April 30, 1957 J. L. HUNTER 2,790,216

METHOD AND APPARATUS FOR THE CONTINUOUS CASTING OF METAL

Filed June 20, 1955 3 Sheets-Sheet 1

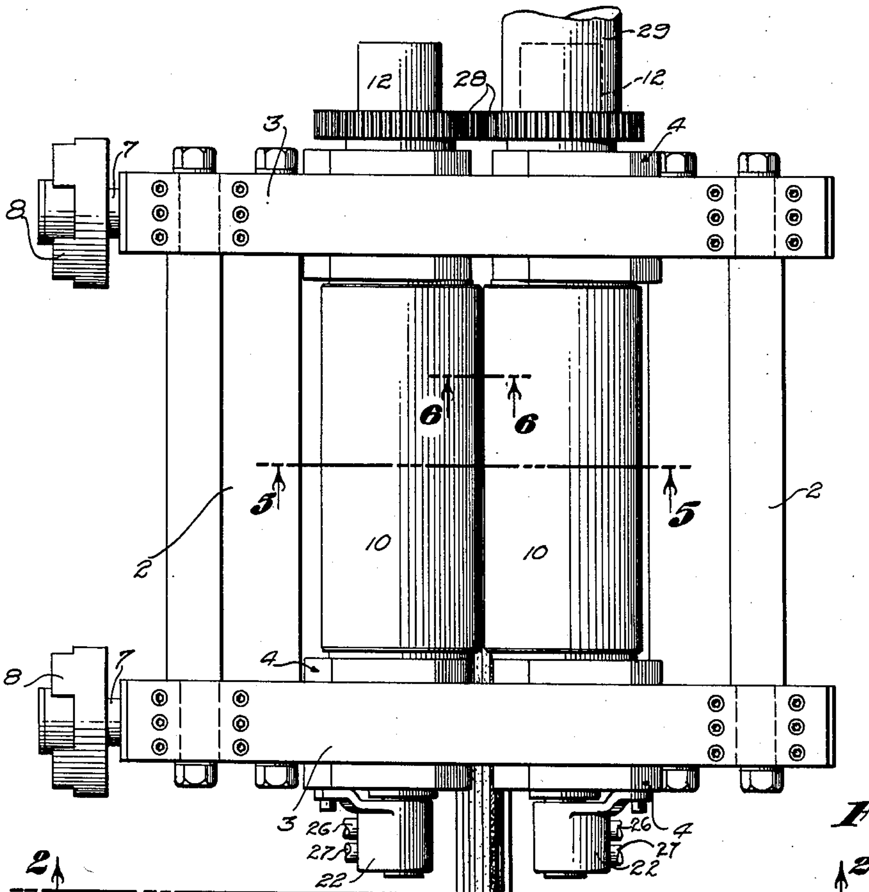

FIG. 1

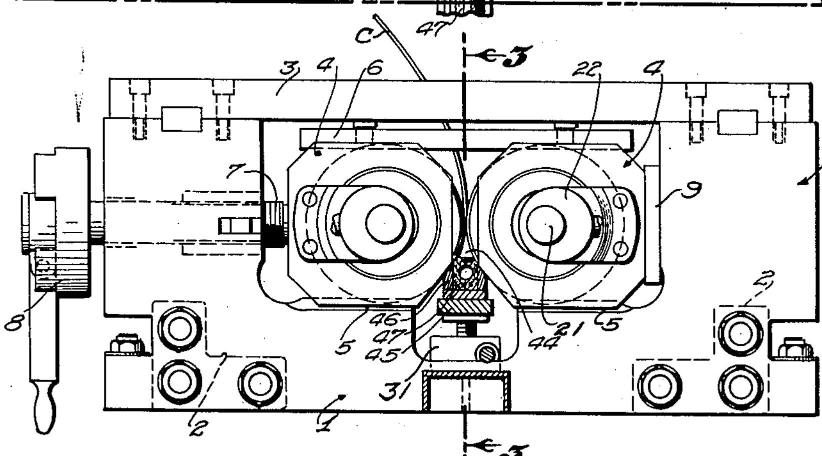

FIG. 2

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METHOD AND APPARATUS FOR THE CONTINUOUS CASTING OF METAL

Filed June 20, 1955 3 Sheets-Sheet 2

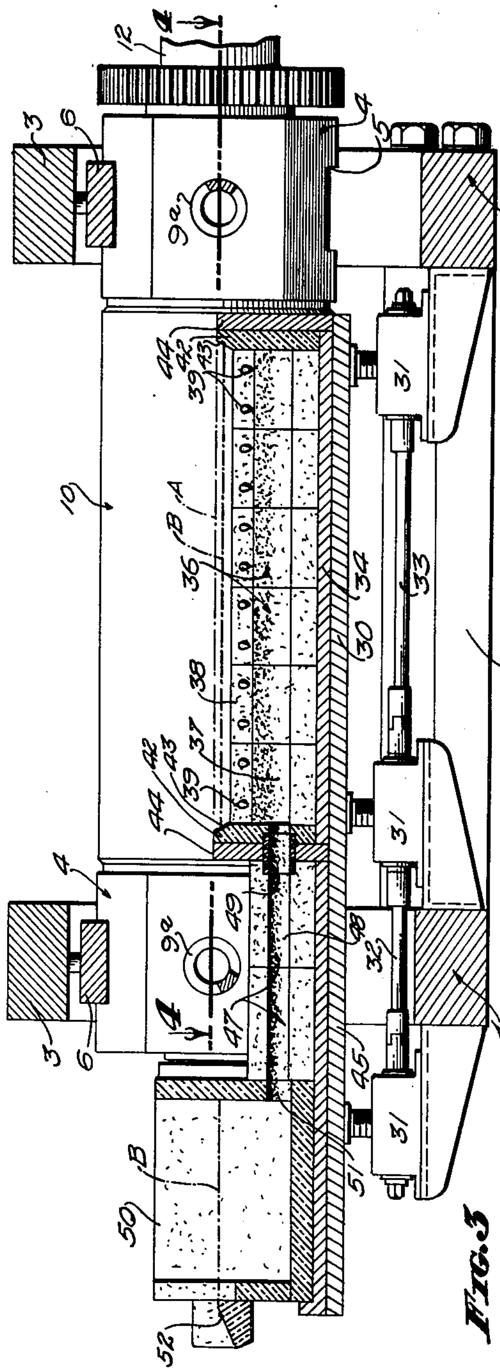

FIG. 3

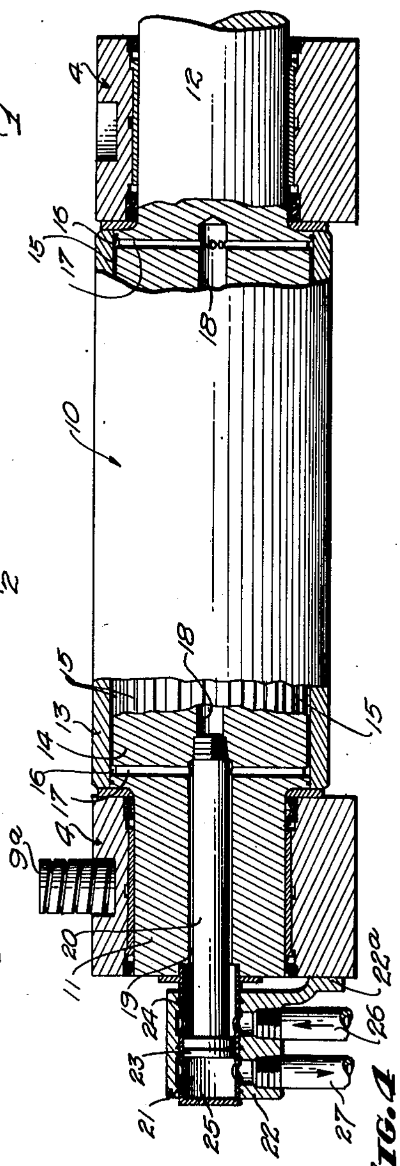

FIG. 4

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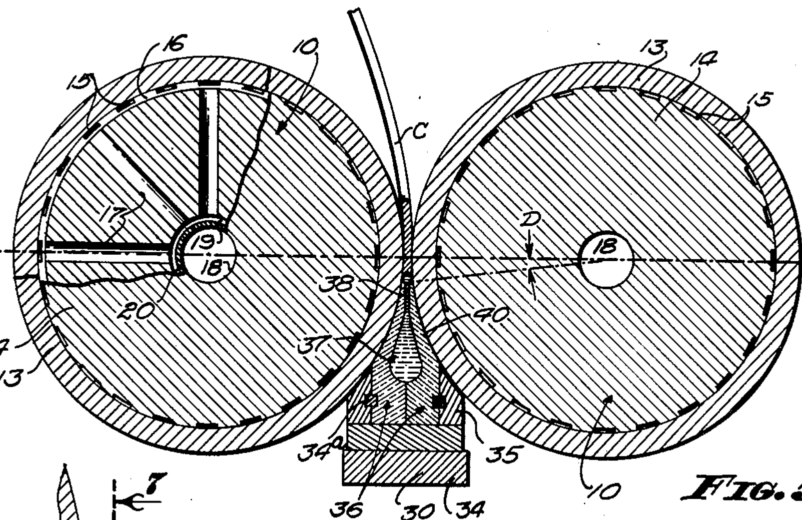

FIG. 5

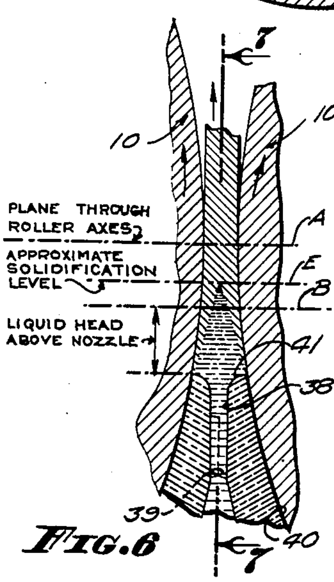

FIG. 6

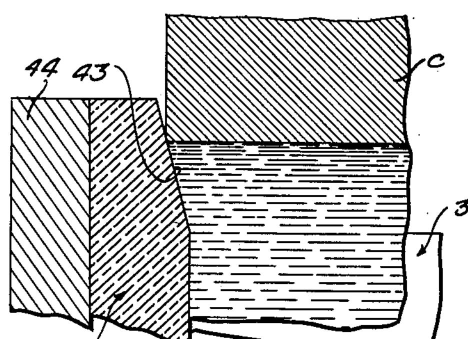

FIG. 7

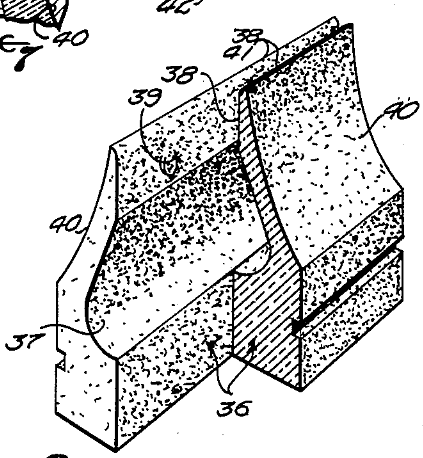

FIG. 8

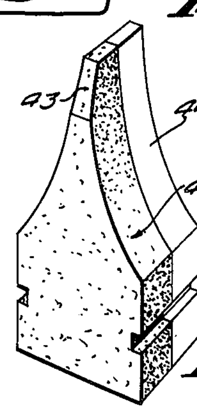

FIG. 9

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METHOD AND APPARATUS FOR THE CONTINUOUS CASTING OF METAL

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Application June 20, 1955, Serial No. 516,621

15 Claims. (Cl. 22—57.5)

This invention relates to method and apparatus for the continuous casting of metal. Included in the objects of this invention are:

First, to provide a means and apparatus whereby a sheet, strip, bar, or rod of metal may be continuously cast with such uniformity in quality and freedom from inclusions or other imperfections that the resulting cast metal may be rolled or otherwise treated, shaped, or formed to develop a final product exhibiting the maximum properties of the metal.

Second to provide a means and apparatus wherein the molten metal is caused to flow from an insulated and enclosed supply conduit without turbulence into and between chilling and forming rollers, and issue as a solidified casting, whereby the formation of inclusions is avoided and a uniform grain structure is produced in the solidified metal issuing between the rollers.

Third, to provide a means and method for continuously casting metal which is, as compared to previous attempts to cast metal continuously, particularly easy to initiate into continuous operation; that is, should the various factors required for optimum operation, such as metal temperature and rate of supply, or casting roller temperature and speed be incorrectly adjusted within predetermined limits, correcting adjustment may be made without discontinuing operation.

Fourth, to provide a means and method for continuously casting metal which, in the event of the formation of "hot spots" (a typical phenomenon occurring during the starting period wherein a hole or near-hole is formed in the casting as it issues from the rollers), the condition tends to be self-curing without stopping the operation; whereas, in prior attempts to effect continuous casting such hot spots formed channels through which molten metal poured out of the casting apparatus, not only requiring shutdown but often creating a hazardous condition.

Fifth, to provide a means and method for contiuously casting metal wherein the liquid metal flows upwardly or upwells at low velocity without turbulence from the outlet of a ceramic nozzle disposed between upwardly moving confronting surfaces of a pair of chilled rollers below the plane defined by the axes of the rollers; the confronting roller surfaces and upper end of the ceramic nozzle forming a casting chamber which converges at its upper portion at approximately the rate at which the metal shrinks due to dissipation of its heat to the rollers, so that maximum heat transfer relation is maintained between the metal and rollers until the metal has completely solidified.

Sixth, to provide a means and method for continuously casting metal utilizing a casting chamber defined between a pair of rollers, whereby the solidified metal may be subjected to rolling pressure and thus worked to improve its properties as it passes between the rollers.

Seventh, to provide means and apparatus for the continuous casting of metal wherein the molten metal is caused to flow without turbulence by means of a slight head of molten metal from an insulated and enclosed supply conduit between chilling rollers and issue as a sound metal casting having substantially uniform width and thickness and substantially smooth surfaces.

With the above and other objects in view, as may appear hereinafter, reference is directed to the accompanying drawings in which:

Figure 1 is a top or plan view of the continuous casting machine with the molten metal supply conduit shown fragmentarily;

Fig. 2 is a partial elevational, partial sectional view, taken along the line **2—2** of Fig. 1;

Fig. 3 is an enlarged, longitudinal, sectional view, taken through **3—3** of Fig. 2;

Fig. 4 is an enlarged, fragmentary, sectional view of one of the rollers and its bearings, taken through **4—4** of Fig. 3 with portions shown in elevation;

Fig. 5 is a further enlarged, transverse, sectional view through **5—5** of Fig. 1, showing the rollers and nozzle blocks and illustrating the manner in which the metal is continuously cast;

Fig. 6 is a still further enlarged, fragmentary, sectional view through **6—6** of Fig. 1, showing adjacent portions of the rollers and the nozzle tip, and illustrating particularly the manner in which the metal flows from the nozzle tip and solidifies as it passes between the rollers;

Fig. 7 is a fragmentary sectional view through **7—7** of Fig. 6, showing the manner in which an end block forms the edge of the cast metal;

Fig. 8 is a fragmentary, perspective view of a pair of complementary nozzle blocks; and

Fig. 9 is a fragmentary, perspective view of one of the end blocks.

The continuous casting machine includes a pair of U-shaped end frames **1** which are secured in parallel relation by cross bars **2**. The legs of each end frame are connected by a tie bar **3** so as to define a large opening in which is mounted a pair of bearing blocks **4**.

The bearing blocks **4** are capable of movement to and from each other, and for this purpose ride on guideways **5** provided on the upper surface of the cross portion of the U-shaped frame **1**. The bearing blocks are additionally guided by a guide bar **6** supported from the tie bar **3**.

One leg of each end frame **1** is equipped to receive an adjustment screw **7**, the inner end of which bears against a corresponding bearing block and the outer end of which is provided with a suitable handle **8** so that the adjustment screw may be rotated. The other bearing block of each pair rests against a pad **9** of predetermined thickness, interposed between the bearing block and the corresponding leg of the end frame. Springs *9a* are interposed between the bearing blocks in each frame to separate them when the screw **7** is backed off.

The bearing blocks **4** disposed in the two end frames are arranged in coaxial pairs, between each pair of which is mounted a roller **10**. Each roller includes end shafts **11** and **12** journaled in the bearing blocks **4**.

As shown best in Figs. 4 and 5, each roller **10** includes a shell **13** of heat-conducting material fitted over a core **14**. The surface of the core is provided with a plurality of longitudinal channels **15**, the ends of which communicate with annular grooves **16** which in turn are intersected by radiating passages **17**.

Each roller **10** is provided with a central bore **18**. The central bore **18** extends through the shaft **11** and is counterbored, as indicated by **19**. A conduit **20** extends through the counterbore **19** to form an inner passage communicating with the central bore **18** and defines, with the counterbore, an annular passage.

Extending from the shaft **11** is a tubular sleeve **21** closed at its extended end and jacketed by a housing **22**. The housing is provided with a flange **22a** for attachment to the bearing block so as to restrain the housing against rotation. The conduit **20** extends into the sleeve **21** and is provided with a flanged end **23** to divide the sleeve into an intake chamber **24** and a discharge chamber **25**. The chambers **24** and **25** are ported for communication with corresponding passageways in the housing **22** which connect with a supply pipe **26** and return pipe **27**.

Suitable coolant is supplied from a source, not shown, and flows through the counterbore **19**, then outwardly through one set of radiating passages **17**, then along the longitudinal channels **15**, and returns through the second set of radiating passages to the central bore **18**, conduit **20**, and return pipe **27**.

The shafts **12** project from their bearings and are provided with intermeshing gears **28** so that the shafts and their rollers rotate at the same speed. One of the shafts **12** is connected to a drive shaft **29**.

It should be observed that in the machine herein illustrated the rollers **10** are intended to occupy a substantially predetermined spaced relation within the limits determined by intermeshing of the gears **28**, and thus produce a cast product of substantially predetermined thickness. However, if it is desired to employ the machine for a range of cast products of different thicknesses, a pair of drive shafts may be connected to the shafts **12** through conventional universal couplings and a standard gear drive unit spaced from the machine, in such case the drive shafts rather than the shafts **12** are gear connected.

Extending longitudinally under the rollers **10** and centered with respect to the slot formed between the adjacent sides of the rollers is a support bar **30**, which is capable of vertical adjustment by means of suitable jack units **31** joined by connecting shafts **32** and **33**, so that the supporting bar **30** may be raised and lowered relative to the rollers.

The portion of the supporting bar **30** located under the rollers **10** receives a base plate **34** to which are attached side plates **35**, defining a channel extending longitudinally with respect to the rollers. Secured within the channel thus formed is a series of nozzle blocks **36**. The nozzle blocks are formed of ceramic material having insulation properties and of such character as to be capable of containing in a molten state the metal to be cast.

The nozzle blocks **36** are preferably arranged in complementary pairs divided along a plane perpendicular to the plane defined by the axes of the rollers **10**. The nozzle blocks may extend the length of the rollers. However, it is preferred to divide the nozzle blocks into relatively short sections, as indicated best in Fig. 3, to facilitate manufacture and replacement of the nozzle blocks. Each complementary pair of nozzle blocks forms a trough having a horizontal passageway **37**, the side walls of which converge upwardly to form a relatively narrow nozzle slit **38**, as shown best in Figs. 5, 6, and 8. Bosses **39** project laterally from opposite sides of the nozzle slit **38** to form lateral supports for the upper portions of the nozzle blocks so as to maintain a nozzle slit of constant width.

The side plates **35** and nozzle blocks **36** are provided with mating key grooves which receive key bars **34a**.

The outer surfaces of the nozzle blocks **36**, above the side plates **35**, form converging concave or arcuate sides **40** which conform substantially to the curvature of the rollers **10**. The nozzle blocks extend into the converging space between the rollers to a point near the plane designated A in Fig. 6 which passes through the roller axes. The discharge end of the nozzle slit **38** is thus relatively thin. It is preferred that the exit end or tip of the nozzle slit **38** be rounded or beveled outwardly toward the rollers, as indicated by **41** in Fig. 6.

The relationship of the nozzle blocks **36**, and particularly the nozzle tips, with respect to the rollers **10** constitute an important feature of this invention, which will be discussed in more detail hereinafter.

Adjacent the ends of the rollers **10**, end blocks or dams **42**, also formed of ceramic material, are provided. The end blocks have the same profile as a complementary pair of nozzle blocks **36**, that is, the sides of the end blocks are curved arcuately to conform to the confronting portions of the rollers. The end blocks extend above the nozzle blocks to the plane A common to the roller axes. The region between the dams **42** and confronting and converging portions of the rollers and above the nozzle blocks forms a casting chamber.

The end portions of the blocks **42**, which project above the nozzle blocks **36**, are beveled, as indicated by **43** and shown best in Figs. 3, 7, and 9, to facilitate the casting of the edges of the solid metal sheet or plate which is cast between the rollers. The function and operation of the beveled faces **43** will be brought out in more detail hereinafter.

The end blocks **42** are backed by metal end plates **44** which also have arcuate sides conforming to the confronting curved surfaces of the rollers. The metal end plates **44** limit upward movement of the entire nozzle assembly and thus prevent crushing of the blocks, particularly the nozzle tips. Also they serve to limit lateral bodily movement of the rollers toward each other.

The support bar **30** projects outwardly through one of the end frames **1** and supports a base plate **45** similar to the base plate **34**. Side plates **46**, indicated in Fig. 2, are secured to the base plate **45** to form a channel which receives a series of conduit blocks **47** formed of ceramic or ceramic-like material. The conduit blocks define a passage **48** which communicates with the passageway **37** through ports provided in the intervening end plate **44** and end block **42**. These ports are lined by a sleeve **49** of ceramic material.

Outwardly of the conduit blocks **47** is a supply box **50** formed of ceramic material into which the molten metal is poured. The supply box has a port **51** communicating with the passage **48**. The supply box is also provided with an overflow spout **52**, the height of which may be adjusted so as to facilitate the maintenance of a liquid level in a plane B, preferably located between the nozzle tip and the plane A passing through the axes of the rollers, as indicated in Fig. 6.

Operation of the continuous casting apparatus is as follows:

To initiate operation, the rollers **10** are adjusted to provide a predetermined spacing therebetween and the support bar **30** is raised so as to bring the nozzle blocks **36** into running engagement with the rollers **10**. The rollers are rotated and coolant is circulated through the coolant passages.

Molten metal is poured into the box **50** and caused to flow through the conduit blocks **47** and passageway **37**, upwell through the nozzle slit **38**, and fill the space above the nozzle tip between the rollers **10** and between the beveled faces **43** of the end blocks, which forms a casting chamber. As the metal emerges from the nozzle tip into the space between the rollers, it lies in the casting chamber, regardless of the speed of the rollers, until it begins to solidify.

As soon as solidification begins, due to the chilling action of the rollers, the rollers grip and carry away the solid metal. If the rollers are turning too slowly, the metal solidifies faster than it is carried away. Under this condition, the entire mass of metal above the nozzle tip becomes solidified, and in addition progressively solidifies downward into the nozzle tip with the result that the entire mass of metal, including the nozzle tip, is drawn between the rollers and crushed.

On the other hand, if the rollers are operating at higher than optimum speed the metal is still carried away as it solidifies. But since it is being carried away faster than the rollers are able to chill the hot molten metal, the metal emerges from between the rollers in the "hot-short" stage. Due to the fact that the metal is "hot-short," it crumbles and breaks up, as it does not have sufficient strength to feed out from the rollers. It therefore lays in the area formed by the surfaces of the rollers above the center line or plane A. Since these surfaces of the rollers diverge upwardly and are constantly moving upwardly and away from the material, no damage is done, and the material continues to accumulate until it is removed. This may be done manually or by use of suitable power tongs.

Because of these conditions, it is possible to start the machine with the rollers turning a little above the optimum speed. This procedure eliminates any danger of the machine jamming due to the freezing of the metal down into the nozzle tip. It should be noted that during the starting period this freezing tendency is aggravated because the initial metal entering through the nozzle blocks is chilled by transfer of some of its heat to the walls of the nozzle blocks. By starting the machine faster than optimum, all of the metal that solidifies is carried away, thus avoiding the possibility of jamming the machine or damaging the nozzle tips. As the nozzle blocks approach the temperature of the metal, the speed of the rollers may be gradually reduced to the optimum speed.

The proper speed is relatively easy to determine. If the speed is too slow, cold laps may be apparent in the surface of the material and the power required to drive the machine will sharply increase. This condition can be readily detected by an ammeter connected to the driving motor and the roller speed changed accordingly, before damage occurs.

If the speed of the machine is above optimum, voids or "hot-spots" will appear in the strip, that is, areas where the metal is not picked up by the rollers. This may occur at either or both edges or any spot across the width of the strip. The metal below these void areas continues to remain molten and is not elevated in the hot-short stage such as occurs during the starting period.

This phenomenon is due to two conditions: first, the fact that heat transfer is much more rapid where the rollers are in contact with the metal which has solidified, and, second, that the molten metal below the void tends to well up and flow laterally toward that area where solidification is still taking place. If the machine is slowed down slightly, the void areas will gradually close until uniform solidification prevails across the entire width of the rolls.

The solid metal, designated C, after passing upwardly between the rollers, may be coiled or fed into other rollers or otherwise subjected to further treatment.

Particular attention is directed to the fact that the diameter of the rollers **10** is quite large as compared to the distance between the nozzle tip and the plane A common to the roller axes. Thus the angle defined between the plane A and the nozzle tip represents only a few degrees of the roller circumference. In the construction illustrated, this angle, designated D, is approximately 9°. The angle may vary between 5° and 20°, depending upon the size of the rollers and the metal being cast.

It is preferred that complete solidification of the metal occur at a level designated E in Fig. 6, which is slightly below the plane A. The optimum level of complete solidification is such that the difference in distance between the rollers at the level E and at the level A is approximately equal to the shrinkage of the metal as it decreases in temperature between these two levels. However, it has been found advantageous to "work" the metal as it solidifies. This is accomplished by causing a complete solidification of the metal at a level wherein the distance between the rollers, as compared to the distance at the plane A, is slightly greater than the thermal shrinkage factor of the metal so that the metal on solidification is subjected to transverse compression. For a given roller diameter, the greater the distance the level E is from the plane A the greater will be the compression force on the metal, resulting in a greater or more severe working of the solidified metal as it passes between the rollers.

With reference to Fig. 7, it will be observed that the liquid metal flows laterally a superficial amount corresponding to the beveled faces **43** of the end blocks. Such superficial lateral flow terminates substantially at the level E.

It will be observed from Figs. 3 and 6 that the molten liquid enters the region above the nozzle tips at virtually zero atmospheric pressure, as the head of the liquid determined by the level of the liquid in the supply box **50** is only a fraction of an inch above the nozzle tips. This is quite important. By reason of the fact that the pressure is substantially zero, the flow of the molten liquid upwardly through the nozzle is substantially free of turbulence. This results in a uniform rate of extraction of heat from the metal so that the build-up of solidified metal on the roller surfaces is particularly uniform. The result is that the crystal structure in the cast product is uniform so that the cast product may be worked in a manner to develop its strength to the fullest extent and a final product of uniform high quality obtained.

The nozzle blocks **36** should conform to the rollers **10** close enough to prevent back flow of metal between the nozzle tips and the rollers, particularly during the starting period. This does not mean that a forced bearing contact is required. A clearance of from .005 to .015 and more, depending upon the metal being cast, may be tolerated between the nozzle tips and the rollers. Progressively greater clearance may be permitted below the nozzle tips.

The slight clearance thus afforded reduces materially heat transfer from the nozzle blocks to the rollers. Such heat transfer is, of course, also minimized by the use of ceramic or ceramic-like material having good heat-insulating properties. The use of an insulating material for the nozzle blocks is desirable so that the temperature of the metal will not be appreciably reduced in its travel from the supply box to the casting region between the rollers. In addition, a ceramic is selected which is inert relative to the metal being cast and which is not wetted by the molten metal.

In order to minimize the starting period and remove absorbed moisture, the nozzle blocks may be peheated. In practice, this is done before insertion of the nozzle blocks into the machine by causing the molten metal to flow through the nozzle blocks until bubbling, caused by vaporizing of absorbed moisture, ceases. After this, the nozzle blocks are cleaned of solidified metal and inserted in the machine.

It is essential that the rollers be completely free of foreign matter which would cause unequal heat transfer from the rollers to the metal. For example, a mere thumb print on the surface of the roller will change the rate of heat transfer in the area of the thumb print sufficient to cause a "hot spot" in the product. That is, in this region a hole or depression will occur in the cast product. After several revolutions, however, the effect of the thumb print is completely dissipated.

It should be observed that due to the fact the casting takes place in a generally upward direction and the molten liquid is under virtually zero pressure, there is no discharge or spewing of the molten liquid in the region of a hot spot. This is of primary importance, for it is probably impossible, during the starting period of a run, to establish the necessary uniform conditions which would completely eliminate hot spots or other imperfections, due to lack of uniformity in conditions throughout the width of the metal being cast. Furthermore, the condition causing the hot spot tends to cure itself rather than create an unstable condition.

It should be pointed out that in previous attempts to effect continuous casting by lateral or downward flow of the metal between rollers, failure of the metal to solidify at or before the point of discharge from between the rollers resulted in a dangerous pouring out of the molten metal from the machine.

With regard to the present invention, the provision of a slight head of molten metal to produce metal flow ensures the presence at all times of a continuous column of molten metal behind the solidifying zone so that sound metal is formed and withdrawn continuously. At the same time, if the rate of solidification is decreased for some reason, there is no force present to cause the escape of molten metal from the apparatus.

In many previous attempts to effect continuous upward casting of metal between rollers, substantial portions of the rollers have been immersed in the liquid metal with the result that the temperature differential between the rollers and the metal apparently approaches an undesirably low value at the critical point of emergence of the metal, a condition unfavorable for dependable, continuous casting. Also, immersion in molten metal of a substantial portion of an internally cooled roller introduces tremendous thermal stresses.

In the exercise of the present invention, only a small arcuate section of the roller surface is in heat-absorbing contact with the heated metal so that, during the comparatively long travel of the roller surface after clearing the metal and return to its casting location, the internally circulating coolant has ample time to completely remove all or the full desired amount of heat absorbed by the roller surface. Thus a maximum temperature differential may be maintained between the roller surface and the metal.

Furthermore, the heat-absorbing capacity of the metal comprising the roller shell **13** can be relied upon to extract the required heat from the molten metal, without depending upon the liquid coolant immediately behind the portion of the shell **13** contacting the molten metal to absorb heat. That is, it may be considered that the metal shell itself absorbs the heat from molten metal being cast and then later transfers the heat to the coolant. As a result the shell **13** can be quite thick as it is fully supported by the core, so that the rollers can exert ample working pressure against the metal.

As pointed out hereinbefore, subjection of the solidified metal to substantial compression between the rollers improves the quality of the issuing product and also ensures continuous and uniform feeding of the cast metal from between the rollers.

The metal or other material employed for the shell **13** depends on the metal being cast. It should not be wetted by the molten metal or react therewith, and should be capable of withstanding thermal shock; also it should have good heat-conducting properties. Copper, copper alloys, aluminum, aluminum alloys, steel, iron or steel alloys, and graphite are suitable, but do not exhaust the range of metals which may be used.

It is desirable that the rollers be as clean and as uniform in surface condition as possible, to avoid "hot spots." Some benefit is obtained by the use of a mold release silicone applied in a thin film when starting. In the casting of aluminum, this film must finally be cleaned off until substituted by an aluminum oxide coating produced in the casting process. Then a thin film of the mold release is again applied and left on. Other non-carbonizing oils may be used.

The range of metals which may be cast by the apparatus herein disclosed is primarily dependent upon the material employed in the ceramic nozzles, as it is essential that the nozzles be capable of withstanding the temperature of the metal in its liquid state and be inert to the metal and not wetted thereby.

For the continuous casting of aluminum, a satisfactory nozzle of ceramic-like material has been formed of diatomaceous silica, asbestos fiber, and a binder. Such a material is manufactured by Johns-Manville under the trade name of "Marinite," under Patent No. 2,326,516, issued August 10, 1943. Many other ceramic or ceramic-like materials are, however, suitable for use as nozzles.

In tests with 2S aluminum, satisfactory runs have been obtained with conditions substantially as follows:

Nominal ¼" x 24" cast strip

Metal temperature supplied to nozzle.	1300° F.
Roller temperature (6" beyond centerline A).	160° F.
Strip temperature (6" above centerline A).	740° F.
Strip speed (surface speed of rollers).	27½" per min.
Height of nozzle tip	1" below centerline A.
Height of head of liquid metal (B)	½" below centerline A.
Strip thickness	.270".
Pounds per min. of cast strip	17.8# per min.

Nominal ⅛" x 24" cast strip

Metal temperature supplied to nozzle.	1300° F.
Roller temperature (6" beyond centerline A).	170° F.
Strip temperature (6" above centerline A).	730° F.
Strip speed (surface speed or rollers).	56" per min.
Height of nozzle tip	⅞" below centerline A.
Height of head of liquid (B)	⅜" below centerline A.
Strip thickness	.158".
Pounds per min. of cast strip	21.2# per min.

PHYSICALS

	⅛"	¼"
Longitudinal:		
Tensile	27,900–27,300	26,600–26,800
Yield	25,900–25,600	24,600–25,400
Elongation, percent	3½–3½	3–3½
Transverse:		
Tensile	29,500–29,700	29,000–29,100
Yield	27,400–27,800	27,300–27,000
Elongation, percent	2½–2½	2–2

In the above tests the strip produced was 24" wide and the rollers were 12" in diameter. After relatively short starting periods the product produced was uniform and free from flaws. Although a particular aluminum alloy is cited as example, it should be emphasized that the example cited is not intended as a limitation, as optimum conditions for the continuous casting of other metals and alloys can readily be established for each installation of apparatus in accordance with this invention.

The method of continuously casting metal is substantially as follows:

Molten metal is caused to flow through an enclosed ceramic conduit, fully isolated from air contamination, and is then caused to flow upwardly or upwell through a nozzle into a casting chamber at velocities below those which would produce turbulence; that is, laminar flow of the molten metal is maintained.

The molten metal is brought into heat-transferring relation with upwardly moving converging walls forming confronting sides of the casting chamber.

The surface speed of the converging walls is maintained at approximately the rate of upward flow of the molten metal. It is a feature of this method of continuous casting that the head of the molten metal be within the vertical height of the casting chamber.

The heat-transferring contact between the metal and confronting walls is maintained until complete solidification of the metal therebetween is effected, whereupon the walls move in paths diverging from each other and free from the cast or solidified metal.

This method of continuously casting metal contemplates the further step of extracting heat from the moving walls, and moving the walls in paths which return to the casting chamber so that the walls on entering the region defining the casting chamber are chilled.

The step of extracting heat from the molten metal is conducted under conditions of substantial temperature differential between the moving walls and the molten metal, and the rate of convergence of the moving walls, particularly beyond the level at which complete solidification takes place, is at least equal to the rate of thermal contraction of the metal as to maintain maximum heat-transferring contact therebetween.

This method of continuous casting of metal contemplates the further step of working the cast metal as it is solidified by application of rolling or compression forces thereon.

While a particular method and apparatus of this invention has been described and shown, the invention is not to be deemed limited thereto but includes the methods and apparatus embraced in the appended claims.

I claim:

1. A continuous casting machine for metals, comprising: a pair of rollers having upwardly movable confronting portions converging to a minimum spaced relation and then diverging from each other; a nozzle formed of heat-insulating material capable of containing in a molten state the metal to be cast, said nozzle fitting between said rollers, directed upwardly between the converging portions of said rollers, and terminating in a nozzle outlet disposed in proximity to the point of minimum spacing between said rollers, said nozzle defining with the confronting portions of said rollers a casting chamber; dams at the axial ends of said rollers forming the ends of said casting chamber; means for supplying molten metal to said nozzle for discharge through said outlet; means for maintaining the pressure of the liquid flowing from said nozzle outlet at a value approximating the pressure represented by a height of the liquid metal corresponding to the height of said dams, whereby the liquid metal upwells turbulent free into said casting chamber; means for cooling said rollers to remove heat transferred thereto by the molten metal, whereby said metal solidifies in the region of minimum space between said rollers; and means for rotating the confronting portions of said rollers upwardly to present continuously cooled surfaces to the molten metal and discharge the solidified metal upwardly.

2. A continuous casting machine for metals as set forth in claim 1, wherein: said casting chamber occupies less than twenty degrees of the circumference of the rollers, and the convergence of said rollers above the solidification level of said metal approximates the rate of contraction of the metal as it cools.

3. A continuous casting machine for metals, comprising: a pair of rollers having upwardly movable confronting portions converging to a minimum spaced relation and then diverging from each other; a nozzle formed of heat-insulating material capable of containing in a molten condition the metal to be cast, said nozzle having an enclosed laterally directed supply passage, and an upwardly directed nozzle slit, said nozzle adapted to be positioned between the upwardly converging portions of said rollers with said nozzle slit extending axially with respect to said rollers and directly upwardly, the upper discharge end of said nozzle defining with the confronting portions of said rollers a casting chamber; dams at the axial ends of said rollers forming the ends of said casting chamber; means for supplying molten metal through said passageway so as to completely fill said nozzle and cause the molten metal to upwell without turbulence into said casting chamber; means for cooling said rollers to remove heat transferred thereto by the molten metal, whereby said metal solidifies in the region of minimum space between said rollers; and means for rotating the confronting portions of said rollers upwardly to present continuously cooled surfaces to the molten metal and discharge the solidified metal upwardly.

4. A continuous casting machine for metals, comprising: a nozzle structure comprising a series of complementary pairs of nozzle blocks defining a horizontal supply passage, the upper side of which converges to form a discharge slit extending lengthwise of said passageway, the exterior side walls of said nozzle blocks converging toward said slit; means defining a pair of upwardly movable converging walls of heat-conducting material conforming substantially to the converging sides of said nozzle blocks and extending above said discharge slit until spaced a predetermined minimum distance, then diverging from each other, the converging portions of said walls above said nozzle slit defining the sides of a casting chamber; dams at the ends of said nozzle structure conforming to said confronting walls to form the ends of said casting chamber; means for supplying molten metal through said supply passage so as to completely fill said nozzle structure and upwell turbulent free into said casting chamber; means for moving said confronting walls upwardly; said walls being in intimate heat-conductive relation with the metal upwelling from said nozzle structure and having sufficient heat-absorbing capacity as to cause solidification of said metal in the region of minimum space between said walls, whereby solidified metal is moved upwardly with said walls from said casting chamber.

5. Apparatus for the continuous casting of metal sheet, comprising: a pair of spaced substantially parallel cylindrical rolls of heat-conducting material; a pair of upwardly directed opposed heat-insulating members, inert to the metal, mounted in the space between the rolls, each having an external surface conforming to a longitudinal surface portion of the adjacent roll; said members defining a cavity converging upwardly toward a longitudinal opening of uniform width near the center line of the rolls; means for feeding molten metal steadily through said cavity and then to cause said molten metal to upwell uniformly throughout the length of said opening into heat transferring contact with said rolls; means for maintaining said molten metal at a pressure insufficient to force the molten metal above the center line of said rolls; mean for internally cooling said rolls; and means for rotating said rolls in the direction of metal flow, at a rate to permit solidification of said metal whereby said rolls discharge therebetween a solid ribbon of cast metal.

6. A continuous casting machine for metals, comprising: a pair of elongated cylindrical rollers formed of heat-conducting material occupying parallel axes and defining confronting portions converging upwardly to a plane defined by said axes, then diverging; an elongated nozzle structure formed of heat-insulating material adapted to fit between the upwardly converging portions of said rollers and terminating in an outlet slit substantially coextensive with the axial length of said rollers and in proximity to and below said plane, said nozzle having a flow passage extending therethrough in communication with said outlet slit; means for supplying molten metal to said passage and said outlet slit for discharge into the region between the upwardly converging portions of said rollers, whereby the molten metal is brought into intimate heat transfer relation therewith; and means for rotating said rollers to move said converging portions from said nozzle outlet slit toward said plane defined by the axes of the rollers, said rollers having a heat-absorbing capacity to effect solidification of the metal approximately at said plane.

7. A continuous casting machine for metals, comprising: means defining a casting chamber having upwardly

moving side walls converging to the top of said casting chamber to form a discharge opening and thereafter diverging, said casting chamber also having an apertured bottom wall formed of heat-insulating material; means for causing substantially turbulent free upwelling of molten metal through the aperture in said bottom wall into said chamber for heat-transferring contact with said side walls; the heat-absorbing capacity of said side walls being sufficient to completely solidify said metal in the upper region of said casting chamber, whereby cast metal is discharged therefrom by upward travel of said side walls.

8. A continuous casting machine comprising a pair of rollers formed of heat conducting material, means mounting said rollers with confronting portions positioned close to one another, means for rotating said rollers so that their confronting portions converge upwardly to the point of minimum spatial relation and then diverge, means forming a chamber for molten metal having an open top and a closed bottom and located wholly in the bight between said upwardly-converging roller surfaces and just below the point of minimum spacing between said surfaces, at least the upper portion of the side walls of said chamber for molten metal being formed by said upwardly-converging portions of said rollers, the portion of said roller surfaces defining the side walls of said chamber for molten metal being between about 5° and about 20° of the circumference of said rollers, means for feeding molten metal to said chamber, and means for cooling the walls of said rollers to remove heat transferred thereto by the molten metal, whereby upon said rotation of the rollers the molten metal solidifies in the region of minimum spacing between said confronting roller surfaces and is discharged upwardly from said region.

9. A continuous casting machine as set forth in claim 8 in which at least the main portions of the walls defining said chamber for molten metal, other than those defined by the confronting wall surfaces of said rollers, are formed of heat-insulating material.

10. A continuous casting machine as set forth in claim 8 in which the lower portion of said chamber for molten metal is formed by a trough of heat-insulating material, the side walls of which are positioned contiguous the upwardly-converging confronting wall surfaces of the rollers.

11. A method of continuously casting metals which comprises continuously causing confronting portions of roller surfaces to move upwardly in converging relation to a point of minimum spacing and then to diverge, maintaining a body of molten metal in the bight between said upwardly-moving, converging surfaces and in contact therewith, restricting the space for contact of the molten metal with said upwardly-converging surfaces to between about 5° to about 20° of the circumference of said roller surfaces extending downwardly from the point of minimum spacing of said surfaces, and cooling said surfaces to cause solidification of molten metal in contact therewith.

12. A method of continuously casting metal as set forth in claim 11 in which said surfaces are caused to converge at a rate corresponding approximately to the rate of thermal contraction of the metal solidified between said surfaces.

13. A method of continuously casting metal as set forth in claim 11 in which said surfaces are caused to converge at a rate greater than the rate of thermal contraction of the metal solidified against said surfaces, so that the solidified metal is subjected to compression as it passes through the point of minimum spacing of said surfaces.

14. A method of continuously casting metal as set forth in claim 11 in which the molten metal in contact with the upwardly-converging surfaces is maintained in a turbulent-free state.

15. A method of continuously casting metal as set forth in claim 11 in which the molten metal is maintained at a pressure insufficient to force it above the point of minimum spacing between said confronting surfaces.

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