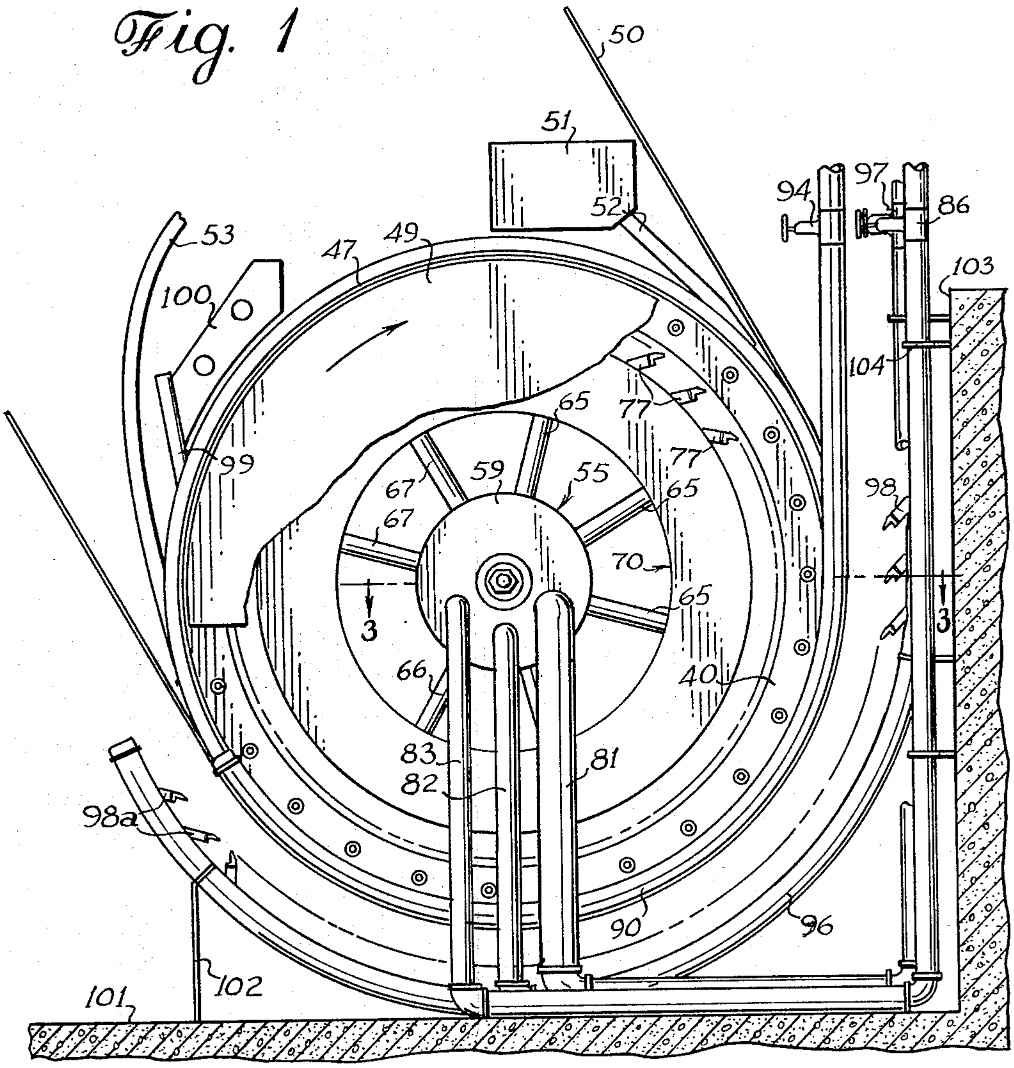
Oct. 18, 1966 D. B. COFER ET AL 3,279,000

APPARATUS FOR CONTINUOUS CASTING OF METAL

Filed Dec. 30, 1963 4 Sheets-Sheet 1

Fig. 1



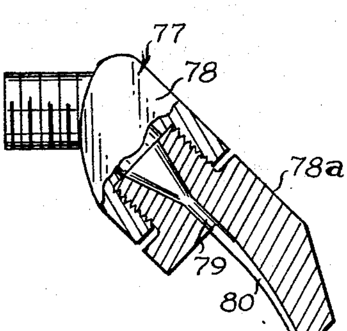


Fig. 2

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APPARATUS FOR CONTINUOUS CASTING OF METAL

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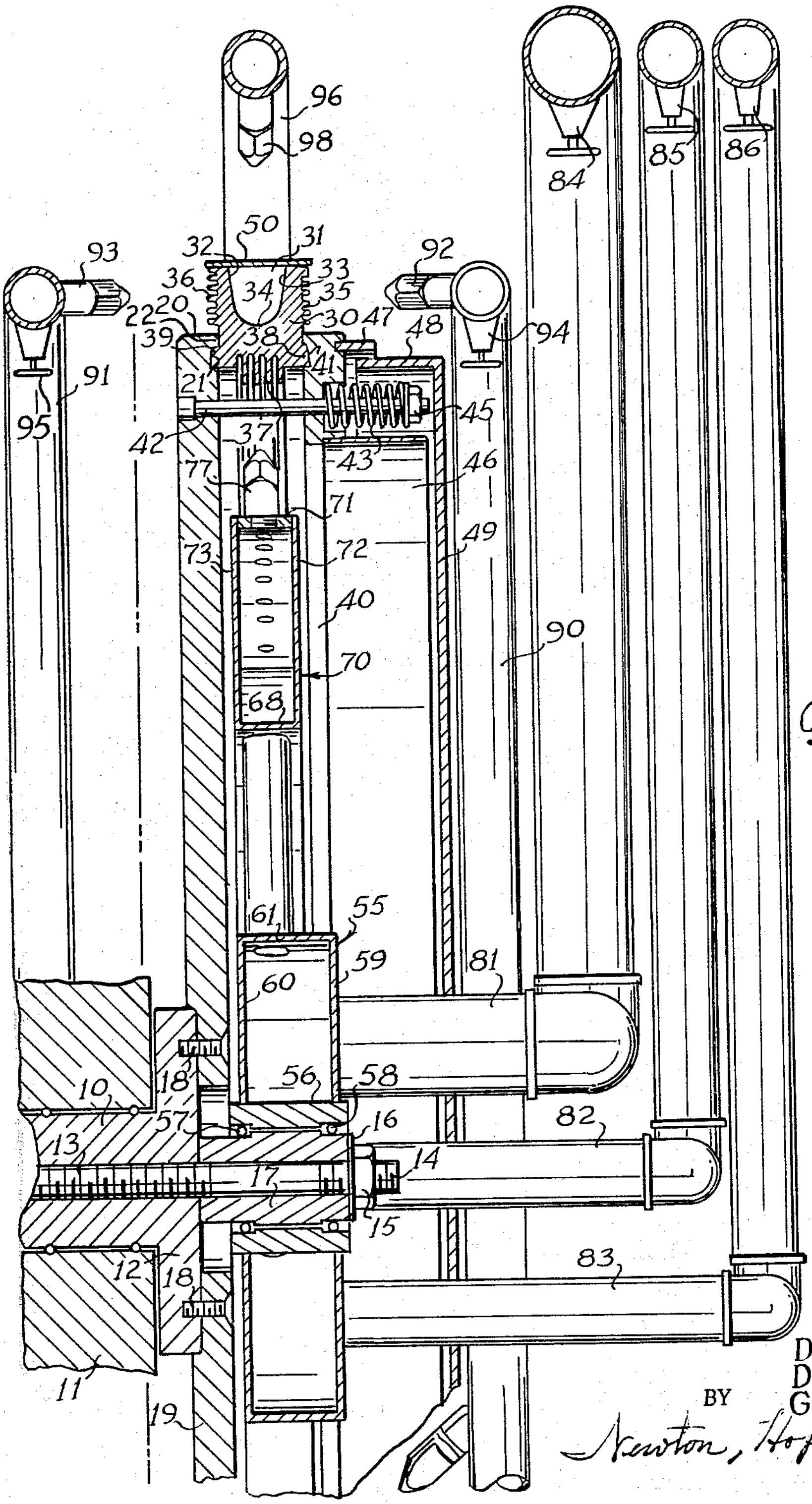

Fig. 3

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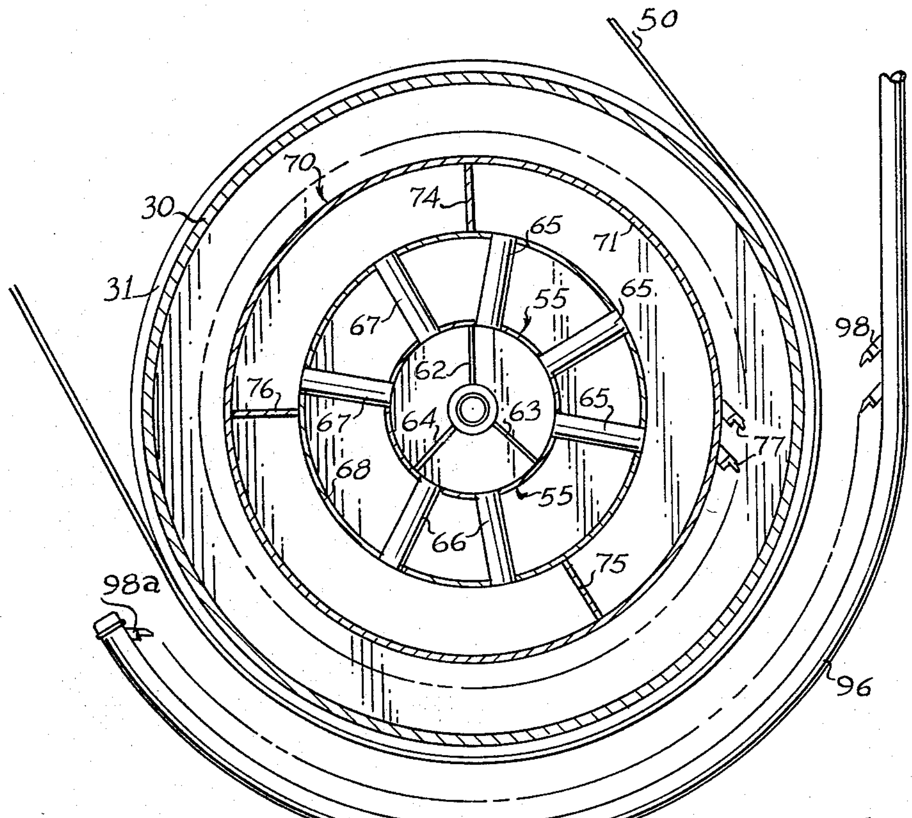

Fig. 4

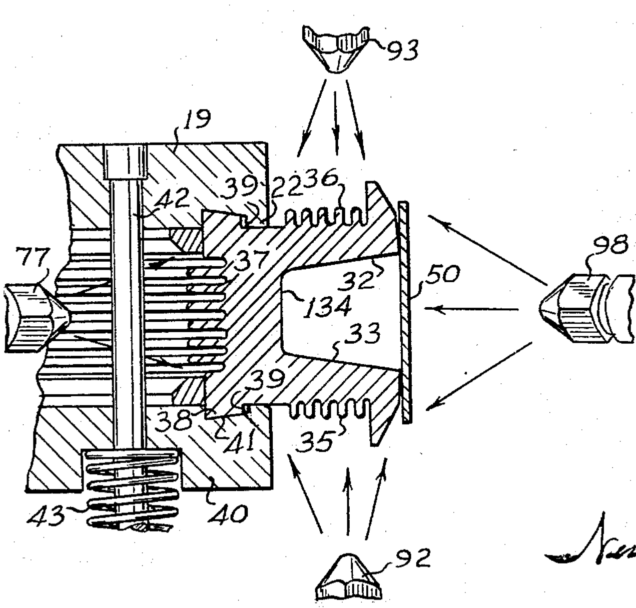

Fig. 5

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APPARATUS FOR CONTINUOUS CASTING OF METAL

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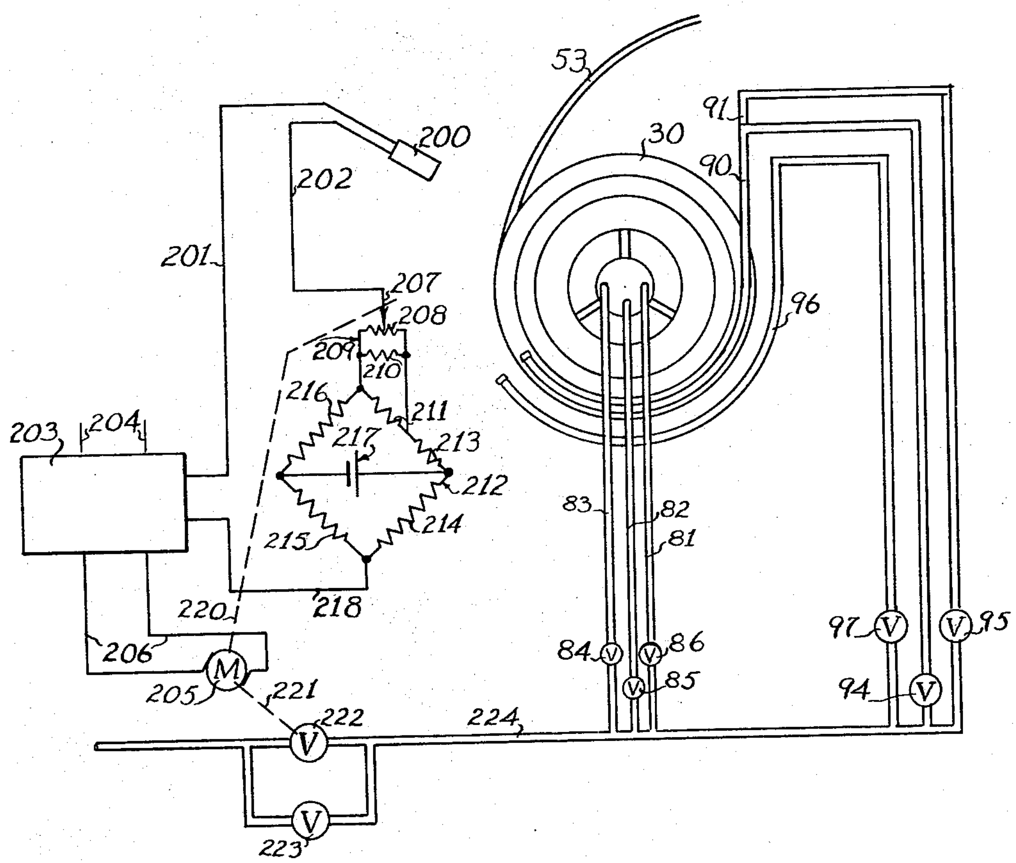

Fig. 6

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3,279,000

APPARATUS FOR CONTINUOUS CASTING OF METAL

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Filed Dec. 30, 1963, Ser. No. 334,197
22 Claims. (Cl. 22—57.4)

This invention relates to apparatus for continuous casting of metal and is more particularly concerned with a continuous casting machine in which different metals may be cast and which is particularly suited for the casting of copper into a continuous rod suitable for subsequently being rolled in a rolling mill, then drawn into wire.

In the past, continuous casting wheels or drums have been employed for casting aluminum bars which have subsequently been drawn into aluminum wire. Indeed, many patents have been issued to Ilario Properzi and others relating to such casting wheels and equipment employed inconjection therewith. U.S. Patent No. 2,865,067 illustrates generally the type of prior art casting wheel to which we refer.

These prior art casting wheels have included a rotatable drum having a grooved periphery, around a portion of which a steel endless belt passes, the belt being of greater length than the circumference of the drum and diverging therefrom on opposite sides. Hence, there is formed an inlet into which molten metal is poured and an exit from which the solidified rod (or bar) is withdrawn. The core or central portion of the drum is hollow to permit the circulation of a coolant, such as water.

When such prior art devices are employed for casting copper, the copper is cooled slowly and as a rule is discharged in an unevenly cooled condition. That is to say that, periodically along the length of the discharged copper, there are dark spots and light spots which apparently affect the internal structure of the copper rod to an extent that in the subsequent rolling operation, the copper rod is not sufficiently ductile to permit its reduction to small diameter wire.

We believe that the uneven cooling of the prior art casting drum is due to the fact that the water coolant is relatively in a quiescent condition adjacent the inside surface of the casting wheel and the sudden heating of this water adjacent the inside surface as the molten metal passes thereby causes a portion of the water to flash boil, the vapors being carried around with the wheel for a short distance and then being collapsed. The flash boiling removes the water from an increment of the casting wheel and the subsequent condensation of the steam permitting the water again to contact the increment as another increment. This sets up a pulsating situation for the water which causes uneven cooling of the increments and also causes the cooling to be slowed to an extent that the prior art casting wheel is impractical for casting copper rods. Thus, it has generally been believed that the continuous casting of copper for subsequent drawing to wire size is impossible or impractical.

The prior art literature has suggested that the conductivity of a copper rod is the function of the initial density of the bar or rod from which the wire is rolled or drawn, the conductivity being directly proportional to the density of the cast bar or rod. Hence, it would appear to be desirable in order to produce a copper wire having as high conductivity as possible to control the conditions under

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which the bar or rod is cast so as to produce as dense a casting as possible. Furthermore, a more dense bar or rod would require less mechanical working in order to produce the more dense wire therefrom.

In the past, cooper has been cast in situ in block or bar form in a mold which is left in ambient air to cool. Under such conditions the copper tends to cool from the sides and bottom slowly, thereby creating the dendritic crystalline structure on three sides; however, the upper portion of the copper appeared to have a spongy structure which is honeycombed with small voids or gas spaces. The density of this copper bar is approximately 8.47–8.59. If such a copper bar were cooled from all sides, the concentration of the spongy structure or small voids in the structure would be toward the central of the bar. The voids or spongy structure interfere with the subsequent drawing of the copper and, in general, tend to make the bar less capable to being drawn into fine wire.

Briefly, the apparatus of the present invention which tends to obviate the problems described above includes a disc-shaped inner flange which is supported concentrically at the end of a rotatable shaft and extends radially therefrom in all directions. A ring shaped or annular casting wheel or member is removably clamped to the front face of the inner flange by a spring loaded outer flange, the spring loading of which permits the casting member to expand and contract with thermal changes. The casting member is provided with a casting groove in its outer periphery while the inner periphery and sides thereof have cooling fins which provide for the rapid dissipation of the heat from the casting member. To facilitate this rapid and even cooling of the molten metal and reduce to a minimum the tendency of the coolant to flash boil, circumferentially spaced jet nozzles are disposed along the inner and outer peripheries of the casting member, the outer jet nozzles directing the coolant against an endless belt, of greater length than the circumference of the casting member, as it partially circumscribes the casting member for closing the open portion of the casting cavity or groove. The inner nozzles direct the coolant against the inner periphery of the casting member and the side nozzles direct the coolant against the sides of the casting member. By such an arrangement the copper or other molten metal, which is continuously poured into the inlet formed by the belt and casting member as they meet, is cooled so rapidly that the gases which would normally create the voids are not given sufficient time to form. Thus, an even dense bar of copper emerges from the exit, the copper having a density sufficient for being drawn into fine wire.

Accordingly, it is an object of the present invention to provide a continuous casting machine which is particularly suited for casting copper rod having characteristics which permit the subsequent drawing of the rod into fine wires.

Another object of the present invention is to provide a continuous casting machine in which the cooling of all sides of the cast metal may be selectively controlled.

Another object of the present invention is to provide a continuous casting machine in which the element defining the casting cavity may be readily and easily replaced and is so retained that thermal changes do not set up stresses in the machine.

Another object of the present invention is to provide a continuous casting machine which is capable of quickly and evenly cooling molten metal immediately after it is received in the casting machine.

Another object of the present invention is to provide, in a continuous casting machine, an efficient means by which the incremental cooling of the motlen metal may be controlled.

Another object of the present invention is to provide a continuous casting machine which is capable of casting a continuous metal rod from molten metal directed into the casting machine, the metal rod having a dense, relatively uniform crystalline structure and being of a cross sectional configuration more suitable for subsequent reduction in cross section.

Another object of the present invention is to provide, in a continuous casting machine, a cooling system which will quickly and efficiently cool the molten metal and casting ring of the casting machine without appreciable flash boiling of the coolant.

Another object of the present invention is to provide a continuous casting machine which is inexpensive to manufacture, durable in structure and efficient in operation.

Other objects, features and advantages of the present invention will become apparent from the following description when taken in conjunction with the accompanying drawings wherein like characters of reference designate corresponding parts and in which:

FIG. 1 is a front elevational view of a continuous casting machine constructed in accordance with the present invention, parts thereof being broken away.

FIG. 2 is an enlarged side elevational view, partially in cross-section, of one of the jet nozzles employed in the continuous casting machine illustrated in FIG. 1.

FIG. 3 is a cross-sectional view taken substantially along line 3—3 in FIG. 1.

FIG. 4 is a vertical cross-sectional view of the continuous casting machine shown in FIG. 1.

FIG. 5 is a cross-sectional view of the peripheral portion of the casting machine illustrated in FIG. 1 and showing a modified form casting cavity having trapezoidal cross-section.

FIG. 6 is a diagrammatical representation of the automatic control for the cooling system of the present invention.

Referring now in detail to the embodiment chosen for the purpose of illustrating the present invention, it being understood that in its broader aspects the present invention is not limited to the exact details herein depicted, numeral **10** denotes a central horizontally extending shaft which is appropriately journalled by a base **11** for rotation about its axis, the shaft being driven by a prime mover, such as a motor (not shown). The shaft **10** defines the central transverse axis of the machine illustrated. Forwardly of the base **11**, the end of shaft **10** is provided with a flat, disc shaped, radially extending, face plate **12**.

The central portions of shaft **10** and face plate **12** are provided with an internally threaded axial bore **13** which threadedly receives one end of a cylindrical stub shaft **14**, the other end of which protrudes along the transverse axis of the machine beyond face plate **12** and is externally threaded to receive the nut **15**. Nut **15** and washer **16** retain a bearing sleeve **17** on the shaft **14** and urge it against the central portion of face plate **12** for rotation therewith.

Surrounding the rear portion of sleeve **17** and secured by bolts **18** to the front or forward surface of face plate **12** is an inner flange **19** which is a disc shaped member having a circular periphery **20**. The inner flange **19** is appreciably larger in diameter than the face plate **12** and its front surface, adjacent periphery **20**, is provided with an annular groove **21**. As best seen in FIG. 3, the groove **21** is defined by concentric inner and outer walls, the inner wall being deeper than the outer wall so that the base position of groove **21** tapers outwardly and forwardly between the concentric walls. Since the groove **21** is spaced inwardly of the periphery **20**, the periphery **20** and groove **21** define, therebetween, a forwardly extending shoulder **22**.

For forming an envelope to receive the molten metal, the inner flange **19** carries a casting member **30**. The casting wheel or member **30** is formed from copper and is a ring shaped member, having a transversely flat outer periphery within the central portion of which is an annular peripheral casting groove **31** for receiving molten metal. In cross-section, casting groove **31** is defined by a pair of inwardly converging opposed flat sides **32** and **33** which converge toward the radial axis of the machine and subtend an angle of approximately 10 degrees therebetween. The casting cavity **31** has either an arcuate, concave bottom **34**, as seen in FIG. 3, or a flat bottom **134**, as seen in FIG. 5. The flat bottom **134** has curved extremities which merge with the inner end portions of sides **32** and **33**, while the rounded, concave bottom **34** is substantially hemispherical to provide end portions which themselves merge tangentially (or essentially tangentially) with the inner ends of sides **32** and **33**.

The forward and rear sides of the casting member **30** are provided with a plurality of diminishing diameter concentric grooves which define therebetween a plurality of spaced, axially extending, annular side fins **35** and **36** from the periphery of the member **30** inwardly to the region of the central portion of member **30**. The central portion of the inner periphery of casting member **30**, in like manner, is provided with inner fins **37** which are spaced axially from each other and are disposed radially parallel to each other.

Adjacent the inner periphery and protruding in opposite directions, i.e., forwardly and rearwardly from the sides of casting member **30**, are a pair of peripheral shoulders **38** and **39**, the inner sides of which are extensions of the inner periphery of casting member **30** and the outer sides of which are concentric with, but of larger diameter than, the inner sides. The faces of the shoulders taper outwardly so that the taper of the face of rear shoulders **39** conforms to the taper of the base portion of groove **21**. As best seen in FIG. 5, the width of groove **21** is greater than the thickness or width of shoulder **39** so that, upon expansion and contraction of the casting member **30**, the shoulder **39** is free to expand and contract in groove **21**.

For holding the casting member **30** in place against the front surface of the inner flange **19**, we have provided an annular outer flange **40** which is carried by the inner flange **19** and yieldably urged against the outer side of casting member **30**. In more detail, the outer flange **40** is a flat, annular member of substantially the same thickness and outer diameter as the inner flange **19**. The rear surface of flange **40** is provided with an annular groove **41** which is opposite to and complementary with groove **21** of inner flange **19** and receives shoulder **38** of the casting member **30**. The flange **40** thence extends inwardly beyond the casting member **30** sufficiently to receive therethrough a plurality of circumferentially spaced, parallel stove bolts **42** which protrude through the inner flange **19**, inwardly of the casting member **30**. The bolts **42** are sufficiently long that they protrude forwardly, i.e., axially, beyond flange **40** and are each provided with a helical spring **43**. One end of spring **43** is received in a counterbored recess in flange **40** surrounding bolt **42**, and the other end engages a washer **44** and urges it against a nut **45** on the end of bolt **42**. Hence, at all times, the casting member **30** is yieldably clamped between inner flange **19** and outer flange **40** and is permitted limited expansion and contraction since the springs, such as spring **43**, will permit the outer flange **40** to move forwardly and rearwardly while being urged rearwardly toward flange **19** into its clamping position.

The inner periphery of outer flange **40** is grooved appropriately for, and receives one side of, and annular inner shield **46** which protrudes forwardly to terminate in about the same plane with the forward ends of bolts **42**.

The front surface, outwardly of bolts **42**, receives an outer annular shield **47**, which is concentric with the inner shield **46**. Between the inner shield **46** and outer shield **47**, and spaced forwardly of flange **40** and outwardly of bolts **42**, is an intermediate annular shield **48** which is carried by the periphery of a front plate **49** which extends over the interior of the machine, the front plate **49** being disposed slightly forwardly of the front edge of shield **46**.

The drum described above is rotated in a clockwise direction as indicated by the arrow in FIG. 1. As best seen in FIG. 1, the usual endless, flat, flexible, metal belt **50**, of greater length than the circumference of the drum described above, passes around approximately 180 degrees of the drum and then passes around an idler drum (not shown). Since the idler drum for belt **50** and drive mechanism for shaft **10** are shown in such patents as U.S. Patents Nos. 2,865,067; 2,659,948; 2,710,433 and 2,659,-949, these features are not illustrated in the present application. The belt **50** is approximately the same width as the width of the casting member **30** and functions to close the outer side of the outwardly opening casting cavity **31**, progressively moving to form a continuously formed, open ended, arcuate, tubular member or envelope having an inlet at approximately the 45 degree position of the casting member **30** and an exit at approximately the 225 degree position of the casting member **30**.

As will be understood by those skilled in the art, molten metal from a pouring pot **51** is introduced by gravity, by way of a spout **52** into the casting cavity **31**, at the inlet of the tubular member, as the belt **50** closes the outer side of the casting cavity **31**. After being cooled and transported in an arcuate path, the cast metal is discharged as a continuous cast rod **53** from the exit end of the tubular member, as the belt **50** diverges from the casting member **30**. During the period of travel along the lower portion of the casting member **30**, the casting member **30** and belt **50** are subjected from all sides to cooling as will be pointed out hereinbelow.

Cooling system

According to the present invention, the cooling system for quickly solidifying the molten metal received in casting cavity **31**, and for further cooling the empty casting member **30** includes a plurality of jet nozzles disposed on the three sides of the casting member **30** and on the fourth side defined by the belt **50**. Each group of jet nozzles directs a high velocity stream of coolant, such as water, against the casting member **30** or belt **50** in such quantity that there is very little opportunity for the coolant, i.e. water, to be vaporized to any great extent, the jet nozzles being so distributed that the cast metal is cooled evenly to a prescribed surface temperature at the time of discharge, and the casting member **30** is further cooled to present a cool surface for receiving additional molten metal.

For supplying coolant to the inner periphery of the casting member **30**, an inner cooling system is provided with three separately or selectively controlled, circumferentially disposed cooling stages having a common inner header or manifold, denoted generally by the numeral **55**. The header **55** is a closed, hollow, annular member having a hub or collar **56** which circumscribes the bearing sleeve **17**, being spaced therefrom by anti-friction bearings **57** and **58**. Front and rear, spaced, parallel, circular plates **59** and **60** are secured to the ends of collar **56** and extend radially therefrom. The peripheries of these plates **59** and **60** are joined by a cylindrical cap **61**.

Within the header **55** are three radially extending divider plates **62**, **63** and **64**, seen in FIG. 4. Plate **62** is disposed upright while plate **63** is disposed approximately 150 degrees therefrom, and plate **64** is disposed at approximately 220 degrees from palte **62**. Thus, three separate compartments are provided in the inner header **55**.

Spoke-like hollow pipes **65**, **66** and **67** radiate from the cap **61** and are received by an annular base member **68** of the hollow outer header **70**. Pipes **65** communicate with the first compartment of the header **55**, the pipes **66** communicate with the second compartment of header **55** and the pipes **67** communicate with the third compartment of header **55**. The outer heater **70** includes an outer annular cap or spray ring **71** concentric with the base member **68** and a pair of side walls **72** and **73** which connect the sides of the base member **68** and the annular cap **71**. The outer header **70** is provided with three baffle plates **74**, **75** and **76** which separate the outer header **70** into three separate compartments, the plate **74** being disposed upright and the plate **75** and **76** being disposed 135 degrees and 270 degrees therefrom.

The outer cap **71** is provided with spaced holes disposed approximately 10 degrees from each other, the holes being internally threaded to receive, respectivly, the jet nozzles **77** which are angled in a clockwise direction at approximately 45 degrees from the radius. As illustrated in FIG. 2, each jet nozzle **77** includes a 45 degree elbow **78** to which is mounted a flat spray nozzle **78*a*** having a body with a jet orifice **79** and a deflector **80**, such as that disclosed in U.S. Patent No. 2,530,671. Each nozzle **77** is arranged to direct the coolant angularly outward to impinge upon the inner periphery of the casting member **30** at a position 17 degrees advanced in a clockwise direction from the outlet of the nozzle **77**.

It will be understood that the inner and outer headers **55** and **70** are disposed concentrically with respect to casting member **30** and the headers **55** and **70** are within the confines of the drum, as defined by the inner flange **19** and the front plate **49**. Three coolant supply pipes **81**, **82** and **83** supply coolant, such as water, respectively, to the compartments of the inner header **55**.

The pipes **81**, **82** and **83** are respectively provided with control means, such as valves **84**, **85** and **86**, by which the amount of coolant flowing to a particular compartment may be varied as desired. Pipes **81**, **82** and **83** are so arranged that they pass through the front plate **49** and provide support therefor. Pipes **81**, **82** and **83** terminate at the front plate **59** of header **55** and are in communication, respectively, with appropriate holes leading to the three compartments of the header **55**. Hence the headers **55** and **70** do not rotate but remain fixed as the drum, including casting member **30**, rotates thereabout.

It will be understood that the pipe **81** communicates with the compartment defined by divider plates **62** and **63**, the pipe **82** communicates with the compartment defined by divider plates **63** and **64** and the pipe **83** is in communication with the compartment defined by divider plates **64** and **65**.

The spokes or hollow tubes **65**, **66** and **67** provide communication between respective compartments of the inner and outer headers **55** and **70**; therefore, the coolant from pipe **81**, after entering the compartment of the inner header **55** passes outwardly therefrom through the three spoke-like tubes **65** into the first stage compartment of the outer header **70**, as defined by divider plates **74** and **75** Thence, the coolant is sprayed by the group of jet nozzles **77** which are disposed from 0 degrees to 135 degrees of the arc of the outer header **70** and constitute the first stage cooling means.

The coolant from pipe **81** is directed by the nozzles **77** against the bottom of successive increments of rotating casting member **30** as the increments approach the zone to receive the molten metal from spout **52**, and as the increments travel approximately 90 degrees immediately after receiving the molten metal.

Since much of the heat of the molten metal must be dissipated during the first quarter revolution of the casting member **30** after receiving the molten metal, the pipe **81** is relatively large, hence the volume of water delivered to nozzles **77** of the first cooling stage is relatively large. The coolant impinges upon the area of fins **37** at acute angles to the path of travel and is deflected, or cascades, downwardly, being collected at the bottom portion of the machine until it overflows around the shields **46** and **47**.

In the second cooling stage, the pipe **82** communicates with a compartment of the inner header **55** so as to feed coolant through two tubes **66** to the outer header **70**, thence through the nozzles **77** which communicate with the compartment between baffles **75** and **76**. As in the preceding stage of cooling, the water from these second stage nozzles **77** is directed against the fins **37** for cooling the metal from the time it passes the first cooling stage until it emerges from the exit as solid rod **53** at a position of approximately 270 degrees as the drum is viewed in FIG. 1. At this point, if the metal is copper, the metal bar **53** should be red hot, or about 1800 degrees F.

It is desirable, between the time an increment of the casting member **30** releases the bar **53** and the time an increment is positioned for receiving the molten metal, to cool the casting member **30** further so that it is relatively cool when the molten metal is received. Thus, a third stage of cooling is provided wherein the coolant from the remaining nozzles **77**, i.e. the nozzles disposed from 270 degrees to 360 degrees with respect to the drum, direct the coolant against the fins **37**. The pipe **83** communicates with the compartment between divider pates **64** and **62** for supplying this coolant through tubes **67** to the compartment between divider plates **76** and **74**, thence to the third stage nozzles **77**.

The coolant from the two latter stages of cooling also collects in the bottom portion of the drum and drains therefrom in the same way the coolant from the first stage drains therefrom.

By varying the openings of valves **84**, **85** and **86** the temperature of increments of the casting member **30** can be varied to achieve controlled cooling of the molten metal, as well as controlled cooling of the casting member **30**.

To supplement the internal cooling system described above, and to cool the metal more evenly from the time it is received until it is discharged as bar **53**, side cooling systems are provided which simultaneously direct the coolant inwardly against opposite sides of the casting member **30**. Also a belt cooling system directs coolant against the outer surface of the belt **50** as it passes around casting member **30**.

The side cooling systems include a pair of arcuate pipes **90** and **91** disposed on opposite sides of the casting member **30** from approximately 90 degrees to 250 degrees of the drum, these pipes **90** and **91** conforming to the curvature of the casting member **30**. All nozzles **92** and **93** (which are each identical to nozzle **77**) are threadedly carried by the pipes **90** and **91**, respectively, and direct coolant in tangential planes inwardly from pipes **90** and **91**, the coolant being directed in a clockwise direction (as viewed in FIG. 1.) inwardly so as to impinge upon and between the fins **35** and **36** at acute angles. The pipes **90** and **91** are provided with valves **94** and **95** whereby the amount of coolant directed against each side of the casting member **30** may be controlled. Hence, the side cooling systems supply a predetermined amount of coolant to both sides of successive increments of the casting member **30** from the time immediately prior to the time the increments release the metal as rod **53**.

The belt cooling system includes an arcuate pipe **96** having a valve **97**, the pipe **96** being disposed concentrically outward of that portion of belt **50** which is disposed around casting member **30**. Nozzles **98**, (which are each identical to nozzle **77**) project inwardly and in a clockwise direction, as viewed in FIG. 1, for directing coolant against the outer surface of increments of the belt **50** from the time the increments of the belt **50** (cooperating with the casting wheel **30**) receive the molten metal until immediately prior to the time the increment of belt **50** releases the metal as rod **53**. The last few nozzles, i.e. the last two nozzles **98***a*, are preferably directed in a counterclockwise direction inwardly so as to retard the spray of coolant along the line of travel of belt **50** as the belt **50** diverges from casting member **30**.

Above the position at which the belt **50** diverges from the casting member is the usual extractor shoe **99** supported by a bracket **100** in the path of travel which the rod **53** could take if it were retained in the casting cavity **31**. The function of this shoe **99** is to deflect the bar **53** outwardly in the event the bar **53** adheres to the cavity **31**.

The mechanism thus far described is disposed in a suitable well in a plant and is supported by the floor **101** of the well. The pipes **81**, **82**, **83**, **90**, **91** and **96** are appropriately supported by brackets such as brackets **102** extending upwardly from floor **101** and by brackets, such as brackets **104**, which project from wall **103** of the well.

Automatic control for cooling system

As seen in FIG. 6, the flow of the coolant may, if desired be automatic and controlled in accordance with the temperature of the metal rod **53** as it emerges from the casting wheel. To accomplish this, a thermocouple type pyrometer **200** is mounted on a suitable support (not shown) adjacent the rod **53** for viewing the same as it emerges from the casting member **30**. Electrical conduits **201** and **202** are connected to the pyrometer **200**, one conduit **201** leading from a conventional direction control mechanism **203** which is responsive to variation in electrical input for controlling the direction of rotation of a motor.

The control mechanism **203**, in turn, is connected to a source of current by wires **204** and to an appropriate reversible motor **205**, via wires **206**. The wire **202** is electrically connected to a variably positionable brush **207** on the resistor **208** of a potentiometer **209**. An additional resistor **210** is arranged in parallel with the resistor **208** and these resistors **208** and **210** are arranged in parallel with a resistor **211** of a first leg of a Wheatstone bridge, denoted generally by numeral **212**.

The first leg of the Wheatstone bridge **212** also has a resistor **213** in series with the parallel disposed resistors **208**, **210** and **211**.

The second, third and fourth legs of the Wheatstone bridge **212** are respectively provided with resistors **214**, **215** and **216**, the resistors **211**, **213** and **214** constituting one side of the bridge **212** and the resistors **215** and **216** constituting the other side thereof.

A source of constant voltage, such as a standard electric cell **217** is connected across the junction of resistors **213** and **214** to the junction of resistors **215** and **216** while a wire **218** leads from the junction of resistors **214** and **215** to the control mechanism **203**.

It will be understood that, initially, the main control circuit, which includes the conduit **201**, pyrometer **200** conduit **202**, potentiometer **209**, bridge **212** and wire **218**, is designed to provide a zero potential when the pyrometer **200** reads a prescribed temperature, such as 1800° F. An increase or decrease in this prescribed temperature will increase or decrease the potential output of the pyrometer **200** and unbalance the main circuit to provide a current flow, in one direction if a higher temperature is read and a current flow in the opposite direction if a lower temperature is read.

The main control circuit, in turn, signals the control mechanism **203** to control the feed of current, via wires **206** to motor **205** to control the actuation and deactuation of the motor **205**, as well as the direction of rotation of the motor **205**. In other words, if the current flows in one direction in the main control circuit, it will dictate that the control mechanism **203** direct current to the motor **205** for causing it to rotate in one direction and if current flows in an opposite direction, in the main circuit, the control mechanism **203** directs current to gen or free hydrogen may also be present. Since all these components produce gases, the voids are created because of the presence of these gases in the metal which is cooled from the outside. The presence of minor amounts of gases in the prior art processes of casting copper create what is known as "tough pitch copper" and is desirable in such prior art processes.

In the process of the present invention, however, the presence of such gases is undesirable and essentially eliminated, giving a dense copper rod **53** which requires less rolling in order to produce a copper wire having the usual density of from 8.87 to 8.94 without the necessity of working the copper sufficiently to eliminate or weld the voids.

The rod **53** which we have produced is relatively small with respect to the prior art, in situ cast bar, the bar **53**, if trapezoidal, such as that produced from cavity **131**, measuring, in cross-section, along its major base (the base adjacent belt **50**) from approximately 1¼ inches to approximately 2 inches and preferably 1¹¹⁄₁₆ inches. The converging sides of the bar **53**, in cross-section, are likewise from approximately 1¼ inches to approximately 2 inches and preferably 1¹¹⁄₁₆ inches while the minor base is from approximately ¾ inch to approximately 1¼ inches and preferably 1 inch exclusive of the curvature radii. If, on the other hand, the rod **53** has a crowned inner side, such as if the bar **53** were cast in cavity **31**, the base thereof i.e., the portion adjacent belt **50** would measure from approximately 1¼ inches to approximately 2 inches and preferably 1.8 inches while the sides would measure from approximately 1⅓ inches to approximately ⅔ inch and preferably 1.25 inches, and the depth of the bar measures from 1 inch to 2 inches, being preferably 1.6 inches. The radius of curvature of the crown would then be from approximately ⅜ inch to ¾ inch and preferably ½ inch.

Since the coolant is directed from four sides against the casting member **30** and against the belt **50**, the molten metal within the casting cavity **31** is, likewise, cooled from all sides.

This creates from the molten metal poured into the mold or casting cavity **31** or **131**, a solidified rod **53** having an acicular grain structure in which the crystals are progressively larger from all sides inwardly. These crystals are oriented generally perpendicular to the surfaces adjacent thereto. Hence, in a typical cross-section of the trapezoidal rod **53**, the crystals which are adjacent the opposite sides of rod **53**, are oriented in generally parallel planes, and protrude inwardly to a central trunk portion disposed perpendicular thereto. The crystals which are adjacent the major base and minor bases are disposed in planes perpendicular to the planes of the crystals adjacent the sides. With even cooling from all sides, diagonal branch lines which extend divergently from the ends of the central trunk, separate the side crystals from the base crystals. Thus, a tree-like appearance is produced wherein the trunk of the tree is generally centered between the sides of the cast metal and branches extend generally diagonally to the corners of the cast metal. This dendritic structure, we have found, is capable of being worked in the rolling mill, and drawn to create small diameter wire.

It will be remembered that the casting member **30** is preferably made from copper itself and because of the rapid cooling of the molten metal, and because of the precooling of the casting member **30**, immediately before it receives the molten copper, there is little danger of the casting members being heated sufficiently at any time to weld to the copper rod **53** as it is formed. The spray within the interior of the drum, as pointed out above, is directed in clockwise direction and hence the coolant which collects in the bottom portion of the drum is urged in clockwise direction and overflows at a position beyond the 180° position so as to pass out of the drum by flowing over the flange **40**, and over the shields **46** and **47**.

Because of the high volume of coolant introduced into the interior of the drum by the pipes **81**, **82** and **83**, the level of the coolant within the drum may build up, thereby increasing the flow of the coolant from the drum. Any coolant which cascades between the headers **55** and **70** and the back flange may readily pass through the open area between the spokes **65**, **66** and **67** and, therefore, there appears to be no concentration of the coolant within the drum in any uneven distribution.

The fins **35**, **36** and **37** permit a rapid cooling of the casting member **30**, thereby drawing out the heat from the metal within the casting cavity **30** at a rate appropriate to provide the dendritic structure of the type which has the trunk portion of the structure centered toward the center of the rod **53**. Furthermore, the casting member being of copper permits the rapid conduction of the heat away from the casting cavity **31**.

If it is found that the structure of the cast rod or bar **53** is uneven, indicating more cooling on one side than another, the appropriate valve or valves, such as valves **84** and **97**, may be opened or closed partially to adjust for the desired amount of cooling along a particular side. Further, if the rod or bar **53** emerges from the casting member **30** at a temperature different from the desired temperature, the valve **86** may be manipulated to alter this temperature. Furthermore, if the portion of the casting member **30**, which is to be cooled immediately prior to receiving the molten metal, is at a higher or lower temperature than desired, manipulation of the valve **86** will result in an adjustment of this temperature.

With the speed of the casting member properly adjusted, the volume of the coolant properly adjusted and the temperature and the flow of the molten metal properly adjusted, the machine will function with little attention.

When the mechanism is to be operated automatically, all manual control valves **84**, **85**, **86**, **94**, **95** and **97** are opened. This permits the valve **222** or the valve **223**, to control the quantity of water fed to the casting wheel. The pyrometer **200**, as explained above, controls motor **205** which, in turn, controls the amount of opening of the valve **222**. Therefore, if the temperature of the surface of rod **53** is too high, the pyrometer **200** signals motor **205** to move valve **222** toward a more opened condition and, conversely, when the temperature of the surface of rod **53** is too low, the pyrometer **200** signals the motor **205** to move valve **222** toward a closed condition.

The bypass valve **223** serves two functions. First, it may be partially opened and operated in conjunction with valve **222** so that the valve **222** simply controls the flow of an increment of the water in pipe **224**. Secondly, in the event of a shut down of the automatic control system, it may be opened completely so that the water is entirely under the control of valves **84**, **85**, **86**, **94**, **95** and **97**.

Furthermore, the automatic control of the water by valve **222** does not preclude the utilization of the valves **84**, **85**, **86**, **94**, **95** and **97** for balancing the distribution of the water, as described above.

It will be obvious to those skilled in the art that many variations may be made in the embodiments here chosen for the purpose of illustrating the present invention without departing from the scope thereof as defined by the appended claims.

We claim:

1. In a continuous casting machine, a rotatable shaft, an inner circular flange carried by said shaft for rotation therewith, an outer circular flange spaced from said inner flange, spring means connecting said outer flange to said inner flange, and an annular casting member releasably carried between said inner flange and said outer flange, said annular casting member protruding outwardly of the peripheries of said outer flange and said inner flange and having a contniuous casting cavity about its outer periphery.

2. In a continuous casting machine, a rotatable shaft, the motor **205** for causing it to rotate in an opposite direction.

As seen in FIG. 6, a linkage **220** is provided between the motor **205** and the brush **207** whereby, when motor **205** rotates, it moves the brush **207** along the resistor **208** in a direction for zeroizing the main control circuit. Thus, when the main control circuit is balanced, the movement of the brush **207**, the motor **205** will be stopped.

When the pyrometer is reading a large temperature differential from the prescribed temperature, it generates a relatively high potential which requires greater movement of brush **207** to balance. Therefore, motor **205** will be rotated to a greater extent before brush **207** is properly positioned to return the main control circuit to a zero potential. It is now seen that the rotation of motor **205** is proportionally responsive to the surface temperature of rod **53** as read by pyrometer **200**.

The motor **205** is connected to and controls, via linkage **221**, a main control valve **222**. The main control valve **222**, together with a manual bypass valve **223** is interposed in the line of a main pipe **224** from a source of coolant under pressure, such as water from a water main (not shown). The pipe **224** leads to the various manual control valves **84, 85, 86, 94, 95** and **97**.

Operation

From the foregoing description, the operation of the present machine should be apparent. It is suitable for the continuous casting of quite a number of molten metals into rods. Specifically, the machine is suitable for casting aluminum, copper, zinc, lead and alloys thereof. The operation of the machine, therefore, will be described with respect to copper, since this is by far the more difficult metal to cast in a form which may be reduced to wire size, and presents a novel way of casting copper. When utilizing the machine of the present invention for casting a continuous copper rod or bar, such as rod **53**, it is desirable that the rod **53** be delivered from the machine as hot as possible without danger of the metal being molten within the central portion thereof, when the rod **53** is delivered to a rolling mill (not shown). Thus we have found that the copper rod **53** should have a surface temperature (as measured by pyrometer) when it emerges from the machine, of approximately 1750° F. and between the range from approximately 1600° F. to approximately 1850° F. Above approximately 1980° F. copper is in a molten state and hence a substantially lower surface temperature should be maintained so as to assure that essentially no molten metal exists in the core or central portion of the rod **53**.

When the machine is to be operated, the shaft **10** is rotated in clockwise direction, as viewed in FIG. 1, at a speed such as to impart a peripheral velocity to the casting member **30** of between 30 and 60 linear feet per minute. The belt **50** is driven by the casting wheel at a like speed and circumscribes from approximately 45° to approximately 225° of the casting member **30**. The belt converges toward the casting member **30** at the 45° inlet position and diverges therefrom at the 225° outlet position. Next, the valves of the cooling system are opened after molten copper is introduced into the groove **31**.

It will be remembered that the third stages of the internal cooling system, i.e., the cooling from 270° to 360° of arc of the casting member **30**, is for the purpose of reducing the temperature of the upper increments of the casting member **30**. Preferably the temperature is reduced to a temperature of from 400° to 450° F. The purpose of reducing the temperature of the upper increments of the casting member **30**, immediately prior to the time that it receives the molten metal, is to increase the life of the casting member **30** and to present a relatively cool surface to the molten metal. The casting member **30**, however, should be maintained at a temperature in excess of the boiling point of the coolant, so that the casting cavity **31** is dry when it receives the molten metal.

During the period in which the belt **50** is not in contact with the casting member **30**, the casting cavity **31** is open and the inside surface of the belt **50** is accessible. A parting or releasing agent is continuously applied to the inside surface of belt **50** and to the surface of the casting cavity **31** so that the resulting cast metal rod **53** will readily part from the casting cavity **31**. While a number of releasing or parting agents are available, we recommend that soot be employed to coat the casting cavity **31** and the inside surface of the belt **50** immediately prior to the time that these members receive the molten metal.

At the 45° position of casting member **30**, the molten metal, such as molten copper, is fed from the pot **51**, through the spout **52**, into the entrance or inlet of the tubular member formed by the convergence of the belt **50** and the casting cavity **31**. The metal is prevented from flowing out of the casting cavity **31** by the belt **50** which closes the open side thereof. Hence the molten metal runs down the right side of the casting cavity, as viewed in FIG. 1, and is solidified so as to build up a base for receiving additional molten metal. When such a base is built up, the molten metal can be received continuously in the inlet of the casting cavity **31**. The first stage cooling, i.e., the cooling from 0° to 135° of the arc of the casting member **30**, cools the molten metal, i.e., copper, from approximately 2200° F. (the temperature at which the molten metal is introduced into the casting cavity **31**) to a temperature of approximately 1980° F., at which time the copper commences to solidify. This is accomplished in only a few seconds after the copper is received at the inlet.

The purpose of cooling the metal rapidly is to convert the molten metal into a solid having as small a grain structure as is feasible and to prevent internal voids due to shrinkage of the metal upon cooling slowly.

As mentioned above, the prior art bar which is cast horizontally in a casting cavity, usually has a density of approximately 8.47 to approximately 8.59 and is subsequently rolled and drawn into the wire having the density of from 8.87 to 8.94. The prior art bar, as cast, is cooled relatively slowly so that the gases therein create a flat or crown set to the upper surface, rather than a concave set or shrinkage cavity. The bar having a concave upper surface is difficult to roll because of the sharp edges at the upper surface.

Contrary to prior art beliefs and practices, the copper cast in the machine of the present invention is cooled quickly enough to produce a casting having an average overall density of 8.83, i.e., a density between approximately 8.75 and approximately 8.89. This copper rod has few, if any, voids or gas holes and essentially no sponge-like structure as would normally be found in horizontally cast copper.

The copper utilized in either case is 99.90%+ pure copper, the major portion of the impurities therein being oxygen in the form of copper oxide. There also are trace amounts of hydrogen and sulphur contained in the molten metal. The process of the present invention contemplates the freezing or solidifying of the molten metal from approximately 2200° F. down to below 1980° F., i.e., to approximately 1750° F. within a very short period of time, approximately two seconds, so as to produce a dense copper rod which is essentially free of any voids. Theoretically, by utilizing such a procedure the oxygen in the copper oxide is not given sufficient time to disassociate and/or combine with the hydrogen or sulphur to produce a gas.

While the reaction which has taken place, when copper is solidified slowly, is not understood completely by us, it has been suggested that the oxygen of the copper oxide combines with trace amounts of sulphur so as to produce sulphur dioxide, and with trace amounts of hydrogen to produce water vapor. Of course, some free oxya circular inner flange mounted on said shaft for rotation therewith, an annular flange yieldably mounted on said inner flange, an annular casting member carried between the peripheries of said flanges and protruding outwardly therebeyond, said casting member having a continuous outwardly opening casting cavity in the outer periphery thereof, a continuous metal belt partially encompassing said casting member and converging toward and diverging from the outer periphery of said casting member, said belt closing the outer side of casting cavity between the positions of convergence and divergence of said belt, means for introducing molten metal into said cavity adjacent the position where said belt converges toward said casting member, a plurality of circumferentially spaced nozzles disposed adjacent the inner periphery of said casting member, conduit means leading from a source of coolant to said nozzles for supplying controlled amounts of coolant to said nozzles, a pair of groups of side nozzles disposed adjacent to the sides of said casting member for cooling that portion of said casting member which is partially encompassed by said belt and a pair of pipes leading respectively to said groups of said side nozzles.

3. In a continuous casting machine, a rotatable shaft, a circular inner flange mounted on said shaft for rotation therewith, an annular flange yieldably mounted concentrically on said inner flange, an annular casting member carried between the peripheries of said flanges and protruding outwardly therebeyond, said casting member having a continuous outwardly opening casting cavity in the outer periphery thereof, a continuous metal belt partially encompassing said casting member and converging and diverging from the outer periphery of said casting member, said belt closing the outer side of said casting cavity between the positions of convergence and divergence of said belt, a plurality of groups of circumferentially spaced nozzles disposed adjacent the inner periphery of said casting member for directing coolant outwardly and circumferentially toward said inner periphery, a plurality of pipes leading from a source of coolant respectively to said groups of nozzles for supplying controlled amounts of coolant to each of said groups of nozzles, a pair of groups of side nozzles disposed adjacent to the sides of said casting member for cooling that portion of said casting member which is partially encompassed by said belt, a pair of pipes leading respectively to said groups of said side nozzles, a group of belt cooling circumferentially spaced nozzles disposed in an arcuate path outwardly adjacent that portion of said belt which partially encompasses said casting member, a pipe for supplying coolant to said belt cooling nozzles, control means for controlling the amount of coolant fed to each group of nozzles, and means for feeding molten metal into the said casting cavity at a position adjacent the position at which said belt converges toward said casting member.

4. In a casting machine; an annular member having an inner surface, an outer surface, two side surfaces extending between said inner surface and said outer surface, and a casting groove in said outer surface; closing means for closing a length of said casting groove so that said closing means and said casting groove define a mold to receive molten metal; support means for supporting and rotating said annular member about an axis so that segments of said mold move along an arcuate path; a header having a chamber positioned within said inner surface of said annular member; means for dividing said chamber into a plurality of compartments disposed in sequence along said path; means for providing a coolant to each of said compartments; and cooling means for discharging said coolant from each of said compartments against said inner surface of said annular member.

5. The casting machine of claim 4 wherein at least two different quantities of said coolant are simultaneously discharged from said compartments against said inner surface of said annular member.

6. The casting machine of claim 5 wherein said different quantities are independently variable.

7. The castings machine of claim 5 wherein one of said quantities is applied at an initial portion of said path and is greater than the other of said quantities.

8. The casting machine of claim 7 wherein said one of said quantities is sufficient to cool molten metal in said mold at a rate greater than any rate elsewhere along said path.

9. The casting machine of claim 4 including a plurality of fins extending from said inner surface of said annular member toward said cooling means for discharging said coolant from each of said compartments.

10. The casting machine of claim 4 wherein said cooling means for discharging said coolant from each of said compartments include a plurality of nozzles positioned to discharge said coolant from said compartments against said inner surface of said annular member.

11. The casting machine of claim 4 wherein said cooling means for discharging said coolant from each of said compartments includes a plurality of nozzles positioned to direct jets of said coolant from said compartments against said inner surface of said annular member.

12. The casting machine of claim 11 wherein said jets are directed in paths which are angularly disposed to said inner surface of said annular member.

13. The casting machine of claim 11 wherein said jets are directed in paths inclined to said inner surface of said annular member in the direction in which said inner surface moves as said angular member is rotated about said axis by said support means.

14. The casting machine of claim 4 wherein said means for dividing said chamber into a plurality of compartments is a plate positioned within said chamber to divide said chamber.

15. The casting machine of claim 4 including second cooling means disposed adjacent said annular member for applying said coolant to one of said side surfaces of said angular member, and third cooling means disposed adjacent said annular member for applying said coolant to the other of said side surfaces of said angular member.

16. The casting machine of claim 15 including means for selectively varying the quantity of said coolant applied to said one of said side surfaces by said second cooling means independently of the quantity of said coolant applied to said other of said side surfaces by said third cooling means.

17. The casting machine of claim 15 including fourth cooling means disposed adjacent said annular member for applying said coolant to said closing means.

18. The casting machine of claim 17 including means for varying the quantity of said coolant applied by said fourth cooling means independently of the quantity of said coolant applied by said second cooling means, the quantity of said coolant applied by said third cooling means, and the quantity of said coolant applied by said cooling means for discharging said coolant against said inner surface of said annular member.

19. The casting machine of claim 4 including spray means disposed adjacent said annular member for spraying said coolant on said closing means.

20. The casting machine of claim 19 wherein said spray means includes an arcuate tubular member having a plurality of nozzles along its length positioned to direct jets of said coolant against said closing means.

21. The casting machine of claim 20 wherein the paths of at least some of said jets are inclined to said closing means in the direction in which said angular member moves as said annular member is rotated about said axis by said support means.

22. The casting machine of claim 21 wherein the paths of others of said jets are inclined to said closing means in a direction opposite to said direction in which said

annular member moves as said annular member is rotated about said axis by said support means.

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