United States Patent
Wang

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[54] **METHOD AND APPARATUS FOR CONTINUOUS CASTING WITH GYRATING MOLD**

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[52] **U.S. Cl.** **164/83,** 164/260

[51] **Int. Cl.** **B22d 11/02,** B22d 27/08

[58] **Field of Search** 164/83, 260

[56] **References Cited**

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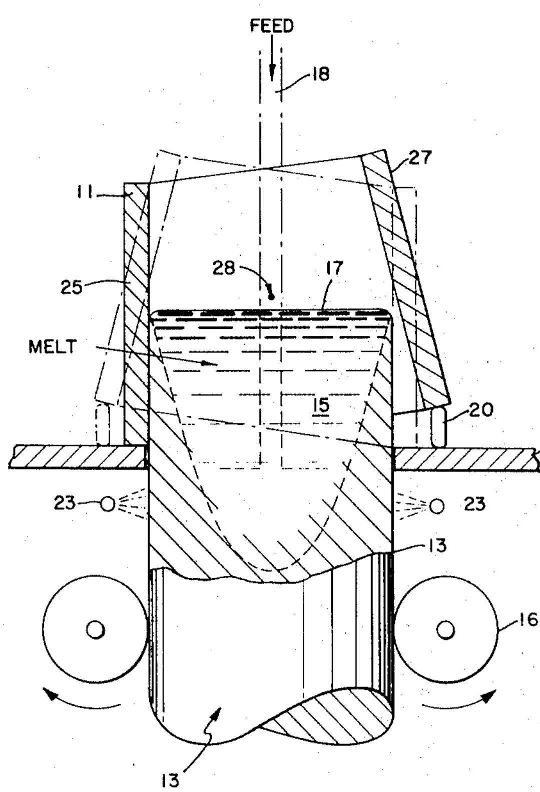
[57] **ABSTRACT**

A method and apparatus for continuous casting of an ingot from a molten metal employing a mold having a conical opening passing vertically through it and a mechanism for gyrating the mold about a point without rotating the mold about a vertical axis. The rate of gyration of the mold is related to the rate of continuous withdrawal of the ingot from the mold.

9 Claims, 3 Drawing Figures



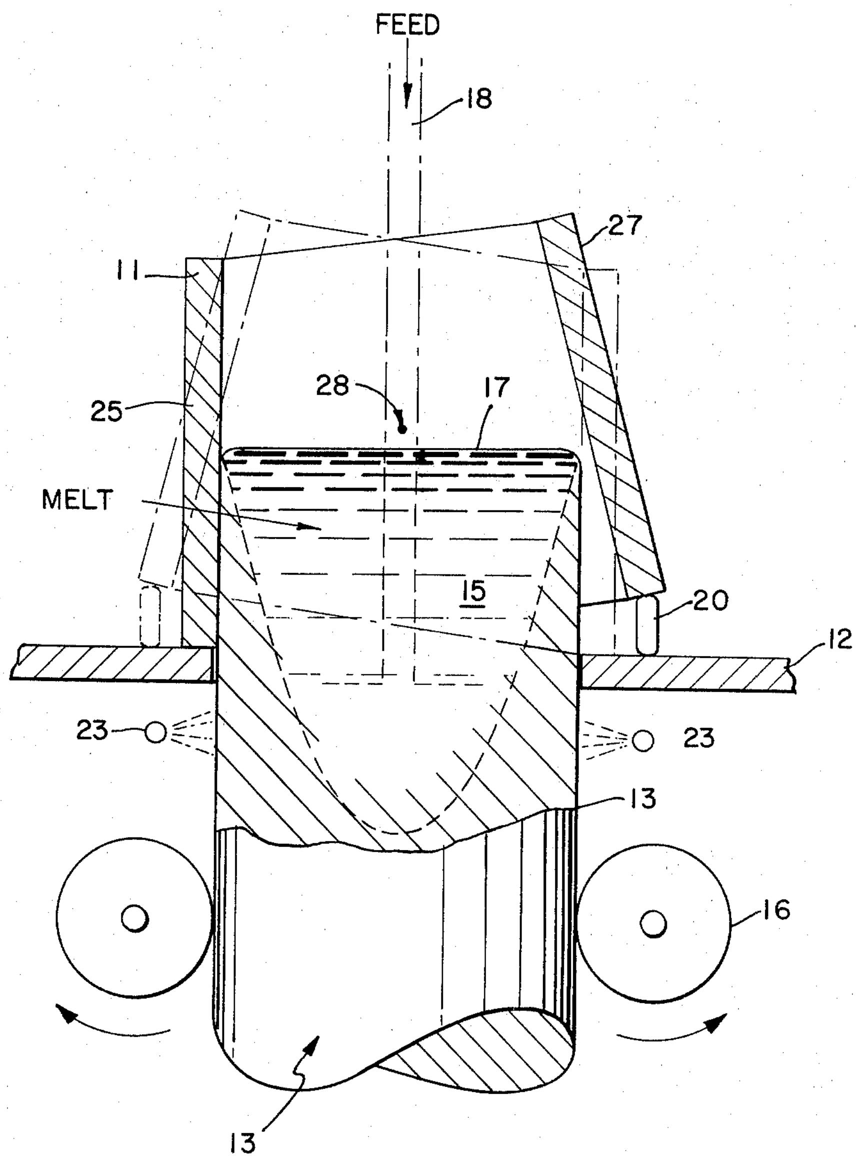


FIG. 1

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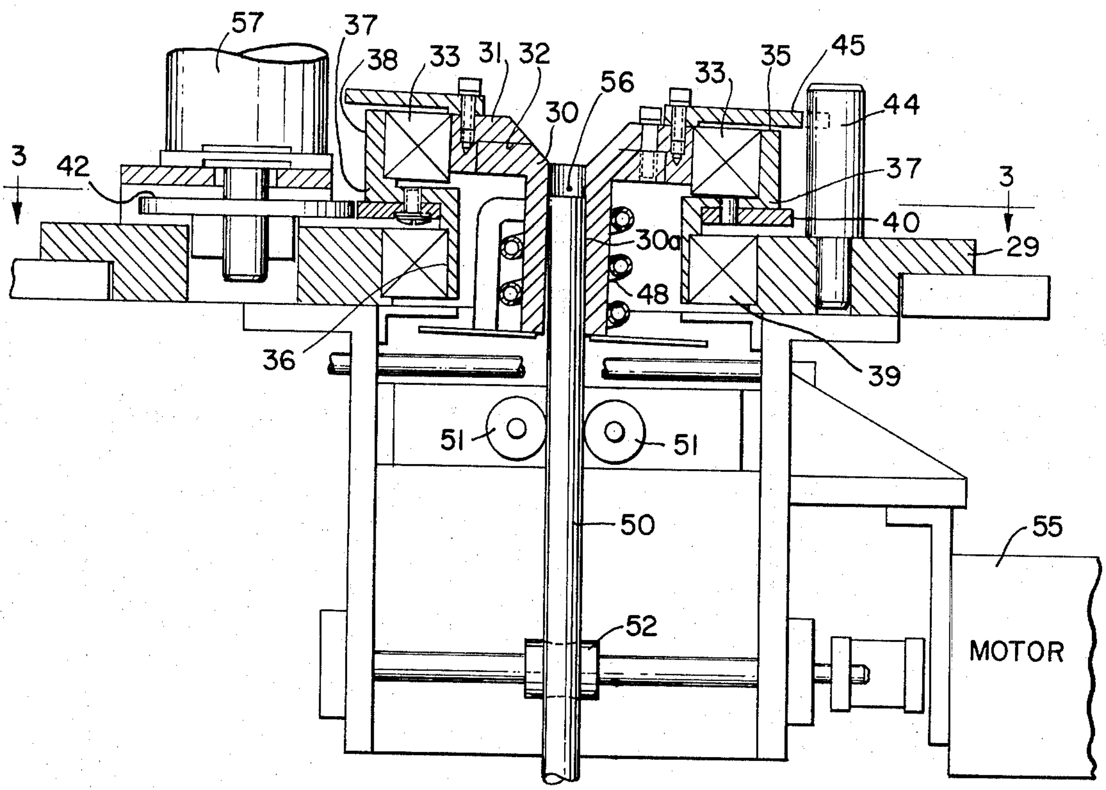

FIG. 2

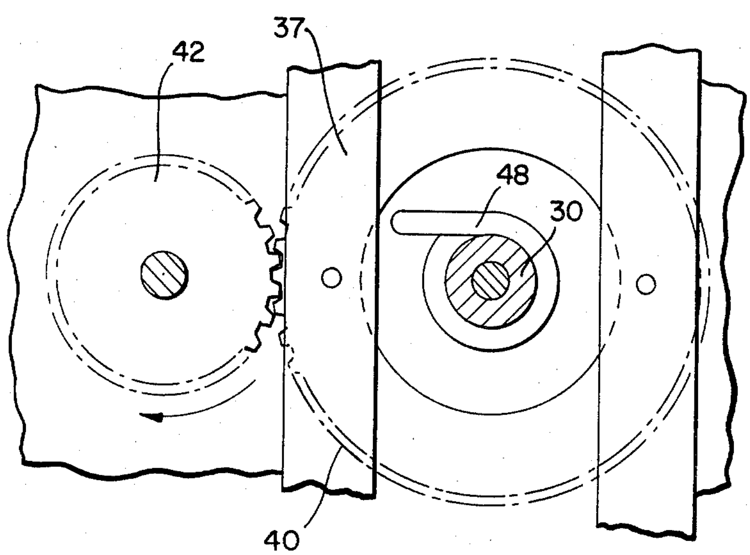

FIG. 3

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METHOD AND APPARATUS FOR CONTINUOUS CASTING WITH GYRATING MOLD

FIELD OF THE INVENTION

This invention relates in general to a method and apparatus for continuous casting of metals and more particularly to a method in which molten metal is delivered to a vertical mold, the cast ingot being withdrawn from the bottom of this mold.

BACKGROUND OF THE INVENTION

The present techniques used for continuous casting of metal ingots does not present an entirely satisfactory result. In a typical continuous casting process, the liquid melt is fed continuously from above into the pool and the cast ingot moves downward in synchronization with the feed rate. The ingot is formed in a generally cylindrical open-ended mold. One problem in the usual process arises from rupturing of the ingot, which allows molten metal to flow through the fissures into gaps which may exist between the ingot and the mold. This escaped metal solidifies and thereby causes defects on the surface of the ingot and increases friction as the ingot is being withdrawn. One method of obviating this difficulty has been to introduce vertical reciprocal motion of the mold as the ingot is being withdrawn. The velocity of reciprocation of the mold is related to the velocity of withdrawal of the ingot. On the downward stroke the mold is moving in the same direction as the ingot and thus there is little or no relative velocity between them and the skin rupture problem is eliminated. On the upward stroke, however, the relative movement between the ingot and the mold may increase to values of three times the ingot withdrawal rate and in this portion of the cycle ruptures may still occur.

SUMMARY OF THE INVENTION

In the continuous casting process of this invention a mold having a conical opening through it is employed. The conical mold is disposed generally in a position so that the opening is vertical. The molten metal is fed from above into the mold with the ingot being formed within the mold and withdrawn at a steady rate from the bottom of the mold. A mechanism is provided to gyrate the cone about a gyration point located on the axis of the cone. The mold does not rotate about the cone axis. As the mold gyrates about the gyration point, that side which is aligned with the vertical axis of the ingot moves downward simultaneously with the withdrawal of the ingot. The pitch of the mold opening and the rate of gyration of the mold are selected so that the velocity of this downward vertical movement of the mold is matched to the withdrawal velocity of the ingot and hence there is no relative movement between the two.

On the opposite side of the mold where the mold wall is tilted by the gyration, there is upward movement of the mold. However, because of the conical shape this portion of the mold wall is moving not only upward but also outward from the ingot wall, thereby substantially eliminating friction between the two. Critical factors in this casting arrangement are the rate of gyration and the gyration point of the cone with respect to the position of the melt level in the ingot. If the rate of gyration is too fast, a downward compressing force may be exerted on the ingot skin. On the other hand, if the rate of gyration is too slow in relation to the ingot withdrawal speed, the meniscus of the liquid may become too high to be supported by the surface tension of the melt and thus spill over. The melt level should be held below the gyration point of the cone in order to ensure that the ingot diameter remains constant. However, if the melt level is too far below the gyration point then the rotational sliding of the surface of the mold on the ingot may become excessive.

DESCRIPTION OF THE DRAWINGS

In the drawing,

FIG. 1 is an illustration generally in diagrammatic form of a casting apparatus suitable for use in the practice of this invention;

FIG. 2 is an illustration in vertical cross-sectional view of a continuous casting apparatus suitable for use in the practice of this invention; and

FIG. 3 is a horizontal cross-sectional view taken along the line 3—3 of FIG. 2.

DESCRIPTION OF PREFERRED EMBODIMENTS

With reference now to FIG. 1, there is illustrated a continuous casting apparatus in accordance with this invention. A cone shaped mold **11**, typically formed of copper, is open at either end and, in the casting process, a cast ingot **13** is withdrawn from the lower end of the mold at a constant rate. The ingot is formed by the solidification of a melt portion **15** within it, which melt is being continuously supplied molten metal through a feed **18**. The cooling process in the ingot **13** is aided by water jets **23** positioned below the mold. The top of the melt **15** is defined by a meniscus **17** within the mold. The mold **11** is arranged to gyrate about a gyration point **28** located on the cone axis without rotation about the axis of the cone by means of a gyrating mechanism shown illustratively as wheel **20**. As the wheel **20** traverses a circular path on the frame surface **12** beneath the peripheral lower edge of the mold **11**, it produces the gyration to the mold. Thus one portion of the mold wall, shown generally as **25** is, at one time, aligned vertically with the ingot, while the opposite wall **27** of the mold is tilted away from the ingot.

If the rate of gyration with respect to the rate of withdrawal of the ingot produced by rollers **16** is properly arranged, then the downward motion of the vertical side **25** will match in velocity the downward movement of the ingot **13**, so that there is no relative motion between them. On the opposite side **27** of the mold, the upward movement of the mold does not introduce friction between it and the ingot **13** wall because the wall **27**, being tilted, does not come in sliding contact with the ingot at this point. The mold illustrated in phantom shows the opposite position during gyration with the wheel **20** located 180° away from its initial position. As the wheel circles under the mold each portion of the mold is raised and lowered in similar fashion to the portions indicated as **25** and **27** in FIG. 1. The relationship between the cone angle, the rate of withdrawal and the rate of gyration can be expressed as follows:

$$R = 2\,G\,D \tan\theta$$

where,

R = rate of ingot withdrawal in inches/minute
G = rate of mold gyration in rpm
D = diameter of mold opening in inches
θ = cone angle.

In a typical example for a small ingot production, a mold inner diameter of ½ inch with a cone angle of 2° would be operated with a gyration rate of 200 rpm and therefore a rate of ingot withdrawal of 7 inches per minute. In general the cone angles of the mold would be expected to be in the range of from about 1° to 4°.

In FIGS. 2 and 3 there is illustrated in cross-sectional views a continuous casting apparatus suitable for use in this invention. The apparatus includes a mold element **30**, which normally would be formed of copper and which has a generally cylindrical form, but wherein the bore **30a** of the mold has a taper between 1° and 4° to form a generally conical shaped opening through it. The lip **32** at the top of the mold **30** is attached to a retaining flange **31**, the latter being supported on a bearing **33**. The bearing **33** is itself supported on a flanged collar **35** which includes an upstanding portion **38** retaining the bearing **33**, a horizontal ring cam surface **37** and a lower collar **36** which bears against a lower bearing **39** for rotation with respect to the fixed base **29**. The cam surface **37** is tapered so that upon rotation with respect to the base **29** the bearing **33** and hence the supported mold **30** wobble about a point **56** on the cone axis introducing the gyration required. A vertical post **44** attached to the base **29** secures a horizontally extending arm **45** from the flange **31** of the mold to prevent the mold from rotating about an axis.

A motor **57** drives a circular gear **42** which meshes with a ring gear **40** attached to the flanged collar **35** to produce rotation of this flange and its cam surface and hence produce gyration of the mold. A water cooling coil **48** surrounds the bore **30*a*** of the mold **30** to aid in the solidifying process. The ingot **50**, cast in the mold, is withdrawn downwardly from the mold **30** through a pair of idler rollers **51** and this withdrawing motion is imparted to the ingot **50** by means of a driving roller **52**. The roller **52** is driven by a motor **55** and, as earlier indicated, the relative speeds of the withdrawing roller and the rotating cam are arranged to control the rate of gyration with respect to both the taper of the mold and the rate of withdrawal.

What is claimed is:

1. A method of continuous casting of a metal ingot from a supply of molten metal comprising the steps of,

gyrating about a point a mold having a vertical cone shaped opening through it, said gyration continuously aligning a portion of the mold side with the vertical axis of the ingot,

continuously supplying molten metal into the top of the opening through said mold while withdrawing the solidified ingot from the bottom opening of said mold at a predetermined rate, and

maintaining the downward vertical movement velocity of said portion of the mold side matched to said predetermined withdrawal rate while tilting a portion of the opposite mold side out of sliding contact with said ingot.

2. A method in accordance with claim **1** wherein the conical opening through said mold has a cone angle θ and wherein the rate of ingot withdrawal is expressed as,

$R = 2\,G\,D \tan\theta$

where,

R = rate of ingot withdrawal in inches/minute

G = rate of mold gyration in rpm

D = diameter of mold opening in inches

θ = cone angle.

3. A method in accordance with claim **1** wherein said molten metal forms within said ingot a melt having a meniscus level defining its upper surface and wherein the point of gyration of said mold is above said meniscus.

4. Apparatus for continuous casting of metal ingot from molten metal comprising,

a mold element having a conical opening extending through it,

means for gyrating said mold element about a point on the axis of said conical opening, such that a portion of the mold side will be continuously aligned with the vertical axis of the ingot

means for continuous supplying said molten metal to one end of the opening through said mold element, and

means for withdrawing continuously at a predetermined rate the solidified ingot from the other end of the opening through said mold element such that said ingot withdrawal velocity is matched to the downward vertical movement velocity of said portion of the mold side.

5. Apparatus in accordance with claim **4** wherein said mold element is formed of copper and is water cooled.

6. Apparatus in accordance with claim **4** wherein said mold element is constrained from rotating about the axis of said conical opening when said element is gyrating.

7. Apparatus in accordance with claim **4** wherein said mold element is positioned so that said conical opening is generally vertical.

8. Apparatus in accordance with claim **4** and further including means controlling the rate of gyration of said mold element to a first velocity and controlling the rate of withdrawal of said ingot, said means for controlling being arranged so that the relationship between the rate of withdrawal of said ingot and the rate of gyration of said mold is

$R = 2\,G\,D \tan\theta$

where,

R = rate of ingot withdrawal in inches/minute

G = rate of mold gyration in rpm

D = diameter of mold opening in inches

θ = cone angle.

9. Apparatus in accordance with claim **4** and further including a base member, said means for gyrating said mold element comprising a rotatable cam element of varying thickness supporting said mold element upon said base element and, means for rotating said cam thereby producing the gyration of said mold.

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