March 17, 1964 R. BAIER 3,124,855

CONTINUOUS CASTING

Filed March 26, 1958 3 Sheets-Sheet 1

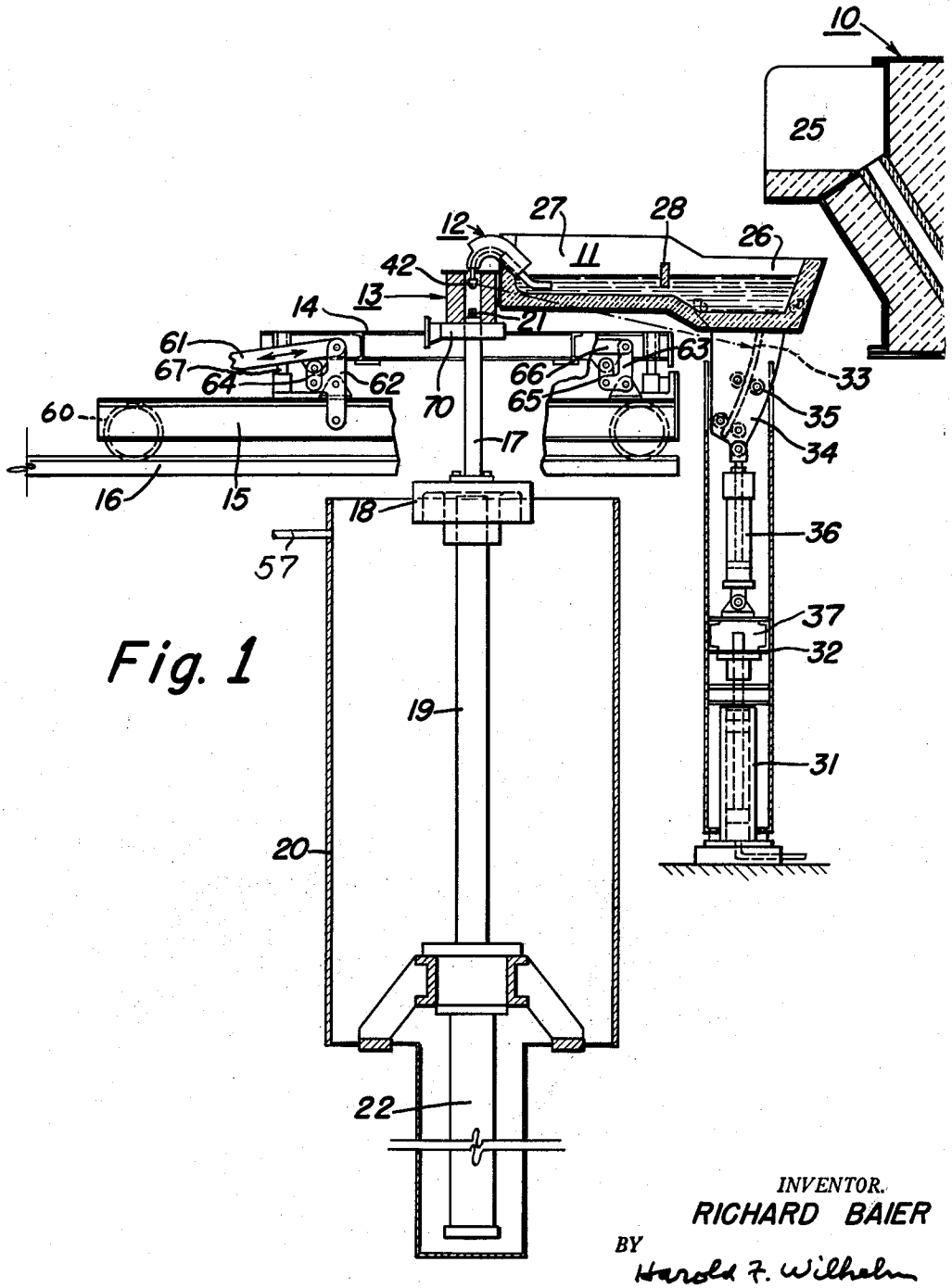


Fig. 1

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CONTINUOUS CASTING

Filed March 26, 1958 3 Sheets-Sheet 2

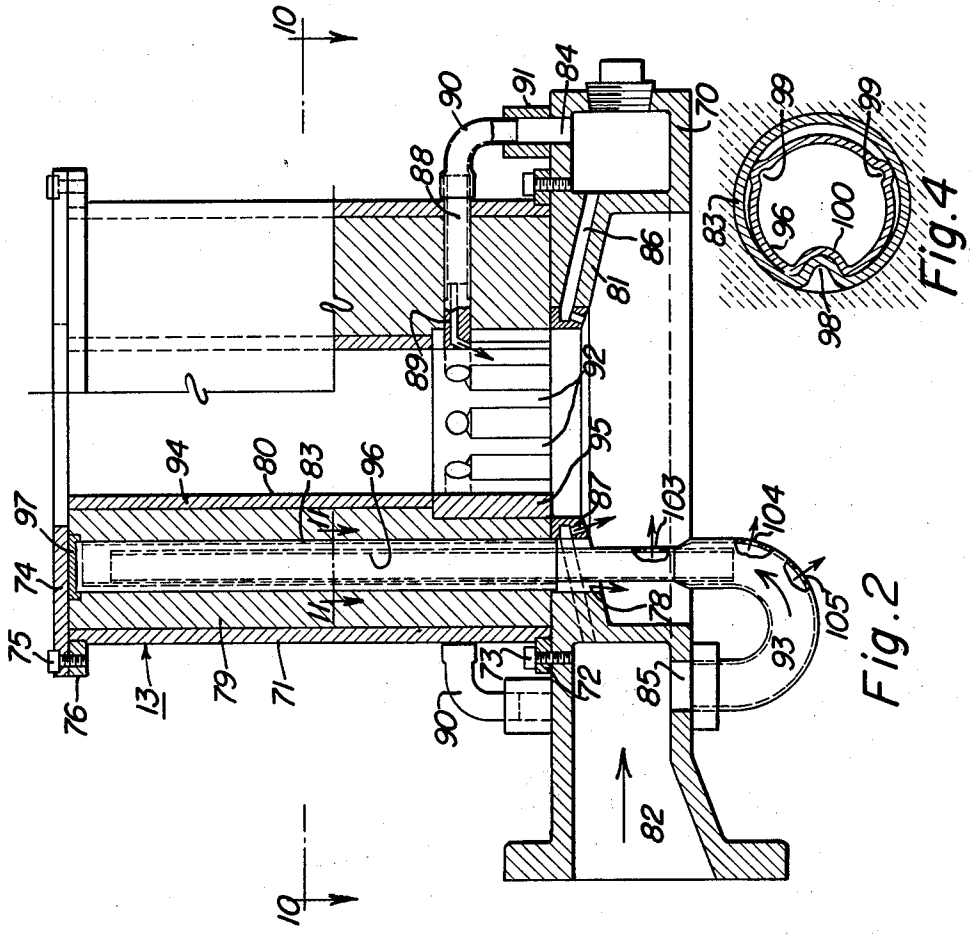


Fig. 4

Fig. 2

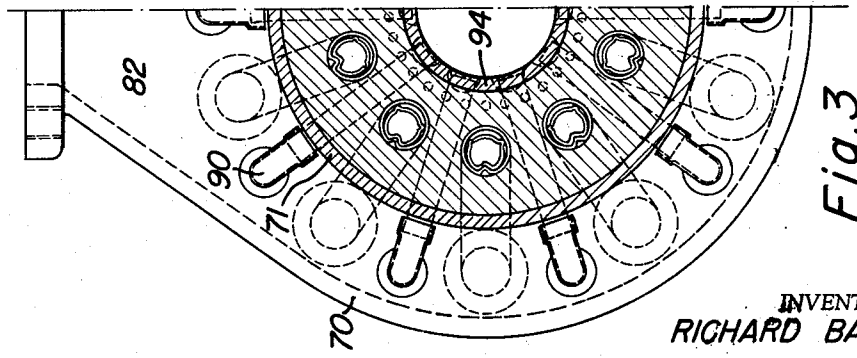


Fig. 3

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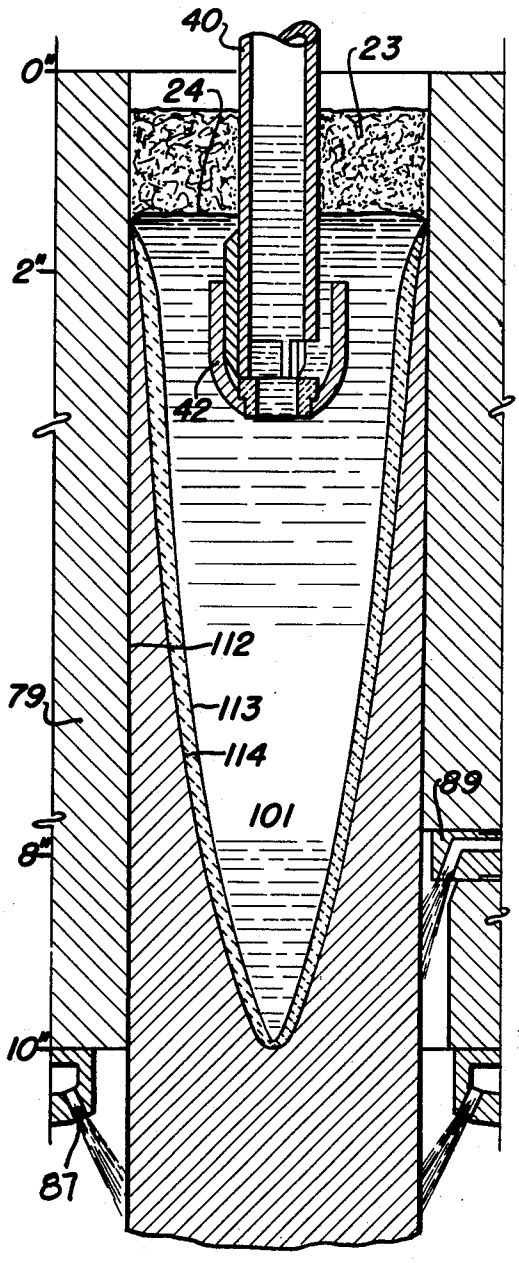


Fig.5

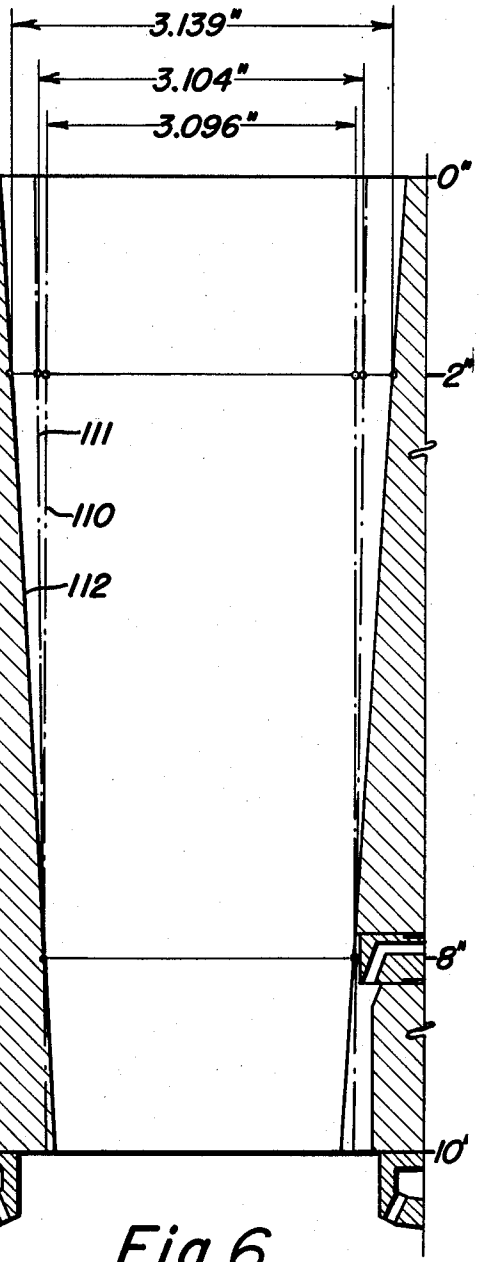


Fig.6

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United States Patent Office 3,124,855 Patented Mar. 17, 1964

3,124,855

CONTINUOUS CASTING

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Filed Mar. 26, 1958, Ser. No. 724,114
5 Claims. (Cl. 22—200.1)

The invention relates to the continuous casting of metals, and more particularly to a casting technique for increasing the rate at which heat can be conducted from the embryo casting.

In continuous casting, the mold limits casting speed by limiting the amount of heat which may be conducted from the embryo casting to the cooling medium. Even though the mold itself is adequately cooled, the problem still remains to conduct heat from the congealing metal product to the mold wall.

According to conventional practise, the mold pocket has either straight sides or a slight taper. With a straight-sided mold, the embryo casting has solid-to-solid contact with the mold wall only near the top of the casting where the liquid metal starts to congeal. As the casting moves downwardly through the mold, it shrinks away from the mold wall, destroying solid-to-solid contact with the mold wall. Natural mold tapers represent an improvement over the straight-sided wall inasmuch as the tapered mold wall attempts to maintain contact with the shrinking casting to reduce the air gap between the casting and the mold wall.

According to the present invention, the contact between the embryo casting and mold wall is greatly improved by using what might be termed a "forced taper operation" to distinguish it from the prior art which has what might be called a "natural taper operation." According to the invention, the embryo casting is positively pulled out of the mold with such force and at such speed as to forcibly wedge the taper on the shrinking casting against the mold taper.

In other words, according to the invention, steepness of taper is so related to linear casting speed as to cause this effective wedging action which plastically deforms the red hot tube comprising the crater shell enclosing the liquid core. The forced taper operation, in a sense, is similar to wire drawing. It requires establishment of a crater shell with a long and deep V, with a strong but plastic shell wall surrounding a soft liquid center, which combination can be readily deformed by pulling it through the tapered mold at a speed exceeding the speed corresponding to a natural taper at which no plastic deformation occurs.

According to a preferred form of the invention, the mold comprises a graphite block having a circular mold pocket suitably cooled by a series of vertical passages having copper tubes for circulating cooling water, which passages are arranged around the mold pocket. The graphite block is surrounded by a metal sleeve to reinforce it against the pressure developed by the forced taper operation. A ring manifold supplies water to the cooling tubes, and the cooling arrangement provides a series of levels of sprays which direct water against the cast product as it leaves the mold.

General objects of the invention are to cast metals, particularly phosphorized copper billets, at greatly increased linear rates; to improve thermal contact between the embryo casting and the mold wall; to produce castings having superior surface and internal characteristics; to provide a mold in which may be cast both oxygen bearing coppers and coppers free of oxygen in commercial quantities; to provide methods and equipment for continuous casting having one or more of the above recited

features and capable of accomplishing one or more of the aforesaid objects.

Other objects and features of the invention will be more apparent from the following description and claims when considered with the accompanying drawings in which:

FIG. 1 is an elevation of the casting system showing holding furnace, pouring ladle, siphon, mold, mold carriage, and mechanism for withdrawing the cast product, certain parts being shown in section;

FIG. 2 is an elevation, mostly in section, of the billet mold;

FIG. 3 is a half plan section, taken on the line 3—3 of FIG. 2, half of the mold being omitted for simplicity of illustration;

FIG. 4 is a cross section taken through a tube assembly on a larger scale; on line 4—4 of FIG. 2;

FIG. 5 is a special diagram illustrating the shape of the crater and the additional thickness imparted to the crater shell by use of the invention; and

FIG. 6 is a further diagram comparing the "forced" mold taper of the invention with the "natural" mold taper of the prior art.

In the accompanying drawings and in the description forming part of this specification, certain specific disclosure of the invention is made for purposes of explanation, but it will be understood that the details may be modified in various respects without departure from the broad aspect of the invention.

Referring to the drawings and more particularly to FIG. 1, the system of casting, utilizing the invention, will be first only generally outlined, after which more detailed description of the method and apparatus will be given.

General Description

A melting furnace (not shown) supplies holding furnace **10** with the molten metal to be cast. The furnace **10** supplies pouring ladle **11** which in turn supplies siphon **12**; the latter supplies mold **13** which is mounted on mold platform **14** which in turn is mounted for vertical reciprocation on carriage **15**.

Carriage **15** is movable horizontally on tracks **16** from over tank **20**, to provide access to the product after it is cast, as hereinafter explained more in detail. It will be understood that a stationary working floor (not shown) is located on opposite sides of the tracks **16**, at the same level as the tracks **16**, on which workmen may walk during pouring.

For effecting the casting operation, a hydraulic starting and lowering mechanism is located within and under tank **20**; this comprises a starting plug **17** mounted on platform **18** which in turn is supported on piston **19** which has working relation with a hydraulic cylinder **22** located below water tank **20**. The upper end of plug **17** is screw-threaded as indicated at **21**.

It will be understood that the starting platform **18**, as shown in FIG. 1, is in approximately its uppermost position with the starting plug **17** projected up inside the mold **13**. The starting plug **17** forms the bottom closure of the mold when initiating the pour. As molten metal is fed into the mold, it freezes around threads **21** and the frozen product is pulled downwardly at uniform speed into the tank **20** by the hydraulic arrangement. Upon completing the casting operation, the starting plug is disengaged from the cast product by relative rotation, screw threads **21** by permitting easy disengagement.

The tank **20** may extend below the top surface of the mold a distance corresponding to the desired length of the cast product, which may be as much as 27 feet long; in such case the hydraulic cylinder arrangement must extend below the mold top more than twice this amount,

or over 54 feet, to accommodate the piston 19 in its fully retracted position.

Alternately, the hydraulic pulling mechanism may be replaced by a conventional roll drive, cut-off mechanism and handling equipment, such as disclosed in Betterton and Poland Patent No. 2,291,204, granted July 28, 1942.

The holding furnace 10 shown is an upright low frequency induction furnace rotatable about a horizontal axis and having a pouring spout 25. It may receive molten metal through a launder or a bull ladle (not shown) from a suitable melting furnace.

The pouring ladle 11 comprises an enlarged bowl 26 constituting a reservoir for the molten metal, and a trough 27 which supports the siphon 12. The ladle also has a skim gate 28. The ladle 11 is supported by a mechanism which permits tilting the ladle to change the elevation of the reservoir with respect to the siphon; raising and lowering the entire ladle without tilting it; and swiveling the entire ladle from a position with the siphon 12 offset from the mold 13 (where it may discharge into a slag pot, not shown) to a position with the siphon over the mold 13 preparatory to lowering it to the position shown in FIG. 1. Siphon 12 includes siphon tube 40 and overflow cup 42 (see FIG. 5).

The supporting mechanism is illustrated somewhat diagrammatically. It comprises an elevator cylinder 31 whose lower end is fixed; cylinder 31 has a piston connected to pedestal carriage 32. Operation of elevator cylinder 31 raises and lowers the entire pedestal carriage 32 as a unit. The pedestal 32 carries an arcuate guide track device 33 on which is movably mounted a ladle carriage 34. Arcuate track 33 is laid out on the arc of a circle whose center is the center of siphon cup 42 and whose radius is indicated by the dot-dash line in FIG. 1.

The ladle carriage 34 carries rollers 35 which ride on the arcuate guide 33. A tilting cylinder 36 connects with a cross member 37 secured to the pedestal 32; and its piston connects with the ladle carriage 34. The pedestal carriage 32 is rotatable about the vertical axis of elevator cylinder 31 to permit the operator to swing the ladle 11 in a horizontal plane as described above.

Operation of elevator cylinder 31 raises and lowers the ladle 11 without tilting it. Operation of tilting cylinder 36 causes ladle carriage 34 to ride on arcuate track guide 33 and thus to tilt the ladle 11 in a vertical plane about the center of siphon cup 42; this tilting may be accomplished in any position of the ladle 11 in its arc of swing around the vertical axis of elevator cylinder 31, and in any elevation of pedestal carriage 32.

It will be understood that with the tip 42 in register with the mold cavity, when the elevator cylinder 31 reaches its lowermost position, the siphon tip 42 is automatically at the proper level within the mold 13 regardless of angle of tilt of the ladle 11. Proper positioning of the tip 42 in the mold causes the tip to be completely submerged in the molten metal when the molten metal occupies its normal position of about 1½ in. below the top of the mold. See FIG. 5.

Any operation of the tilting cylinder 36 to tilt the ladle 11 in either direction operates to change the level of the metal in the ladle and, with the pedestal carriage 32 at its lowermost position, does not change the elevation of the tip 42 from its proper position in the mold.

Thus, with the tip 42 in its proper position in the mold, metal level in the ladle 11 may be changed either by tilting the ladle, or by adding metal to the ladle or by removing metal from the ladle. The control of metal level in the ladle is used to control rate of metal flow through the siphon 12 as explained hereinafter. The ladle may be tilted backward (i.e. carriage 34 lowered) far enough to stop flow through the siphon.

The manner of conveying molten copper from the holding furnace 10 to the mold 13 will be briefly outlined. The pouring ladle 11 receives the metal stream from the holding furnace 10. The ladle bowl 26 is covered with charcoal and it delivers metal from a point near the bottom under the skim gate 28 in the usual manner.

The manner of handling the hot metal will depend on the nature of the metal. In the case of tough pitch copper, for example, the metal stream may fall through air in passing from holding furnace 10 to pouring ladle 11. This is generally suitable also for highly deoxidized coppers. However, with all coppers, and particularly with oxygen-free and low residual phosphorous deoxidized coppers, it may be advisable to use a reducing gas here to prevent oxygen absorption. With phosphorized copper, a cover 23 of carbonaceous material such as flake graphite is maintained on the free surface 24 of the molten metal in the mold, as discussed more in detail below.

During the continuous casting operation, the platform 18 may be lowered at a uniform speed which is variable at will. Accuracy may be maintained within a limit of one percent of constant speed by a special high precision hydraulic system (not shown).

The red hot billet casting, emerging from the mold is rapidly chilled by a series of pressurized water sprays 89, 87, 103–105 (see FIG. 2) described hereinafter, and the large volume of water is collected in tank 20 (FIG. 1). This water is removed at any desired level as by a suitable drain line 57. The water may be circulated by a circulation and pumping system, through a cooling device, and back to the water manifold 70 on the mold 13 as described hereinafter. The intensity of cooling of mold 13 is so high that, even at the high casting speeds employed, the molten metal congeals practically as soon as it touches the mold wall, causing the edge of the crater shell 101 (FIG. 5) to extend substantially to the free surface 24.

In the description, certain metals, sizes, values and dimensions are given for purposes of illustration. These are given for convenience of disclosure only, it being understood that the teachings of the invention apply to other metals, sizes, values and dimensions. Unless otherwise indicated, the prior and following description applies to casting phosphorous deoxidized copper circular billets having a nominal diameter of about three inches.

The construction and operation of the pouring ladle 11 and siphon 12 is disclosed and claimed in Patent 3,066,364, granted December 4, 1962, on an application which is a division of the present application. For simplicity, the details of this construction and operation are not disclosed here, but reference is made to said Patent 3,066,364 for a complete disclosure, such as patent being made a part hereof by reference.

It is preferred that the pouring operation be started and continued using the construction and observing the precautions outlined in said Patent 3,066,364.

Mold

The mounting for mold 13 will now be described (FIG. 1). The mold is supported on carriage 15 having four wheels 60 riding on two rails 16; thus the entire mold may be rolled out of the way to give access to the top of tank 20 in the casting pit and to the hydraulic mechanism for the removal of the cast product, after the pouring operation is completed.

The mold 13 is supported by a frame 14 which is vertically oscillated by a reciprocating mechanism. A suitable prime mover (omitted for simplicity) is mounted on carriage 15, which reciprocates connecting rod 61. Rod 61 is pivoted to a series of bell crank levers 62 on one side of the frame 14. A series of bell crank levers 63 are pivoted to the carriage on the other side of frame 14. Links 64 and 65 pivotally connect bell crank levers 40 and 41 to oscillatory frame 14. A connecting rod 66 connects bell crank levers 62 and 63. A series of guide posts 67 are supported on carriage 15, and slidably engage guides on frame 14 to insure vertical reciprocation of the mold in a substantially vertical straight line.

Any suitable means may be provided to vary stroke and frequency of vertical reciprocation of the mold. For example, to vary stroke, the drive motor may have a crank arm whose length is adjustable. To vary frequency, motor speed may be changed.

When casting coppers free of oxygen, it is desired to protect the surface of the liquid metal from contact with oxygen. A preferred method, in the case of phosphorus deoxidized copper, is to use a graphite flake cover 23 on the top of the molten metal in the mold. The reciprocating action of the mold works the graphite flakes down the mold wall where they finally emerge at the bottom and are washed away by the water sprays. However, other carbonaceous materials may be used, and for some purposes, air displacement by a non-oxidizing gas is all that is necessary.

Referring more particularly to FIGS. 2, 3 and 4, the mold 13 will now be described.

The mold 13 comprises a composite graphite block supported in a metal frame comprising a bottom annular manifold 70 and a circular sleeve 71. The sleeve 71 has a bottom ring 72 welded thereto which ring is bolted to the manifold at 73. The frame has a top annular plate 74 covering the ends of the cooling tubes 83. Bolts 75 secure this plate to a ring 76 which is welded to sleeve 71. The manifold 70 rests on suitable cross pieces forming part of platform 14 reciprocably mounted on carriage 15.

As shown in FIGS. 2 and 3, the graphite block comprises a main block 79 having upper and lower removable sleeves 94, 95. The graphite block 79 and sleeves 94, 95 are made from suitable commercial graphite and are machined to the shape indicated.

The sleeves 94, 95 are removable mainly to facilitate repair of the mold in case the molding surface 80 is damaged. If desired, the sleeves may be omitted and the graphite block made unitary, with the molding surface 80 machined directly into the main block as illustrated in FIG. 5.

The interior mold surface 80 is machined to vary from a true cylinder in the taper hereinafter discussed. Both sleeves 94, 95 carry the taper and the lower sleeve also carries the water passages and supporting ribs 92 as hereinafter described.

In order to obtain optimum heat transfer, the sleeves 94 and 95 must be carefully fitted into the main block 79. The contacting surfaces are cylindrical and are carefully machined so that solid-to-solid contact is obtained between sleeve and block without any fluid layer at the interface which will interfere with excellent heat transfer.

The sleeves 94, 95 are preferably made oversize with respect to the block. The sleeves are assembled into the block by forcing the sleeves axially into the block.

The compression fit between main block and sleeves must be sufficiently severe to obtain the solid-to-solid, fluid-free contact at operating temperatures. Since the sleeves and block are made of the same material, and since the sleeves will run at a higher operating temperature than the block, good thermal contact is positively maintained during the casting operation.

A tight fit is desirable also between the graphite block 79 and outer steel jacket 71, to properly reinforce the frangible graphite against the disruptive forces caused by the expandible cooling tubes 83 and by operation of the "forced" taper described hereinafter. To obtain such tight fit, the outer sleeve 71 is preferably made slightly smaller than the graphite block 79. The metal sleeve 71 is heated and shrunk onto the graphite block; or these members may be axially forced together.

The manifold 70 is annular. At its upper and inner corner is an extension ledge 81 facing the interior of the mold. The manifold 70 has an inlet passage 82 having a flange for connection with a pipe (not shown) which supplies the manifold with cold water. Additional inlet passages located at equidistant points on the annular manifold may be provided, if desired, for the large quantities of water supplied to the mold.

The manifold 70 delivers water to the main cooling tubes 83 and to five levels of water sprays. For this purpose the manifold has a series of top holes 84; a series of bottom holes 85; its ledge 81 has a series of drilled passages 86; the ledge contains holes 78 to clear the main cooling tubes 83.

The water delivery to the top or first level sprays will now be described. The graphite block 79 has a series of horizontal radial passages containing cross tubes 88. Each cross tube has a nozzle tip 89 having a downwardly directed discharge passage disposed at a 20° angle to the vertical. The cross tubes 88 connect with elbows 90 which are connected to fittings 91 connected to the top holes 84 in the manifold 70.

It will be noted that the inner face of the lower sleeve 95 has clearance bays below the discharge nozzles 89 providing, in effect, vertical ribs 92 which are available to support the casting while the water sprays are directed between the ribs onto the surface of the casting before it leaves the mold; this insures cooling the surface of the casting below the plastic range while so supported.

The second level of sprays is provided by nozzle holes 87 drilled into the ledge 81 and connecting with the passages 86 in the manifold. The axes of the nozzle holes 87 may have an angle with the vertical of about 20°.

The third, fourth and fifth levels of sprays are provided by openings 103, 104 and 105 located in cooling tubes 96 and in the return bends 93. All of these spray openings direct water against the emerging casting in the directions indicated by the arrows. The return bends 93 connect lower openings 85 with inner tubes 96.

The main cooling tubes will now be described. The outer cooling tubes 83 are loosely disposed in the upper ends of openings 78 in the ledge 81, and have special fits with the drilled and reamed openings in the graphite block 79 through which they pass. The inner tubes 96 are disposed inside of the outer tubes 83 and extend short of the top of the outer tubes. The outer tubes 83 have top caps 97 silver soldered thereto.

The outer cooling tube 83 has a normal size which is oversize with respect to the opening in the graphite 79 in which it fits. The outer tube 83 is provided with an inner longitudinal rib 98 (FIG. 4) which limits the force exerted by the copper tube on the graphite when the copper tube is forced into the graphite block and also when the tube expands from heat under casting conditions.

The inner tube 96 has two longitudinal external ribs 99 and a longitudinal internal rib 100. Internal rib 100 surrounds internal rib 98, and the external ribs 99 space the inner tube from the outer tube to form the water passages illustrated particularly in the drawing.

The relationship between the cooling tubes and the graphite blocks is most important. The outer copper tubes 83 are fitted oversize in the drilled and precisely reamed graphite holes at room temperature. The tubes being of copper will expand more than the graphite mold block at casting temperatures and thus improve initial contact pressure during the service period.

The longitudinal expansion rib 98 avoids placing undue stress on the graphite since the expansion of the tube is accommodated by elastic collapse of the rib under compression and thus the copper tube maintains the desired surface-to-surface fit with the graphite 79.

Thus, a great volume of water is fed into the lower ends of the inner tubes 96, which water overflows at the upper ends of the inner tubes and passes down between the tubes 83, 96, as indicated by the arrows. In order to obtain maximum heat transfer, the ribbed side of the outer tube 83 faces the outer side of the mold wall so that the circular side faces the mold surface liners. The fit of the inner tube 96 within the outer tube 83 determines the dimensions of the return passage for the water which is shaped to provide maximum water flow over

the smooth surface facing the molding space, and minimum flow on the back side. These provisions accomplish both high velocity flow and economy of water, while providing maximum cooling efficiency.

The details of construction and fit of the inner and outer cooling tubes **83**, **96**, the manner of connecting the various bends and elbows for the sprays, form no part of the present invention. For details of these and for other detail of the mold, reference is made to prior application, Serial No. 606,518, filed August 27, 1956, now Patent No. 2,946,100, in the names of Richard Baier, John Stuart Smart, Jr., and Albert J. Phillips.

There are certain inherent advantages in a circular arrangement of cooling tubes and outer shell. The natural stress reinforcement afforded by the outer shell **71** permits placing the expandible cooling tubes **83** closer to each other, and closer to the mold cavity, without danger of fracturing the graphite. The circular outer sleeve **71** reinforces the mold also against the fracturing pressures caused by the "forced" taper as discussed below.

It will be understood that the advantages of the circular shape applies also to those non-circular casting cavities which do not depart too much from circular, that is, which have cross sections more or less symmetrical around a longitudinal axis with respect to radial heat transfer; as, for example, equilateral triangle, square, hexagon, octagon, and even an oblong which does not depart too much from square.

The above statement applies not only to the tensile reinforcement afforded by the outer shell **71** to stresses caused by the expandable cooling tubes, but also to stresses applied by the forced taper operation discussed below.

Forced Taper

The mold pocket wall **80** is especially tapered. It is provided with what may be called for convenience a "forced" taper, to distinguish it from prior art tapers which may be called "natural" tapers. In a word, I so relate the steepness of taper to linear casting speed that I forceably wedge the shrinkage taper on the cast product against the taper on the mold pocket so as to plastically deform the red hot tube comprising the crater shell enclosing the liquid core.

The forced taper operation, in a sense, is similar to wire-drawing. It requires the establishment of a crater shell with a long and deep V, with a strong but plastic shell wall surrounding a soft liquid center a combination that is readily deformed by pulling it through the tapered mold. Weak and thin shells must be avoided because they merely tear apart. Shallow V's that are formed by casting at low speeds, as described in the prior art, are not sufficiently plastic and will hang up in the tapered mold rather than deform. The combination of mold design factors and operating technique needed to accomplish the desired result will be more readily apparent from the following discussion.

It will be understood that a "natural" taper can be designed to follow the shrinkage pattern of the casting, as it passes through the mold, rather closely at any particular linear billet speed; a slow linear casting rate which produces a well cooled cross section permits the use of a steeper mold taper (i.e. at a larger angle to vertical) than a rapid linear casting rate where the shape is emerging from the mold at a higher temperature, but in either case precaution must be taken to prevent hang up, which results from the use of excessive tapers in molds constructed and operated according to the prior art. Accordingly, with natural tapers, a small but finite clearance is necessary between the billet and mold wall along the major length of contact in such molds.

The forced taper of the present invention depends on the discovery that the natural taper can be greatly exceeded by creating a freezing zone capable of easy deformation along its entire length of contact with the mold wall, while simultaneously employing the forced contact to improve the rate of heat extraction from the shell to mold wall to such a degree that the shell wall congeals sufficiently strong and thick to resist rupture at the high operating speed necessary to create the deep V required.

Perhaps a better understanding of the forced taper will be obtained from the following explanation, when considered particularly with FIGS. 5 and 6; these figures are based on data obtained from comparative tests, in a full size pilot installation, in which billets were cast both by the natural taper and forced taper methods. The liners are omitted in these figures for simplicity of explanation. In both FIG. 5 and 6 the vertical distances correspond. The overall length of the graphite mold pocket is ten inches, and the different levels in the molds are indicated by the inch numbers, the top of the mold being the zero level.

In FIG. 6 the delineation of the tapers is deliberately exaggerated (but not the given dimensions) to better illustrate the invention. Line **110** indicates true cylindrical mold surface without any taper whatsoever. Line **111** indicates the taper of a mold following prior practice where the natural taper theoretically fits the natural shrinkage of the cast product as it is formed in the mold. Line **112** indicates the greatly increased forced taper of the invention.

When operating with the forced taper, the diameter of the mold cavity at the 8 in. level pretty much controls the diameter of the product as it emerges from the mold. On the other hand, when operating with a natural taper, the diameter of the mold cavity at the 2 in. level pretty much controls the diameter of the product as it emerges from the mold; this is for the reason that decrease in diameter of the product between the 2 in. level and the 8 in. level is due entirely to natural shrinkage, i.e. without plastic deformation.

With both forced taper and natural taper, decrease in diameter below the 8 in. level is due entirely to natural shrinkage of the congealed product as it is cooled by the sprays. The free metal surface **24** was kept at about the 1½ in. level in both cases. All other pertinent factors, including linear casting speed, were the same in both cases. In both cases, the "working portion" of the mold taper ran from about the 2 in. level to the 8 in. level, although the taper was applied to the mold wall from one end of the mold to the other, for convenience in manufacture.

The diameter of the cold billet at room temperature was 3.033 in both cases, i.e. when made according to natural taper and according to forced taper. The diameter of the mold cavity at the 8 in. level was 3.096 inches in both cases. The diameter of the mold cavity at the 2 in. level with natural taper was 3.104 inches. The diameter of the mold cavity at the 2 in. level with forced taper was 3.139 inches.

A comparison of natural taper line **111** with forced taper line **112** indicates clearly how much the embryo crater shell is "wire-drawn," or pressed inwardly, by the positive pulling, independent of weight, of the continuously cast product.

The advantage of the forced taper will be more apparent from FIG. 5. The inner line **113** indicates the shape of the crater obtained by using the "forced" taper action of the invention. The outer line **114** indicates the shape of the crater formed by using a "natural" taper. The greatly increased thickness of the crater shell, primarily at around the 2 in. level where it is hottest and most prone to tear, constitutes eloquent testimony to the improved cooling effect possible with the invention.

Although the comparative casts, from which these lines were obtained, were made at the same linear casting speed of about 40 in. per min., the product cast by the natural taper method had major defects in its surface showing that the 40 in. per min. speed was too fast to obtain good surface characteristics. On the other hand, the cast product made by the forced taper method had

excellent surface characteristics which, together with the great percentage increase in thickness of the crater shell at around the 2 in. level, indicated that considerably higher speeds than 40 in. per min. were commercially feasible.

It will be appreciated that a mold with forced taper demands a long deformable V crater at all times in order to prevent hang up. This is particularly pertinent to the conditions at the start of operation—starting speeds must be considerably faster than those required by conventional molds, and little or no delay is permissible in initiating withdrawal of the cast product, once the molten metal has reached the operating level in the mold.

The data from which the shape of the crafter and shell (using both natural taper and forced taper operations) was constructed in FIG. 5, was obtained by actual test using methods forming no part of the present invention.

It will be understood that the natural taper **111** on the mold wall is not necessarily of uniform steepness throughout the length of the mold. The line **111** is shown straight for simplicity of illustration but actually, this line may be a curve whose slope varies along the length of the mold. The taper angle (with respect to vertical) is usually greater at the top of the mold and decreases toward the bottom.

In order to obtain maximum effect from the forced taper throughout the operating length of the mold, the angle of the forced taper at each level in the mold must be steeper than the corresponding natural taper angle at that level. In practice, a uniform forced taper throughout the entire length of the mold has been found to operate satisfactorily, which uniform taper angle is equal to or greater than the maximum natural taper angle. This has the advantage of providing the proper taper angle on that part of the mold wall surrounding the free surface of the molten metal, regardless of variation in the level of this surface, thus obtaining good contact between mold wall and crater shell even at its point of formation. In any event, forced contact between the taper on the crater shell and the severe mold taper **112** should be continuous between the 2 in. and 8 in. levels.

Comment

The five sets of sprays illustrated are important participants in the total cooling. When casting phosphorized copper at the rate of about 40 inches per minute with the 3 inch diameter billet, the bottom of the liquid V zone or crater **101** is about even with the bottom of the mold (FIG. 5). Therefore, the highest sprays, which are located above the bottom of the mold, are impinging on a red hot surface with a small liquid core. Consequently, the sprays as a whole, remove most of the sensible heat and a small portion of the latent heat under such conditions, and this total is well over 50% of the overall heat extraction.

It is very desirable that the sprays operate with such high velocity and proper tangential direction that the cooling is effected by warming the water, not by generating appreciable steam. Low velocity sprays used in the uppermost position would result in steam at sufficient pressure to force its passage upward in the mold between the casting and mold wall. This results in shallow scalloping of the surface of the billet, if the steam reaches the solidifying surface. Accordingly, both pressure and direction are used to create a downward venturi action which eliminates this effect. The downward direction of the first and second level sprays **89**, **87** is sufficient to insure overall venturi action.

It will be noted that the top level of sprays **89** applies cooling while the wall ribs **92** are still available to contact and support the crater shell. It will be understood that, even though natural shrinkage causes the casting to tend to lose contact with the ribs **92**, the ribs still fit the casting sufficiently closely to remove substantial amounts of heat. Thus, at the zone defined by the ribs **92**, heat is removed from the casting by contact with both liquid medium and solid medium. In other words, the zone of cooling by contact with a solid medium overlaps the zone of cooling by a liquid medium.

The forced taper and the overlapping of a cooling zones minimizes the possibility of break-through of the crater shell with consequent spillage of molten metal, and permits casting at higher withdrawal speeds without sacrifice of safety; it also prevents reheating of the billet with its attendant defects such as internal and external cracking, etc.

It will be understood that, with no reheating, all points throughout the solidified section of the product assume progressively lower temperatures as they move down through the mold. That is to say, the temperature of any given point progressively drops and never rises as that point moves through the mold.

It will be understood that reheating may very well occur if no mold taper is used, or even when using a natural mold taper if finite clearance should occur between the cast product and the mold wall as the cast product shrinks away from the mold wall; or if there is any spacing between the zones of solid and liquid cooling. The hotter metal in the crater is always available to raise the temperature on the surface of the cast product, if that surface is not adequately cooled.

The graphite blocks may be of any grade or quality of graphite, including materials containing graphite, such as graphite coated carbons, and the term graphite as used in the claims is intended to cover such equivalents. In general, it is preferred to use the type of graphite which has maximum density and mechanical strength as well as maximum heat conductivity.

The invention may be employed to cast any metal or alloy, such as steel, silver, nickel, aluminum, magnesium and particularly copper. It is especially useful for casting oxygen-bearing copper such as tough pitch copper in any desired size; and for casting coppers free of oxygen such as oxygen-free or phosphorous deoxidized copper.

The term "oxygen-bearing copper," as used herein, is intended to include tough pitch copper as well as copper containing a lesser amount of oxygen; it is intended to include any copper in which oxygen is in available form for attacking the graphite if the reaction temperature of the graphite is exceeded.

On the other hand, the term "copper free of oxygen," as used herein, is intended to cover those coppers known as phosphorous deoxidized copper containing both high phosphorous and low residual phosphorous, any other deoxidized copper such as copper deoxidized by lithium, boron, calcium, etc., and also those coppers referred to as "oxygen free"; in other words, any copper in which there is no oxygen available for attacking the graphite at its reaction temperature.

For casting coppers free of oxygen, it is preferred to introduce a protective layer **23** (FIG. 5) of discrete particles of carbonaceous material, such as flake graphite, lamp black, pulverized anthracite, etc., floating on the surface of the molten metal in the mold. A mixture of flake graphite and fine carbon particles known as Micronex was used quite successfully in tests. This was spooned in on top of the free molten surface in the mold from time to time, to maintain the blanket.

This cover acts as a protective blanket to prevent oxygen absorption and also prevents build-up of phosphate slag or other extraneous material on the mold wall. Reciprocation has a special purpose when casting coppers of this type, since it also feeds a controlled film of carbonaceous material between the mold and casting, resulting in a superior cast surface.

Oxygen bearing coppers act decidely differently. Here, reactive carbon produces defects, and the use of a bare mold wall is preferable to the nuisance of trying to apply an inert mold dressing and maintaining a uniform coating at all times.

The amplitude and the frequency of reciprocation of the mold is related to the cross section being cast, the amount of taper and the casting rate. In general, I have found that the ratio of reciprocation frequency (in number of cycles per minute), to casting speed (in inches per minute), should be about eight or ten to one, with an amplitude of 2 mm. (.08 in.). That is to say, 180 cycles per min. at a linear casting rate of 20 in. per min., or 350 cycles per min. at a linear casting rate of 40 in. per. min. A short stroke is generally to be preferred since this avoids excessive clearance between mold and casting on the downward portion of the stroke.

By stroke or cycle is meant a complete round trip movement of the mold from bottom position back to bottom position. The movement is substantially simple harmonic, varying from zero speed at upper and lower ends to maximum speed between the upper and lower ends of the amplitude of movement.

It is desired that the maximum instantaneous speed of the mold be greater than the uniform linear speed of the billet to provide a small gap between mold taper and casting taper and thus to permit a certain amount of the cover 23 to feed down the mold wall between mold and cast product.

While certain novel features of the invention have been disclosed herein, and are pointed out in the annexed claims, it will be understood that various omissions, substitutions and changes may be made by those skilled in the art without departing from the spirit of the invention.

What is claimed is:

1. The method of continuously casting metal in a mold, said mold having a mold pocket, said mold pocket having a graphite wall with an effective length of longitudinal taper converging toward its discharge end, said mold pocket having, with respect to its longitudinal axis and throughout said effective length of taper, a cross section substantially symmetrical with respect to radial heat transfer, said effective length of taper being greater than the maximum cross-sectional dimension of the mold pocket at said effective length of taper, the angle of said taper, with respect to said longitudinal axis, being sufficiently small that the mold pocket retains substantial uniformity of cross section throughout said effective length of taper; said method comprising melting the metal at a point removed from the mold and feeding molten metal into the mold pocket, casting and cooling at such rates as to form a crater shell with a comparatively long, slender, substantially circular crater extending along the mold pocket a distance equal at least to the effective length of taper, said molten metal having a free surface in the mold, positively pulling the congealed casting out of the mold with such force and at such speed as to wedge the small taper of the crater shell directly against the small mold taper to plastically permanently deform and lightly draw the crater shell over substantially the entire effective length of mold taper and around the peripheral surface of the crater shell, thereby to permanently slightly decrease the cross section of the emerging embryo casting, the wedging action serving to increase heat flow across the interface from crater shell to graphite wall.

2. The method of claim 1 in which the angle of taper, with respect to said longitudinal axis, is several times greater than the taper angle of a corresponding mold having a natural taper and operating at the same casting rate, natural taper being defined as that taper which substantially fits the natural shrinkage of the casting allowing the casting to emerge from the mold without plastic deformation.

3. The method of claim 1 in which the metal being cast is a copper base metal.

4. The method of claim 1, and longitudinally reciprocating said mold.

5. The method of claim 1, said mold pocket having a solid wall cooling zone and a liquid cooling zone, said solid wall cooling zone carrying the taper, said taper converging downstream to said liquid cooling zone, said method including applying water at said liquid cooling zone directly to the emerging casting.

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