METHOD OF CONTINUOUSLY CASTING TUBES USING A ROTATING MANDREL

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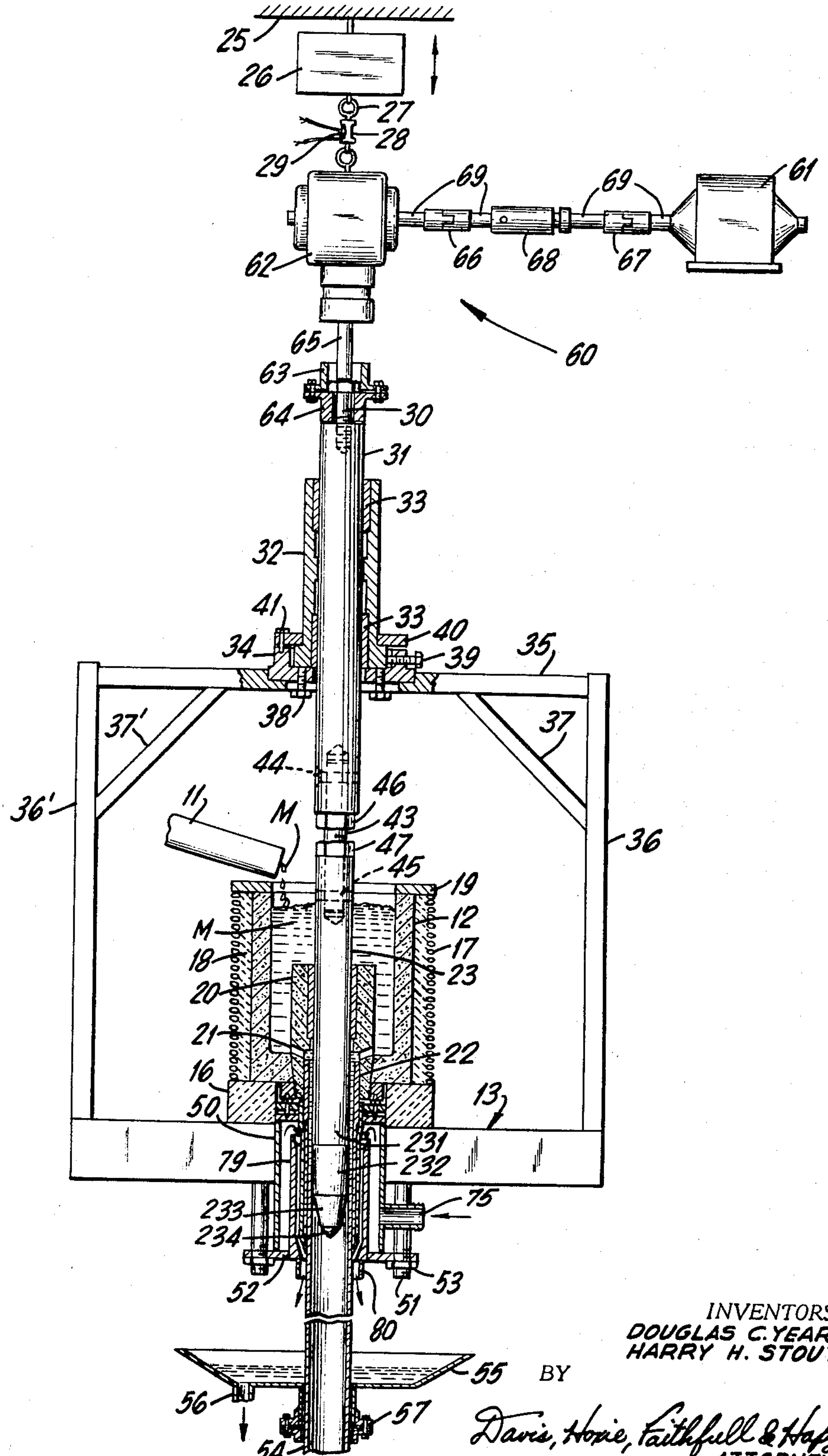


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# METHOD OF CONTINUOUSLY CASTING TUBES USING A ROTATING MANDREL

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4 Claims. (Cl. 164—85)

## ABSTRACT OF THE DISCLOSURE

Tubing is continuously cast by solidifying molten material as it is withdrawn from a casting zone defined by a rotating central mandrel and a surrounding mold.

## DISCLOSURE OF INVENTION

This application is a continuation-in-part of an application by Douglas C. Yearley, Ser. No. 468,771 filed July 1, 1965.

This invention relates to a method and apparatus for the continuous casting of hollow metal tubes. It has particular reference to apparatus for such casting which includes a rotatable mandrel and to the related method.

Continuous casting of tubes comprises the uninterrupted flow of molten metal to one end of a casting mold, uninterrupted withdrawal of solid metal from the other end of the 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 surfaces 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 the position and stability of the solid/liquid interface, 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 movement relative to a mold which is fed from a molten pool of metal maintained in a reservoir above the mold. The mandrel is adapted to permit rotation relative to the mold. In starting the tube casting operation, molten metal is first fed to the mold from the overlying reservoir while the mandrel is in a withdrawn position 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 movement by guide means adjustable laterally to effect accurate centering of the mandrel relative to the mold.

According to our method, rotation of the mandrel with respect to the mold, either in a clockwise or counterclockwise direction or with rotational oscillation, has been found to improve substantially the metal grain and thus the ductility of the inner surface of cast tubes. We believe that any such mandrel rotation, within limits as to the rotational rates, will improve the ductility of the inner surface of a tube cast according to our method. When castings are made without any form of mandrel rotation, the inner surface of the tube lacks ductility and may crack when subjected to plastic elongation (i.e. an internal bend test or a standard tensile test). These cracks also develop as laps on the internal diameter of the tubing during cold drawing, causing the resultant finished tube to be rejected as defective. When tubes are made with a rotating mandrel, no cracking occurs in the internal diameter when elongated and the casting can be successfully fabricated.

The direction of rotation of the mandrel according to our method may be clockwise or counterclockwise or it may be oscillatory wherein the direction is reversed periodically. Such reversal may occur after less than a complete revolution, at the end of each revolution, or at the end of several revolutions. Satisfactory castings have been obtained over a wide range of rotational speeds up to 900 r.p.m. The preferred range appears to be between 10 and 100 r.p.m.

As stated, mandrel rotation according to our method will improve the ductility of the inner surface of the cast tubing. However, the manner of rotation of the mandrel may induce or reinforce an adverse swirl effect upon the outer surface of the tubing, which also must be considered to determine the optimum manner of rotation of the mandrel.

While mandrel rotation above a minimum rate and not at excessive rates will improve the ductility of the inner surface of a tube cast according to our method, if the rotation of the mandrel reinforces the swirl which would otherwise exist, cracking may occur in the outer surface of the tube. Mandrel rotation which minimizes the swirl is therefore generally preferred.

When a liquid drains through an opening under the force of gravity, it will swirl due to the Coriolis effect, which in the Northern Hemisphere ordinarily produces a clockwise rotation. However, if a force other than from gravity and the rotation of the earth is exerted on the liquid in the clockwise direction, this force will reinforce that causing the Coriolis effect. If the added force is counter-clockwise it will counteract the rotation from that effect but may cause an undesirable swirl of its own. The problem of swirling is greater when casting a thin wall tube, particularly at a high casting rate. In such a case it is difficult exactly to counteract the swirl which would otherwise exist because an undesirable counter swirl is readily induced by mandrel rotation. We have found that in such a case it is preferable to oscillate the mandrel and that the spiral effect is substantially eliminated. When casting thick wall tubes it is sufficient to rotate the mandrel in the direction counter to that of the swirl which would exist under the casting conditions if the mandrel were not rotating.

The thinner the wall thickness of the casting made according to our method, the greater the tendency for the metal to swirl in the die increasing the spiral effect and causing the resulting cast tube to crack when elongated. The faster the casting speed the greater the tendency for such cracking. In general, when casting a thin wall tube we prefer to use a slower rotational speed for the mandrel and oscillatory motion of the mandrel in such a case is preferred. In casting a thicker wall, we, therefore, prefer to use a relatively higher mandrel rotational speed than for tubes having thinner walls, and for the thicker wall tubes, in general, we prefer to rotate the mandrel in one direction, counter to the direction of swirl which would exist under the conditions of casting with the mandrel not rotating. By a "thin" wall tube we mean one having a wall thickness on the order of 0.2 of an inch and by a "thick" wall tube we mean one having a wall thickness of the order of 0.5 of an inch.

Using our invention, 3 inch diameter tubes having a wall thickness of .380 have been successfully cast from phosphorus bearing copper at 20 inches per minute at mandrel rotation speeds between 20 and 40 r.p.m. in either direction and at 20 r.p.m. effective speed with the direction reversed every revolution to provide oscillatory motion. Without mandrel rotation, cracks would result in the internal surface of such a tube if it were elongated.

The method and apparatus of our invention may also be used successfully to produce good quality tubes (for example, made with phosphorus deoxidized copper) having overall diameters of 1½ to 4 inches with wall thicknesses ranging from 0.17 to 0.45 inch, 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 figure, which is a vertical view of a preferred form of the apparatus of our invention.

Referring to the figure, metal M in molten form is introduced from an external source, no 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 it intermediate its right front and rear corners and left front and rear corners support **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.

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 mandrel **23** is caused to rotate or oscillate by means of rotating device **60**. A variable speed motor **61** is connected to a right angle gear drive **62** by a shaft **69** having universal joints **66** and **67** and sliding coupling **68**. The vertical output shaft **65** of the right angle drive **62** is attached to guide post **31** by coupling flanges **63** and **64** which is fixed to guide post **31** with bolt **30**.

The lower end of mandrel rotating device **60** is connected by a bolt **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 pressurized. 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**. Water passing through jacket **50**, along the path indicated by the arrows of the figure, 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**. The cast tube is discharged through the bottom of quench tank **55** by way of a sealed outlet **57** welded to the quench tank **55**. The tube is pulled downwardly through seal **57** by withdrawal rolls (not shown).

Graphite guide bearing **20** is centrally mounted in crucible **12** by a press-taper fit. A lining sleeve 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. 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 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 about 1.5 inches long and had 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. It is also satisfactory to use a mandrel having a single tapered portion having a taper on the order of about 1° and being as long as the effective length of the metal solidification zone, which is generally in the range of about 3 to 9 inches.

The casting mold assembly includes the graphite liner **22** which is placed within the cooling jacket **50** and firmly seated and sealed against water leaks. Water under pressure is fed through a flexible hose (note shown) to inlet nipple **75** of cooling jacket **50**, rising vertically and entering a narrow annular gap between the graphite die 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 existing cast tube **54**.

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** is fully withdrawn from the mold into the guide bearing **20**, and the mandrel rotated. 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 the withdrawal rollers.

The mandrel **23** 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 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 this zone 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 through the tube 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 in the mold **22** as described above. If irregular surface conditions, particularly the internal surfaces, are detected the mandrel position is easily adjusted in angular relation to the mold to correct the surface irregularities. The tapered mandrel permits easy control of the wall thickness of the tube during casting by varying the vertical position of the mandrel. It may be desirable to vibrate the mold by any of several conventional means (not shown).

*Example*

Using the apparatus shown in the figure, we cast a 3½ inch diameter tube of phosphorus deoxidized copper having a wall of 0.310 of an inch. The mandrel was rotated for 15 seconds at 20 r.p.m. in one direction followed by 15 seconds of rotation at the same speed in the opposite direction.

Swirling of the molten metal in the mold was substantially reduced and the resulting tube was substantially improved in quality. The interior surface of the tube was ductile and did not crack when subjected to plastic elongation.

The present invention makes it possible to increase substantially the quality and production rate of tubes continuously cast. The amount of material required during initial start-up of the process is reduced. The gain structure and surface characteristics of the cast tubing are substantially improved. It also permits satisfaction of a wide range of conditions and the continuous casting of a variety of alloys while maintaining desirable grain structure and surface characteristics.

The use of a rotating mandrel improves the ductility of the internal surface of the cast tube and thus produces a tube which resists internal cracking if the tube is subjected to plastic elongation.

We 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 to form an annular space between said end of the zone while continuing said feeding, cooling and discharging the product, thereby converting the discharging product from a rod to a tube, and rotating said mandrel within said zone to control the characteristics of the discharging tube.

**2.** A method according to claim **1**, wherein said mandrel is rotated in a range of speeds between 10 and 100 r.p.m.

**3.** A method according to claim **1**, wherein said mandrel rotation is oscillatory motion.

**4.** 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 tube from the opposite end of said zone, rotating a mandrel positioned within said zone to form an annular space between the ends of said zone, and adjusting the rotation and position of the mandrel to control the characteristics of the discharging tube, said mandrel being rotated in a direction and in a range of speeds between

10 and 100 r.p.m. which substantially nullifies swirling of the molten metal entering said casting zone.

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