Aug. 27, 1968 D. C. YEARLEY 3,398,780

CONTINUOUS CASTING OF TUBES

Filed July 1, 1965 3 Sheets-Sheet 1

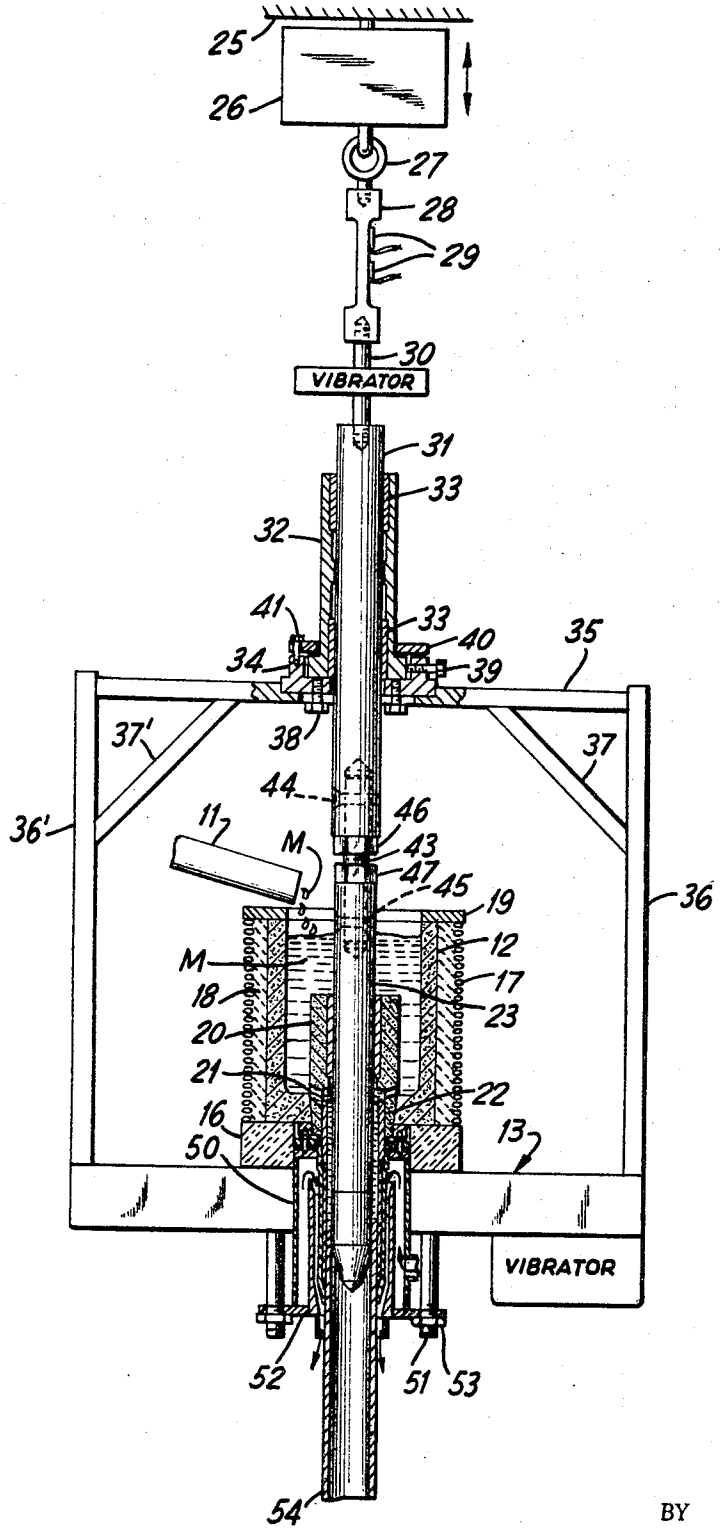


FIG. 1a

INVENTOR.
DOUGLAS C. YEARLEY

BY

Davis, Hoxie, Faithfull & Hapgood
ATTORNEYS.

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Filed July 1, 1965 3 Sheets-Sheet 2

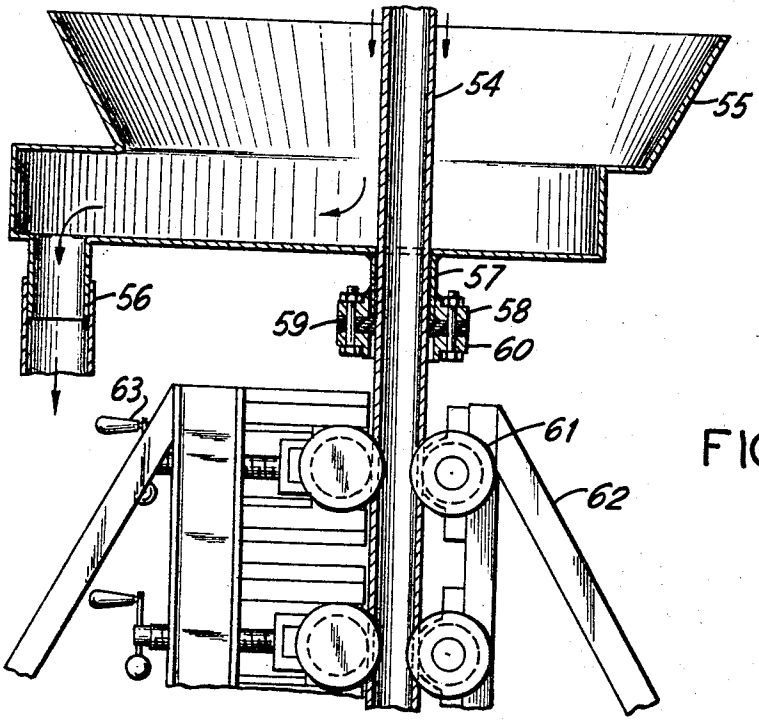


FIG. 1b

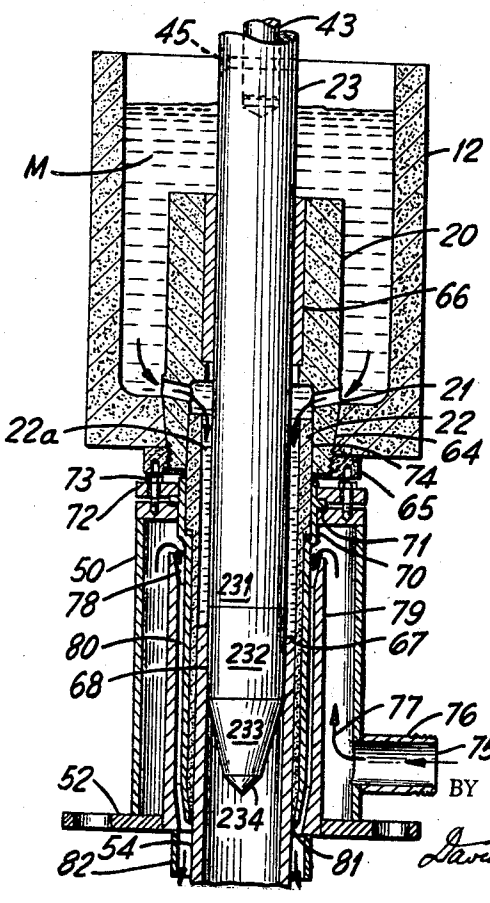


FIG. 2

INVENTOR.
DOUGLAS C. YEARLEY

BY

Davis, Hoxie, Faithfull & Hapgood
ATTORNEYS.

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Filed July 1, 1965 3 Sheets-Sheet 3

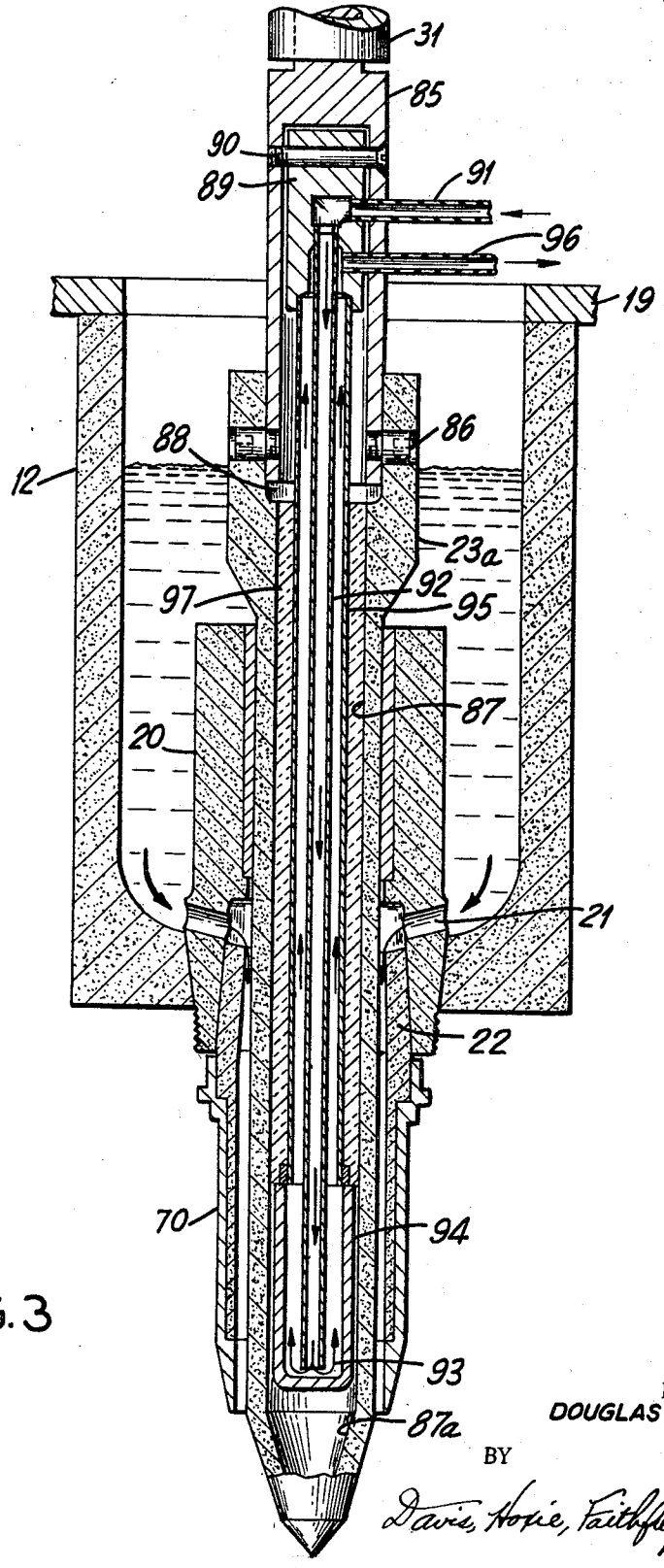


FIG. 3

INVENTOR.
DOUGLAS C. YEARLEY

BY

Davis, Hoxie, Faithfull & Hapgood
ATTORNEYS.

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CONTINUOUS CASTING OF TUBES

Douglas C. Yearley, Westfield, N.J., assignor to Phelps Dodge Copper Products Corporation, New York, N.Y., a corporation of Delaware

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8 Claims. (Cl. 164—49)

ABSTRACT OF THE DISCLOSURE

Continuous casting of tubes by solidfying molten material as it is withdrawn from a solidification zone defined by the insertion of a central mandrel into the exit aperture of a liquid zone to create an annular aperture of adjustable dimensions to control the characteristics of the cast product.

SPECIFICATION

This invention relates to a method and apparatus for the continuous casting of hollow metal tubes.

Continuous casting of tubes comprises the uninterrupted flow of molten metal to one end of a casting mold and the removal of heat from the metal to solidify it as it is formed into the desired sectional shape during passage of the metal through the mold. Tubing is cast continuously by the use of an inner core or mandrel positioned within a cylindrical mold or die. The molten metal is supplied under pressure or by gravity feed to the annular space between the mandrel and the cylindrical mold. The mold is cooled to solidify the metal, and cast tube is drawn from the mold by rollers or the like which grip the outer surface of the tubing.

In general, the relatively slow rates of continuously casting tubing in prior apparatus and the poor quality of such tubing are serious problems which heretofore have made it economically impractical to continuously cast tubing for direct fabrication into commercial tubing. Those problems are due in part to adhesion of the metal to the surfaces of the mold and the mandrel and to shrinking of the metal on the mandrel during the cooling and solidifying phase of the process. These difficulties have persisted despite various counteracting measures which have been attempted, such as vibrating the mold and providing the mandrel with a taper in the direction of the metal movement through the mold.

Other factors which have precluded extensive use of continuous tube casting for direct fabrication to commercial tubing include the difficulty in starting the tube casting process, the tendency for the cast tube to have an intolerable degree of eccentricity and lack of control over the solidification process in the mold during the casting operation.

Control over the solidification process is important since the process of solidification, including the rate of solidification and its location, determines the properties of the resulting tubing such as surface quality, tensile strength, elongation, grain size, etc.; and lack of control of that process will, of course, give poor properties in the tubing.

This invention provides an improved apparatus for the continuous casting of tubes and a new method for such casting, which will allow for the manufacture of high quality tubes on a commercial and economical basis. It eliminates start-up difficulties, provides a concentric tubing of good quality which may be rapidly and economically fabricated into commercial tubing. Another important aspect of this invention is that it permits the molten metal used to form the tubing to be fed to the casting mold by gravity without any need for metering that flow or the use of a feed spout to deliver and position the metal in the mold.

According to the present invention, the mandrel is mounted for vertical movements relative to a mold which is fed from a molten pool of metal maintained in a reservoir above the mold. The latter, in turn, is mounted for vertical vibratory movements in which it is guided by means for preventing lateral displacement of the mold. In starting the tube casting operation, molten metal is first fed to the mold from the overlying reservoir while the mandrel is withdrawn, whereby solid rod is drawn initially from the exit or lower end of the mold; and then, as the feed of molten metal is continued, the mandrel is lowered through the reservoir so that the tapered lower end of the mandrel enters the mold to a depth sufficient to effect transition from rod to tube casting. The mandrel is guided in its vertical movements by guide means overlying the reservoir and adjustable laterally to effect accurate centering of the mandrel relative to the mold.

In the preferred form of the new apparatus, the mold and the mandrel are provided with separate cooling systems. Also, to prevent adhesion of the metal during casting and to improve the grain structure of the cast tube, the mold and the mandrel are vibrated vertically either in unison or separately.

The method and apparatus of my invention have been used successfully to produce good quality phosphorous deoxidized copper tubes having overall diameters of 1½ to 4 inches with wall thicknesses ranging from 0.17 to 4.45 inches, at speeds in excess of 2 feet per minute and with an error of concentricity of less than 0.01 inch.

The invention may be better understood from the following description of a specific example as illustrated by the accompanying drawings, in which:

FIGS. 1*a* and 1*b* are together a vertical view of a preferred form of the apparatus of my invention;

FIG. 2 is an enlarged vertical sectional view of the mold and the crucible forming the feed reservoir, as shown in FIG. 1*a*; and

FIG. 3 is an enlarged vertical sectional view of a modified form of the mandrel having a separate cooling system.

Referring to the drawings, particularly FIG. 1*a*, metal M in molten form is introduced from an external source, not shown, by means of a launder or trough **11** into a generally cylindrical crucible **12** of graphite mounted on a vertically movable platform **13**. The latter has a generally rectangular shape in plan view and any conventional means (not shown) may be used to support it.

The platform **13** has attached to its intermediate its right front and rear corners and left front and rear corners supports **36** and **36'**, respectively. Struts **37** and **37'** reinforce cross bracket **35** which is attached at each of its ends to supports **36** and **36'**. These members support the upper portion of the apparatus, as more fully hereinafter explained.

The platform has attached to its a vibrator (shown schematically) which may be of any conventional design, preferably one to impart a vertical sinusoidal vibratory motion to the platform **13** and thus to the casting apparatus. By rigid connection (by means not shown) of supports **36** and **36'** with the bar **30** both the mandrel and the mold may be vibrated by the same means. Without that connection the mandrel may be used without vibrat-

ing it or it may be vibrated independently by attaching a conventional vibrator, such as an ultrasonic transducer, shown schematically, to bar **30**.

In practice, I have found it suitable to provide the vertical vibrations to the casting apparatus with an amplitude of about 1/20 to 1/4 inch at a frequency ranging from a few hundred to several thousand cycles per minute.

Heat from crucible **12** is insulated from platform **13** by insulating bricks **16**. The crucible is enclosed in an induction coil **17** carrying water as the coolant and supported in place by refractory lining **18** of material such as silica or the like which is rammed between the coil and the outer surface of the crucible. The open end of the crucible is suitably provided with a plate **19** of ring form. Mounted within the crucible **12** through a central aperture in the bottom thereof is a guide bearing **20** also of graphite and having generally radial and sloped feed ports **21** to allow passage of the liquid metal into a cylindrical casting mold **22**. The latter is closely surrounded by the lower portion of bearing **20**, and the upper portion of this bearing forms a close sliding fit around a graphite mandrel **23** so as to center the mandrel in the graphite casting mold **22**.

The mandrel **23** is supported from an overhead support **25** from which depends (shown schematically) hoist means **26** for raising and lowering the mandrel. The hoist **26** may be hand or motor driven, but preferably is a conventional hand operated worm gear which allows precise positioning of the mandrel. Suitably attached to hoist **26** is a depending eye bolt **27** connected to one end of a strain measuring device **28**. Elongation of device **28**, by tensile strain on the depending mandrel **23**, is detected by strain gauges **29** suitably mounted on strain device **28** and connected electrically to a conventional indicator (not shown) for indicating the amount of strain on the device **28** and thus the downward force exerted on mandrel **23** during the tube casting operation. As such strain measuring devices are well known in the art, further description of the device **28** and its associated elements is unnecessary.

The lower end of strain measuring device **28** is connected by a bar member **30** to a guide post **31**. The latter is held in vertical alignment with the guide bearing **20** and mold **22** by a steel guide bearing **32** into which precision-machined bronze bushings **33** have been pressured. Guide bearing **32** is mounted in an alignment box **34** secured to cross bracket **35**. Orientation of the guide bearing **32** in the mounting box **34** is adjustable by bolts **38** for angular positions with the vertical and is adjustable horizontally by radial bolts such as bolt **39**. Guide bearing **32** is locked in its adjusted position by a cover plate **40** and bolts **41**.

Mandrel **23** is rigidly connected to guide post **31** by a connecting pin **43**. A cross bolt **44** connects one end of the connecting pin **43** to the guide post **31** while a similar cross bolt **45** connects the mandrel **23** to the other end of connecting pin **43**. To prevent wobble between the guide post **31** and the mandrel **23**, two lock-nuts **46** and **47** are threaded on pin **43** and tightened against the guide post **31** and mandrel **23**, respectively.

Liquid metal in the casting mold **22** is solidified in the mold portion lying within a cooling jacket **50**. The latter is provided at the bottom with an annular flange plate **52** through which extend a plurality of studs **51** depending from platform **13**. Jacket **50** is held in position by nuts **53** threaded on studs **51** and bearing against the bottom of flange plate **52**.

The metal solidifying between mold **22** and mandrel **23** is withdrawn as tube **54**, which passes downward into a quench chamber **55** (FIG. 1*b*). Water passing through jacket **50**, along the path indicated by the arrows in FIG. 1*a*, flows downward to chamber **55** to serve as the quenching liquid. The quench chamber **55** is drained through exit port **56** to a recirculating water system with means to cool the water (not shown), the cool water being circulated to jacket **50** through inlet port **75** (FIG. 2). The cast tube discharged through the bottom of quench tank **55** by way of a sealed outlet comprising a boss **57** welded to the quench tank **55** and welded to a flange **58**. Several rubber gaskets **59** are firmly, clamped by a ring **60** to the welded flange **58** to form a seal which wipes the surface of the cast tube **54** as it discharges. The tube is pulled downwardly through seal **59** by withdrawal rolls **61** mounted on a fixed stand **62** and tightened into position against the tube by adjusting screws **63** having operating handles **63***a*.

Referring now to FIG. 2, graphite guide bearing **20** is centrally mounted in crucible **12** by a press-taper fit, as at **64**, and is held in place by a graphite nut **65** tightened on threads on the lower end of the guide bearing. A sleeve **66** is provided on the inner surface of the graphite guide bearing **20** and may be easily replaced in the event of wear to insure a close-tolerance slide fit between the mandrel **23** and guide bearing **20**. Mandrel **23** is positioned in mold **22** by operation of hoist **26** and adjustment of box **34** (which may be adjusted upon wearing of graphite guide bearing **20**), to effect concentric solidification, as at **67**, at the desired portion of the tapered section **68** of mandrel **23**. Thus, the cast tube **54** will have essentially a uniform wall thickness.

Mandrel **23** is cylindrical for substantially its entire length from its upper end to a distance just short of its lower end. This cylindrical portion is indicated in FIG. 2 by numeral **231**. The next lower portion **232** is given a slight taper and the next lower portion **233** has a greater taper of about twice the rate of the taper of portion **232**. The tip portion **234** is not necessarily tapered, although it is preferable to provide it with a point to allow the mandrel to penetrate easily the surface of the molten metal as the mandrel is lowered into the mold. In one design for a machine casting a tube with a 3-inch O.D., the mandrel was 2 feet long, portion **231** was 20 inches long with a diameter of 2.35 inches, portion **232** was 2.5 inches long with a taper of 1° while portion **233** was provided with a taper of 2°. The taper of each of the two portions is not critical, however, since the mandrel can be positioned during the casting to the precise position required to satisfy the requirements of the tube being cast.

The casting mold assembly includes the graphite liner **22** which is shrunk-fit within a copper sleeve **70**. These parts are then placed within the cooling jacket **50** and firmly seated and sealed against water leaks by an asbestos gasket **71** clamped by a retainer ring **72** and bolts **73**. The assembly of the cooling jacket **50** and mold (**22** and **70**) is then press-fitted into socket **74** of guide bearing **20**. Water under pressure is fed through a flexible hose (not shown) to inlet nipple **76** of cooling jacket **50**, rising vertically along path **77** and entering a narrow annular gap **78** between the copper-graphite die assembly and an inter-baffle **79**. The water then flows downward at high velocity through the annular space **80** within baffle **79** and impinges on the surface of exiting cast tube **54** at **81**. The water is prevented from splashing outwardly by a retaining skirt **82**.

Referring now to FIG. 3, there is shown a preferred mandrel of my invention having details for cooling the mandrel. The modified mandrel **23***a* is inserted in a graphite crucible **12** into which a graphite guide bearing **20** has been press fitted, as described above. The graphite mandrel **23***a* extends downward through the guide bearing **20** into the casting mold **22**, restricting the molten metal to the annular space therebetween to form a cast tube. The mandrel **23***a* is suspended from a hoist **26** and aligned as described above with respect to the alignment of mandrel **23** shown in FIG. 1*a*.

A pin **85** connects mandrel **23***a* to post **31** shown in FIG. 3. Pin **85** is connected to post **31** by a bolt (not shown) and to mandrel **23***a* by four radially positioned cap screws **86**. Mandrel **23***a* is internally bored, as at **87**, substantially completely through to its tapered end as

shown at **87***a* and is counterbored to a larger internal diameter at the heavy upper section in the portion **88**. Axial passages for the water cooling system are provided within the bored cavity of the connecting pin **85** and the cavity of mandrel **23***a*. This water cooling system comprises a cooling manifold **89** connected to the connecting pin **85** by a transverse bolt **90**. Water or other suitable coolant is fed into the cooling manifold **89** through an input pipe **91** and flows downward through a central tube **92**, discharging along path **93** into the cooling chamber **94**. The coolant is forced back up the mandrel through the annular space within an outer tube **95** surrounding the input tube **92**. The returning coolant enters the cooling manifold **89** and is discharged through the exit tube **96**. Above the cooling chamber **94**, the outer tube **95** is surrounded by a heat insulating sheath **97** to prevent heat loss in these areas where cooling is not desired.

In operation, the continuous casting of rod (i.e., a solid casting without a hollow center) is initially effected with the lower end of mandrel **23***a* raised into the upper part of guide bearing **20** by hoist **26**. The mandrel **23***a* is then lowered into the mold to establish tube casting. During the casting, the coolant is circulated through the mandrel to increase removal of heat from the metal being cast, particularly in the portion of the mold adjacent the mandrel cooling chamber **94**. The rate of coolant circulation is adjusted in accordance with the conditions of casting, including the nature of the metal or alloy being used, the dimensions of the tube being cast and the rate of withdrawal.

Before the start of casting, the graphite crucible **12** is preheated, as by means of the induction heating coil **17**, to temperatures in excess of the melting point of the metal or alloy to be cast. A moderate flow of a coolant, such as cold water, is circulated through jacket **50** to prevent overheating of the mold **22**. The graphite mandrel **23** or **23***a* is fully withdrawn from the mold into the guide bearing **20**, and the mold, or the mandrel, or both, as desired, may be vibrated. If both are vibrated they may be vibrated synchronously by the same source, as previously stated, or independently, as required. The molten metal or alloy M is then introduced into the crucible **12** from which it flows through the feed ports **21** in guide bearing **20** into mold **22**. A starting cup (not shown), which has previously been placed in the mold, receives and holds the liquid metal until it solidifies. The resulting solid rod, serving only as a starting rod, is withdrawn; and the coolant water flow rate is increased sufficiently to keep the temperature from rising while the solid rod is continuously cast from the mold. Casting speeds are then increased to the desired steady-state tube casting rate by increasing the speed of withdrawal rollers **61**.

The mandrel **23** or **23***a* is then gradually lowered into the mold to form the continuously cast product into a tube. This transition from rod to tube is made with care to prevent a sudden grabbing of the mandrel by the solidifying metal, causing a possible fracture of the cast. This transition may be facilitated by the use of easily detectable load indications on the strain gauges **29** calibrated according to the particular casting desired.

The zone **67** (FIG. 2) within the mold, where the molten metal becomes solidified for tube casting, is displaced downwardly from the zone where solidification for casting the solid rod occurs. The position of zone **67** is controlled by the positioning of mandrel **23**. If the mandrel is inserted (lowered) beyond the proper position, excessive shrinkage pressure is developed on the mandrel causing transverse checks and cracks on the inside surface of the tube. If the mandrel is insufficiently lowered to the proper position, ripples are produced on the inner surface of the tube.

As the tube is first cast, test cuts on the tube surface indicate deviation in concentricity of the mandrel with respect to the mold. These deviations or error in concentricity can be corrected by adjustments, during the casting operation, of the lateral position of mandrel **23** or **23***a* in the mold **22** as described above. If irregular surface conditions, particularly the internal surfaces, are detected or observed, the mandrel position is easily adjusted in angular relation to the mold to correct the surface irregularities. The feature of the tapered mandrel permits easy control of the wall thickness of the tube during casting by varying the vertical position of the mandrel. The mold or mandrel, or both, are vibrated as stated according to the desired characteristics of tubing and its material.

With the present invention, it is possible to increase substantially the production rate of tubes continuously cast. The provision for raising and lowering the mandrel, in combination with the continuous feed of molten metal from the pool maintained in crucible **12** above the mold, allows for control of the mandrel variables and enables continuous casting of thin-walled tubing of 4-inch O.D. or less. The means for laterally and angularly positioning the mandrel allows for correction during the casting operation of error in eccentricities. The mandrel being provided with a locally cooled portion in the vicinity of the solidifying zone allows for higher casting speed and improved quality of cast tube. In addition, the means for vibrating the mold and the mandrel, individually or jointly, satisfies a wide range of conditions that are desirable in respect to the preferred grain size and surface characteristics of the various metals and alloys that are used.

I claim:

1. A method of continuously casting tubes which comprises the steps of continuously feeding molten metal into one end of a casting zone while cooling said zone and while discharging a solidified metal product in the form of a rod from the opposite end of said zone, gradually inserting a mandrel into said zone while continuing said feeding, cooling and discharging steps, to form an annular space between said ends of the zone and thereby convert the discharging product from a rod to a tube, and adjusting the position of the mandrel in said zone as the tube is discharging therefrom, to control the character of the discharging tube.

2. A method of continuously casting tubes which comprises the steps of maintaining a pool of molten metal, continuously feeding molten metal by gravity flow from the lower portion of said pool directly into the one end of a casting zone while cooling said zone and while discharging from the other end thereof a solidified metal product in the form of a rod, gradually inserting a mandrel into said zone from said one end thereof while continuing said feeding, cooling and discharge steps, to form an annular space between said ends of the zone and thereby convert the discharging product from a rod to a tube, and adjusting the position of the mandrel in said zone as the tube is discharging therefrom, to control the character of the discharging tube.

3. A method according to claim **2**, further comprising vibrating said molding zone axially.

4. A method according to claim **2**, further comprising vibrating said mandrel axially.

5. A method according to claim **2**, further comprising vibrating said mandrel and molding zone jointly in the axial direction.

6. A method according to claim **2**, further comprising vibrating said casting zone axially, vibrating said mandrel axially at a frequency and amplitude different from that of the vibration of said molding zone, and restraining said zone and mandrel against lateral displacement during said vibrations thereof.

7. A method according to claim **4**, wherein said mandrel is vibrated at ultra-sonic frequency.

8. A method according to claim **2**, further comprising

cooling the portion of said mandrel nearest said lower end of the molding zone.

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J. SPENCER OVERHOLSER, *Primary Examiner.*

R. S. ANNEAR, *Assistant Examiner.*