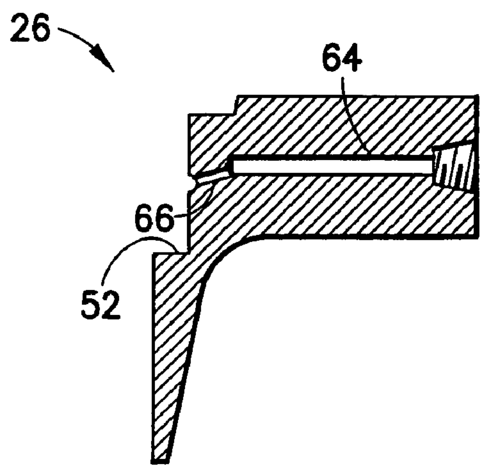

FIG.8

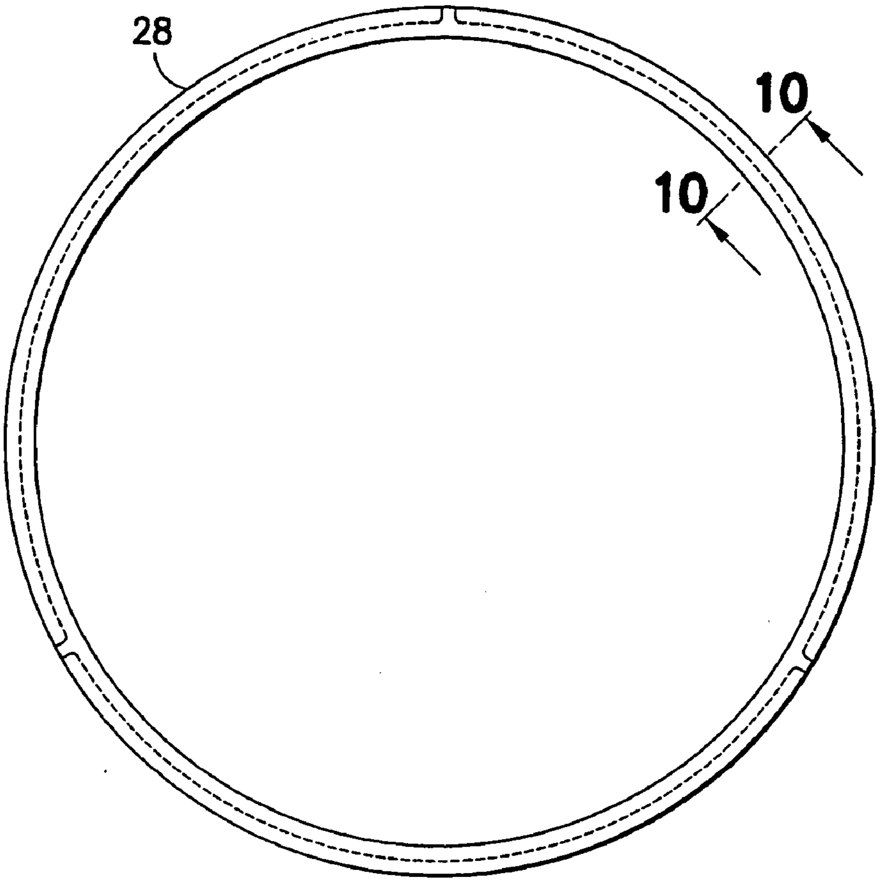

FIG.9

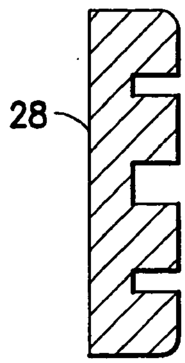

FIG. 10

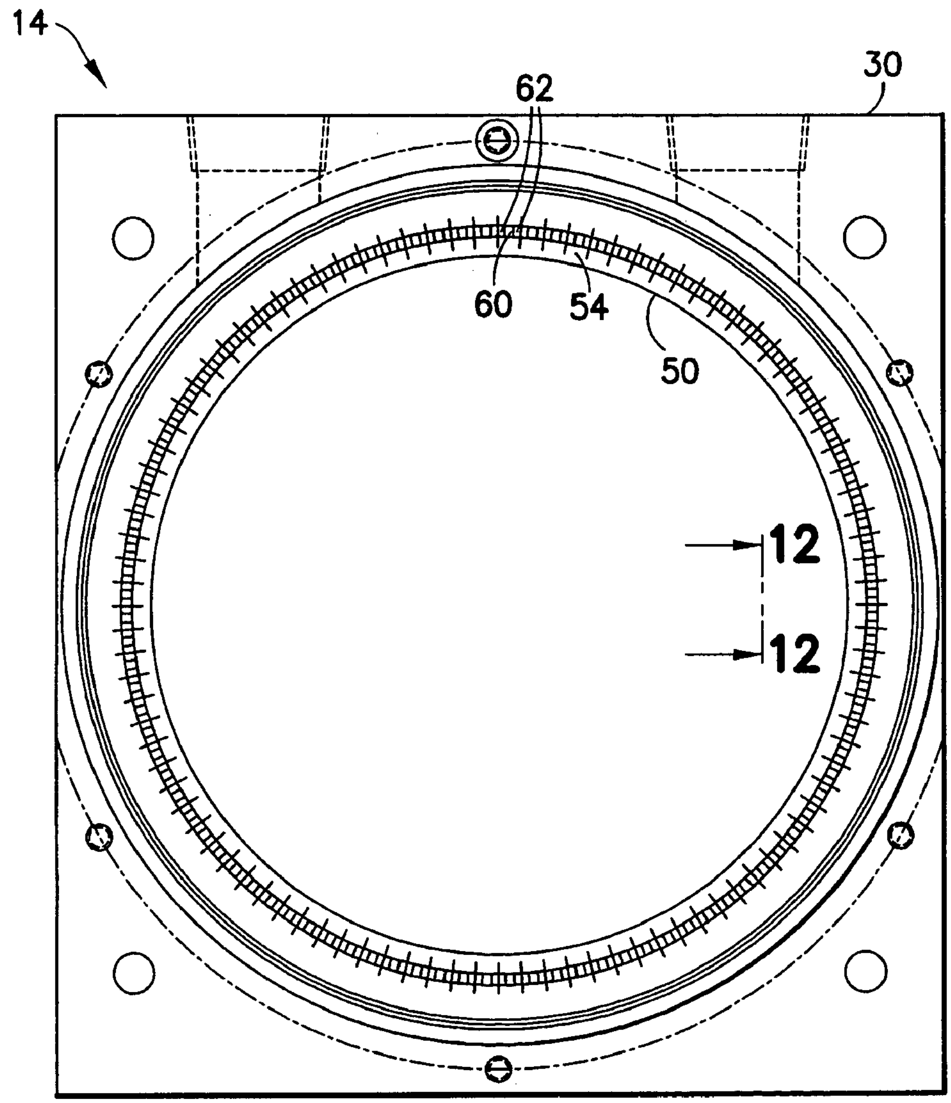

FIG. 11

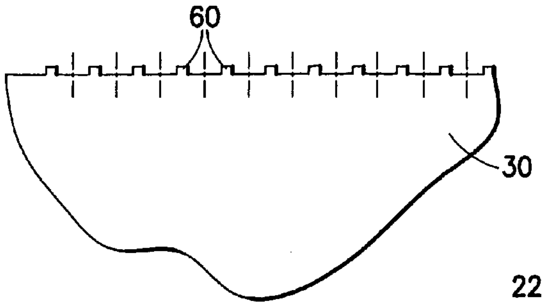

FIG.12

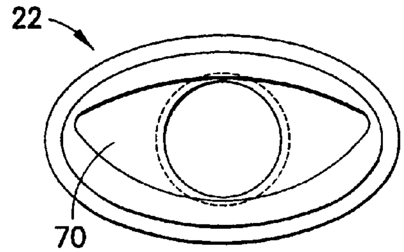

FIG.13

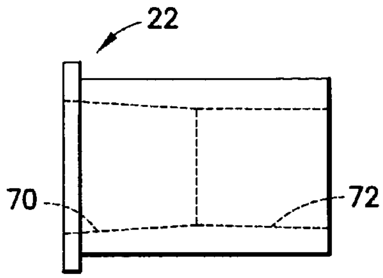

FIG.14

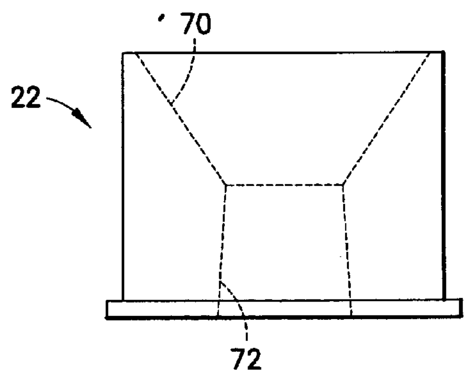

FIG.15

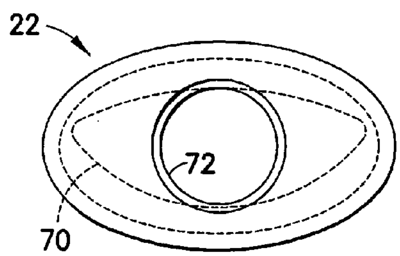

FIG.16

HORIZONTAL DIRECT CHILL CASTING APPARATUS AND METHOD

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates generally to direct chill casting machines. More particularly, the present invention relates generally to horizontally oriented direct chill casting machines adapted to produce metal articles of indefinite length. Further, the present invention is directed to methods of direct chill casting metals, such as aluminum, into elongated metal articles, such as billets, rods, slabs, etc.

[0003] 2. Description of Related Art

[0004] Direct chill casting is a well-known technique in the art for casting metal, such as aluminum, into elongated metal articles such as billets. When casting molten metal in such a fashion, the molten metal is generally introduced into a vertically oriented and open-ended mold cavity having a support located at the discharge end. The support, or bottom block, is lowered slowly while the molten metal flows downward in the cavity. The wall of the direct chill casting mold is continuously cooled so that a solid skin of metal forms in contact with the wall. The metal is fully solidified further downstream in the mold cavity to form the elongated metal article.

[0005] A recent improvement in direct chill casting techniques is the use of a graphite or graphite-like ring in the wall of the direct chill casting mold. The graphite ring generally forms a solid but fluid permeable wall section in the mold cavity. One example of a direct chill casting apparatus or casting mold incorporating a graphite or graphite-like ring is disclosed in U.S. Pat. No. 4,598,763 to Wagstaff et al.

[0006] In the Wagstaff '763 patent, the graphite ring is located below a peripheral wall in a vertically oriented mold cavity of the casting mold. The peripheral wall is formed by a ring of insulative refractory material. The peripheral wall defines a sharp corner or overhang immediately upstream of the graphite ring. The graphite ring is fluid permeable. During operation of the casting mold, the graphite ring is supplied with lubricating oil and gas, which at least partially solidifies the molten metal flowing downward in the mold cavity (i.e., forms a solid skin of metal). The fluid permeable graphite ring allows the lubricating oil and gas to diffuse therethrough. Several other Wagstaff et al. patents are known in the field and which each generally disclose the use of a graphite ring in a direct chill casting mold and, particularly, a vertically-oriented direct chill casting mold. Additional pertinent Wagstaff et al. patents in the field include U.S. Pat. Nos. 5,582,230; 5,323,841; 5,318,098; and 4,947,925. Each of the Wagstaff et al. patents identified hereinabove is incorporated herein by reference.

[0007] The Wagstaff '098 patent discloses a conventional, vertically oriented direct chill casting mold incorporating a graphite ring. This reference further discloses a liquid coolant discharge device for solidifying the molten metal downstream of the graphite ring. The coolant device is in the form of a liquid coolant box that defines a plurality of holes for supplying liquid coolant onto the surface of the metal passing downward from the graphite ring. The holes are downward directed (i.e., angled) to discharge the coolant onto the metal body generally formed at the graphite ring.

[0008] U.S. Pat. No. 4,947,925 to Wagstaff et al. discloses a direct chill casting mold that is generally configured to form rectangular cross section ingots and the like. The casting ring used in the casting mold disclosed by this reference is divided into four (4) generally rectilinear wall segments that are secured together with mechanical fasteners.

[0009] U.S. Pat. No. 5,582,230 to Wagstaff et al. discloses a direct chill casting mold that incorporates a similar downstream coolant device to that disclosed in the Wagstaff '098 patent. The coolant device is adapted to apply liquid coolant directly on the outer surface of the semi-solidified metal passing downward from the graphite ring when the casting mold is in use. The mold cavity is provided with a plurality of fluid discharge openings through which pressurized jets of fluid are discharged onto the surface of the semi-solidified metal. The liquid cooling streams or jets are discharged through two sets of openings.

[0010] While direct chill casting molds incorporating a graphite or graphite-like ring are known in the art, there still remains room for improvement in the field, particularly at the interface between the graphite ring and the molten metal in the mold cavity of the direct chill casting mold during operation of the casting mold.

SUMMARY OF THE INVENTION

[0011] The present invention relates generally to a casting apparatus for direct chill casting metal along a horizontal axis. The casting apparatus comprises a tundish for containing a supply of molten metal, a casting mold, and a starter block associated with the casting mold. The casting mold is in fluid communication with the tundish through a passage defined in the tundish wall. The casting mold is generally comprised of a header plate, a casting ring, and a feed ring. The header plate defines an arcuate shaped opening connected to the passage. The header plate has an upstream side and a downstream side. The downstream side defines a recess having a tapered sidewall. The casting ring is connected to the downstream side of the header plate and defines a groove proximate to the sidewall of the header plate. The feed ring is disposed in the groove for cooling and at least partially solidifying molten metal flowing through the casting mold. The starter block is generally positioned within the casting ring.

[0012] The sidewall of the header plate preferably tapers outward from a central axis of the casting mold. The sidewall may taper directly to the feed ring. The feed ring is preferably made of graphite. The feed ring may be fluid permeable and the casting ring may be configured to supply cooling and lubricating fluid to the feed ring. A cooling ring may be connected to the casting ring. The cooling ring may define a plurality of raised teeth. The cooling ring may cooperate with the casting ring such that the teeth form a plurality of spray nozzles for delivering cooling fluid sprays at least to the casting ring during operation of the casting mold. The cooling ring may define an annular chamber in fluid communication with the spray nozzles. The annular chamber may be adapted to supply cooling fluid to the spray nozzles for application at least to the casting ring during operation of the casting mold.

[0013] The feed ring may be connected to the casting ring by a threaded connection. The arcuate shaped opening may comprise a diverging opening. The passage defined in the tundish wall may be at least partially convergent.

[0014] The present invention also relates generally to casting molds for direct chill casting metal. The casting mold of the present invention generally comprises a header plate, a casting ring, and a feed ring. The header plate defines an arcuate shaped opening. The header plate has an upstream side and a downstream side. The downstream side defines a recess having a tapered sidewall. The casting ring is connected to the downstream side of the header plate and defines a groove proximate to the sidewall of the header plate. The feed ring is disposed in the groove for cooling and at least partially solidifying molten metal flowing through the casting mold.

[0015] Further, the present invention relates to methods of direct chill casting metal. In the method of the present invention, the direct chill casting apparatus generally comprises a tundish, a casting mold, and a starter block associated with the casting mold. The tundish contains a supply of molten metal. The casting mold is in fluid communication with the tundish through a passage defined in the tundish wall. The casting mold is generally comprised of a header plate, a casting ring, and a feed ring. The header plate defines an arcuate shaped opening connected to the passage. The header plate has an upstream side and a downstream side. The downstream side defines a recess having a tapered sidewall. A casting ring is connected to the downstream side of the header plate and defines a groove proximate to the sidewall of the header plate. The feed ring is disposed in the groove for cooling and at least partially solidifying molten metal flowing through the casting mold.

[0016] The method generally comprises withdrawing the starter block in the casting ring, delivering molten metal to the casting mold through the tundish passage in the tundish wall and the arcuate shaped opening in the header plate, and cooling and at least partially solidifying the molten metal at the feed ring to form a metal article. The step of delivering molten metal may comprise the molten metal diverging outward in the casting mold along the sidewall of the header plate before contacting the feed ring. The feed ring may be fluid permeable and the casting ring may be configured to supply cooling and lubricating fluid to the feed ring. The method may comprise supplying the cooling and lubricating fluid to the feed ring to cool and at least partially solidify the molten metal at the feed ring.

[0017] A cooling ring may be connected to the casting ring. The cooling ring may define a plurality of raised teeth and cooperate with the casting ring such that the teeth form a plurality of spray nozzles. The method may further comprise delivering cooling fluid sprays at least to the casting ring through the spray nozzles to cool the casting ring during operation of the casting mold. The cooling ring may define an annular chamber in fluid communication with the spray nozzles. The method may further comprise the supplying of cooling fluid from the annular chamber to the spray nozzles.

[0018] Further details and advantages of the casting apparatus and method of direct chill casting metal of the present invention will become apparent when reading the following detailed description in conjunction with the drawing figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] **FIG. 1** is a cross sectional view of a horizontal direct chill casting apparatus comprising a tundish and casting mold in accordance with the present invention;

[0020] **FIG. 2** is a cross sectional view of the casting mold used in the casting apparatus of **FIG. 1**;

[0021] **FIG. 3** is a front view of the casting mold of **FIG. 2**;

[0022] **FIG. 4** is a cross sectional view of a header plate used in the casting mold shown in **FIGS. 1 and 2**;

[0023] **FIG. 5** is a front view of the header plate of **FIG. 4**;

[0024] **FIG. 6** is a cross sectional view of a casting ring used in the casting mold shown in **FIGS. 1 and 2**;

[0025] **FIG. 7** is a front view of the casting ring of **FIG. 6**;

[0026] **FIG. 8** is a cross sectional view taken along line **8-8** in **FIG. 7**;

[0027] **FIG. 9** is a plan view of a feed ring used in the casting mold shown in **FIGS. 1 and 2**;

[0028] **FIG. 10** is a cross sectional view taken along line **10-10** in **FIG. 9**;

[0029] **FIG. 11** is a discharge end view of the casting mold of **FIG. 2** showing a cooling ring used in the casting mold of **FIGS. 1 and 2**;

[0030] **FIG. 12** is a cross sectional view taken along line **12-12** in **FIG. 11**;

[0031] **FIG. 13** is a tundish side view of a tundish opening connecting the tundish and casting mold in the casting apparatus of **FIG. 1**;

[0032] **FIG. 14** is a cross sectional view taken along a vertical axis of the tundish opening of **FIG. 13**;

[0033] **FIG. 15** is a cross sectional view taken along a horizontal axis of the tundish opening of **FIG. 13**; and

[0034] **FIG. 16** is a casting mold side view of the tundish opening of **FIGS. 13-15**.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0035] For purposes of the description hereinafter, the terms "upper", "lower", "right", "left", "vertical", "horizontal", "top", "bottom", and derivatives thereof shall relate to the invention, as it is oriented in the drawing figures. However, it is to be understood that the invention may assume various alternative variations and step sequences except where expressly specified to the contrary. It is also to be understood that the specific devices and processes illustrated in the attached drawings and described in the following text are simply exemplary embodiments of the invention. Hence, specific dimensions and other physical characteristics related to the embodiments disclosed hereinafter are not to be considered limiting.

[0036] Referring to the **FIG. 1**, the present invention is a casting apparatus **10** adapted to direct chill cast solid cross section metal articles (not shown). The casting apparatus **10** is generally comprised of a tundish **12** and a casting mold **14** in fluid communication with the tundish **12**. The tundish **12** is adapted to maintain a supply of molten metal, for example, molten aluminum or magnesium, which is supplied to the casting mold **14**. Other typical metals that may be used in the casting apparatus **10** include zinc, bronze, copper, or other non-ferrous metals.

[**0037**] The tundish **12** generally includes an outer shell **16**, which is preferably made of metal such as steel, and an insulating layer **18** lining the outer shell **16**. The insulating layer **18** is preferably a refractory material that is suitable for use with aluminum or magnesium alloys and the like. The insulating layer **18** defines a molten metal holding chamber **20**, which maintains a ready supply of molten metal for delivery to the casting mold **14** during operation of the casting apparatus **10**. As shown in **FIG. 1**, a passage **22** (hereinafter "tundish passage 22") is formed in the insulating layer **18** and outer shell **16** for supplying the casting mold **14** with molten metal. The tundish passage **22** is at least partially convergent, as illustrated, to facilitate the delivery of molten metal to the casting mold **14**. Further details of the tundish passage are discussed hereinafter in connection with **FIGS. 13-16**. The tundish passage **22** generally has two functions. First, the tundish passage **22** allows non-turbulent passage of molten metal to the casting mold **14** and, second, prevents surface defects by directing the hot molten metal to the bottom of the casting mold **14**.

[**0038**] Referring to **FIGS. 1-3**, the casting mold **14** is preferably fixedly connected to the outer shell **16**. The casting mold **14** is generally comprised of a header plate **24**, a casting ring **26** connected to the header plate **24**, a feed ring **28** connected to the casting ring **26** and, preferably, a cooling ring **30** connected to the casting ring **26**. The header plate **24** is connected, preferably fixedly, to the outer shell **16** by a header clamp **32** and mechanical fasteners **34**. The header plate **24** defines an arcuate shaped opening **36**, which is in fluid communication with the tundish passage **22** in the tundish **12**. The opening **36** admits molten metal into the casting mold **14** during operation of the casting apparatus **10**. As shown in **FIGS. 1 and 2**, the opening **36** is preferably formed as a divergent opening.

[**0039**] Referring to **FIGS. 1-5**, the header plate **24** has a first or upstream side **38** and a second or downstream side **40**. The downstream side **40** faces inward toward a mold cavity **42** of the casting mold **14**. The mold cavity **42** is generally defined by the downstream side **40** of the header plate **24**, the casting ring **26**, and a bottom or starter block **44**. During operation of the casting apparatus **10** and casting mold **14**, the starter block **44** is initially positioned or seated within the casting ring **26** and is slowly withdrawn from the casting ring **26** while molten metal simultaneously flows into the mold cavity **42** through the opening **36** in header plate **24** and the tundish passage **22**, as is conventionally known in the art.

[**0040**] The downstream side **40** of the header plate **24** defines a depression or recess **46**. The recess **46** has tapered sidewall **48** as shown in **FIGS. 1 and 2**. The tapered sidewall **48** generally tapers outward from a central axis L of the casting mold **14**. Preferably, the sidewall **48** tapers from the arcuate opening **36** in the header plate **24** substantially to the feed ring **28** so that the molten metal received into the mold cavity **42** during operation of the casting mold **14** smoothly transitions from the header plate **24** to the feed ring **28**, where the molten metal is at least partially solidified to form an elongated metal article. The tapered sidewall **48** provides uniform molten metal flow and delivers the molten metal smoothly to the solidification interface, which occurs substantially at the feed ring **28**.

[**0041**] Referring to **FIGS. 1-10**, the casting ring **26** is located next to the header plate **24** and is preferably connected fixedly to the header plate **24** with mechanical fasteners, for example. The casting ring **26** may be made of metal, such as aluminum, copper, or steel. The casting ring **26** has an elongated inner wall **50**, which defines an annular recess **52**, which generally faces mold cavity **44**. As shown, the recess **52** is preferably located immediately adjacent and downstream of the header plate **24**. The feed ring **28** is disposed in the recess **52** and is preferably mounted fixedly to the casting ring **26**, for example by a threaded connection. The feed ring **28** is preferably a fluid permeable graphite ring and is used to at least partially solidify the molten metal passing flowing through the mold cavity **42** during operation of the casting apparatus **10** and casting mold **14**, as described further hereinafter. The use of graphite rings in direct chill casting apparatus is well known in the art as discussed previously in connection with the Wagstaff patents, which were previously incorporated herein by reference.

[**0042**] Referring to **FIGS. 1-12**, the cooling ring **30** is located next to the casting ring **26**. The cooling ring **30** is configured to cool the casting ring **26** and fully solidify the at least partially solidified metal passing the feed ring **28** when the casting mold **14** is in operation. The cooling is configured to deliver cooling fluid sprays onto an outer surface **54** of the elongated wall **50** of the casting ring **26** and, preferably, the surface of the at least partially solidified metal passing the casting ring **26**. The cooling ring **30** is preferably mounted fixedly to the casting ring **26**, for example by mechanical fasteners. The cooling ring **30** may be made of metal such as aluminum, copper, steel or stainless steel, or a non-metallic material material, such as a polymer of suitable properties.

[**0043**] The cooling ring **30** defines an annular chamber **58** therein. The annular chamber **58** is adapted to hold a supply of cooling fluid, such as water, which is to be applied to the outer surface **54** of the elongated wall **50** of the casting ring **26** and the at least partially solidified metal passing the feed ring **28** and casting ring **26** during operation of the casting mold **14**. Preferably, the cooling fluid (i.e., water) is applied to the outer surface **54** and semi-solidified metal as cooling sprays. For this purpose, the cooling ring **30** defines a plurality of raised teeth **60**. The cooling ring **30** is connected to or cooperates with the casting ring **26** such that the raised teeth **60** define or form a plurality of spray nozzles **62** for supplying the cooling sprays onto the outer wall **54** of the casting ring **26**. The spray nozzles **62** are in fluid communication with the annular chamber **58**, which supplies the cooling fluid to the spray nozzles **62**. The spray nozzles **62** are generally directed inward the central axis L of the casting mold **14**. The raised teeth **60** and, hence, spray nozzles **62** are preferably spaced regularly around the casting ring **26** to provide substantially uniform cooling fluid sprays onto the outer wall **54** of the casting ring **26** and onto the semi-solidified metal passing from the casting ring **26**.

[**0044**] The feed ring **28** is fed with a cooling and lubricating fluid or combination of fluids, such as caster oil, canola oil, peanut oil or appropriate synthetic lubricant, for solidifying the molten metal admitted to the casting mold **14** from the tundish **12** and flowing through the mold cavity **44** during operation of the casting mold **14**. The cooling and lubricating fluid is delivered to the feed ring **28** by a system of conduits defined in the casting ring **26**. The system of conduits includes a circumferentially extending supply conduit **64** that circulates the cooling and lubricating fluid circumferentially through the casting ring **26**, and a plurality of transversely extending branch conduits **66**, which supply the cooling and lubricating fluid directly to the fluid permeable feed ring **28**. The fluid permeable feed ring **28** allows the cooling and lubricating fluid to reach the surface of the feed ring **28** to cool and at least partially solidify the molten metal flowing through the mold cavity **42** from the tundish **12**. The feed ring **28** operates in a substantially analogous manner to graphite rings known in the art, such as those disclosed in the Wagstaff patents discussed previously.

[**0045**] Referring to **FIGS. 13-16**, the tundish passage **22** defined in the sidewall of the tundish **12** is shown. The tundish passage **22** facilitates the movement of molten metal from the tundish **12** to the casting mold **14**. The molten metal flows by gravity from the molten metal holding chamber **20** through the tundish passage **22** (i.e. head level differences between the chamber **20** and tundish passage **22**). The tundish passage **22** is a generally convergent passage that is divided in two portions or regions. In particular, the tundish passage **22** includes a first portion **70**, which forms the convergent area in the tundish passage **22**, and a second portion **72**, which is generally cylindrically shaped. The first portion **70** forms the entry region or opening to the tundish passage **22** and allows molten metal to smoothly transition into the tundish passage **22** from the holding chamber **20**. The second portion **72** forms the outlet of the tundish passage **22** and delivers molten metal to the arcuate opening **36** in the header plate **24**. The arcuate opening **36** is generally divergent over its length and allows the molten metal flowing into the mold cavity **42** to smoothly transition into contact with the downstream side **40** of the header plate **24**.

[**0046**] Referring to **FIGS. 1-16**, the casting apparatus **10** generally described hereinabove operates substantially as follows. Initially, the starter block **44** is seated in the casting ring **26** proximate to the header plate **24**. As the starter block **44** is withdrawn from the casting ring **26**, molten metal flows from the holding chamber **20** into the tundish passage **22**. The first portion **70** of the tundish passage **22** funnels the molten metal into the second portion **72**. The molten metal then flows into the mold cavity **42** of the casting mold **14** through the divergent arcuate opening **36**. As the molten metal flows into the mold cavity **42**, the molten metal diverges outward along the sidewall **48** formed in the downstream side **40** of the header plate **24**. The molten metal diverges outward until it contacts the feed ring **28**. The feed ring **28** freezes the molten metal to form a solid outer skin of solidified metal in contact with the feed ring **28**. The now at least partially solidified metal passes to the casting ring **26** where it is fully solidified into the desired metal article, such as a billet. The at least partially solidified metal flows along the elongated wall **50** of the casting ring **26** where it is cooled and solidified. The casting ring **26** and at least partially solidified metal are cooled by the application of cooling fluid sprays as indicated previously, which are emitted by the spray nozzles **62** defined by the raised teeth **60** formed on the cooling ring **30**. The cooling fluid for the cooling sprays is supplied from the annular chamber **58** defined by the cooling ring **30**. The annular chamber **58** is preferably in fluid communication with an external source of cooling fluid, such as water.

[**0047**] While the present invention was described with reference to preferred embodiments of the casting apparatus and casting mold, those skilled in the art may make modifications and alterations to the present invention without departing from the spirit and scope of the invention. Accordingly, the foregoing detailed description is intended to be illustrative rather than restrictive. The invention is defined by the appended claims and all changes to the invention that fall within the meaning and range of equivalency of the appended claims are to be embraced within their scope.

What is claimed is:

1. A casting mold for direct chill casting metal, comprising:

a header plate defining an arcuate shaped opening, the header plate having an upstream side and a downstream side, the downstream side defining a recess having a tapered sidewall;

a casting ring connected to the downstream side of the header plate and defining a groove proximate to the sidewall of the header plate; and

a feed ring disposed in the groove for cooling and at least partially solidifying molten metal flowing through the casting mold.

2. The casting mold of claim 1, wherein the sidewall tapers outward from a central axis of the casting mold.

3. The casting mold of claim 2, wherein the sidewall tapers to the feed ring.

4. The casting mold of claim 1, wherein the feed ring is made of graphite.

5. The casting mold of claim 1, wherein the feed ring is fluid permeable and the casting ring is configured to supply cooling and lubricating fluid to the feed ring.

6. The casting mold of claim 1, further comprising a cooling ring connected to the casting ring.

7. The casting mold of claim 6, the cooling ring defining a plurality of raised teeth and cooperating with the casting ring such that the teeth form a plurality of spray nozzles for delivering cooling fluid sprays at least to the casting ring during operation of the casting mold.

8. The casting mold of claim 7, the cooling ring defining an annular chamber in fluid communication with the spray nozzles, the annular chamber adapted to supply cooling fluid to the spray nozzles for application at least to the casting ring during operation of the casting mold.

9. The casting mold of claim 1, wherein the feed ring is connected to the casting ring by a threaded connection.

10. The casting mold of claim 1, wherein the arcuate opening comprises a diverging opening.

11. A casting apparatus for direct chill casting metal, comprising:

a tundish for containing a supply of molten metal;

a casting mold in fluid communication with the tundish through a passage defined in the tundish wall, the casting mold further comprising:

a header plate defining an arcuate shaped opening connected to the passage, the header plate having an upstream side and a downstream side, the downstream side defining a recess having a tapered sidewall;

a casting ring connected to the downstream side of the header plate and defining a groove proximate to the sidewall of the header plate; and

a feed ring disposed in the groove for cooling and at least partially solidifying molten metal flowing through the casting mold; and

a starter block associated with the casting ring.

12. The casting apparatus of claim 11, wherein the sidewall tapers outward from a central axis of the casting mold.

13. The casting apparatus of claim 12, wherein the sidewall tapers to the feed ring.

14. The casting apparatus of claim 11, wherein the feed ring is made of graphite.

15. The casting apparatus of claim 11, wherein the feed ring is fluid permeable and the casting ring is configured to supply cooling and lubricating fluid to the feed ring.

16. The casting apparatus of claim 11, further comprising a cooling ring connected to the casting ring.

17. The casting apparatus of claim 16, the cooling ring defining a plurality of raised teeth and cooperating with the casting ring such that the teeth form a plurality of spray nozzles for delivering cooling fluid sprays at least to the casting ring during operation of the casting mold.

18. The casting apparatus of claim 17, the cooling ring defining an annular chamber in fluid communication with the spray nozzles, the annular chamber adapted to supply cooling fluid to the spray nozzles for application at least to the casting ring during operation of the casting mold.

19. The casting apparatus of claim 11, wherein the feed ring is connected to the casting ring by a threaded connection.

20. The casting apparatus of claim 11, wherein the arcuate shaped opening comprises a diverging opening.

21. The casting apparatus of claim 11, wherein the passage defined in the tundish wall is at least partially convergent.

22. A method of casting metal in a direct chill casting apparatus, comprising:

a tundish containing a supply of molten metal;

a casting mold in fluid communication with the tundish through a passage defined in the tundish wall, the casting mold further comprising:

a header plate defining an arcuate shaped opening connected to the passage, the header plate having an upstream side and a downstream side, the downstream side defining a recess having a tapered sidewall;

a casting ring connected to the downstream side of the header plate and defining a groove proximate to the sidewall of the header plate; and

a feed ring disposed in the groove for cooling and at least partially solidifying molten metal flowing through the casting mold; and

a starter block associated with the casting ring;

the method comprising the steps of:

withdrawing the starter block in the casting ring;

delivering molten metal to the casting mold through the passage in the tundish wall and the arcuate shaped opening in the header plate; and

cooling and at least partially solidifying the molten metal at the feed ring to form a metal article.

23. The method of claim 22, the step of delivering molten metal comprising the molten metal diverging outward in the casting mold along the sidewall of the header plate before contacting the feed ring.

24. The method of claim 22, wherein the feed ring is fluid permeable and the casting ring is configured to supply cooling and lubricating fluid to the feed ring, the method further comprising supplying the cooling and lubricating fluid to the feed ring to cool and at least partially solidify the molten metal at the feed ring.

25. The method of claim 22, further comprising a cooling ring connected to the casting ring, the cooling ring defining a plurality of raised teeth and cooperating with the casting ring such that the teeth form a plurality of spray nozzles, the method further comprising delivering cooling fluid sprays at least to the casting ring through the spray nozzles to cool the casting ring during operation of the casting mold.

26. The method of claim 25, the cooling ring defining an annular chamber in fluid communication with the spray nozzles, the method further comprising supplying cooling fluid to the spray nozzles from the annular chamber.

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