Sept. 3, 1968 I. ROSSI ETAL 3,399,716

METHOD FOR COOLING HOT METAL, ESPECIALLY CONTINUOUSLY CAST METAL

Filed Jan. 17, 1966 2 Sheets-Sheet 1

Fig. 1

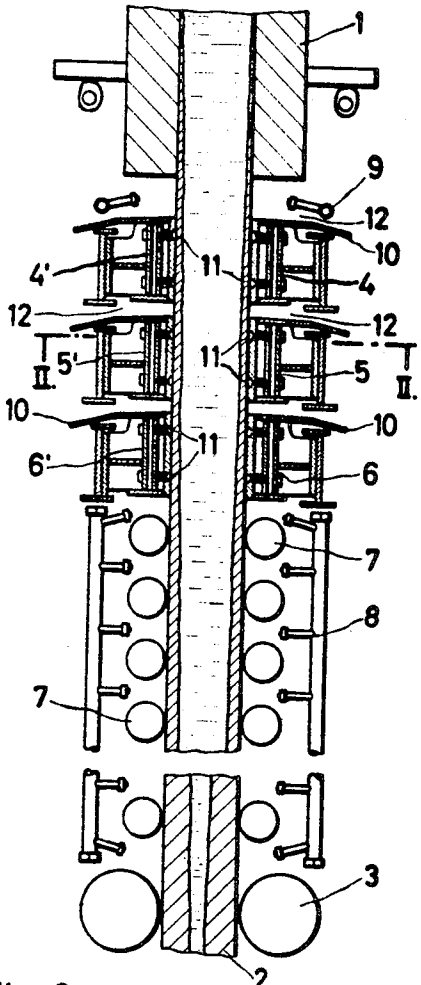


Fig. 3

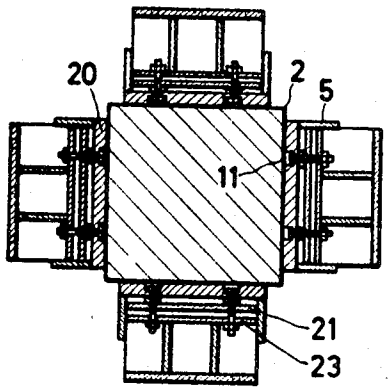


Fig. 4

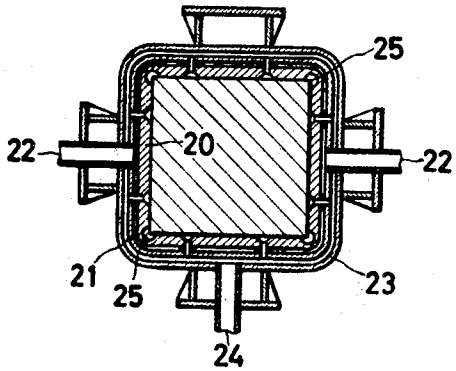


Fig. 2

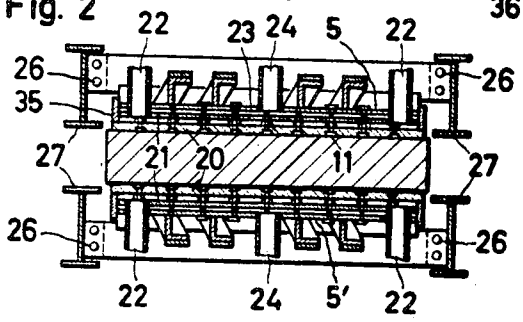
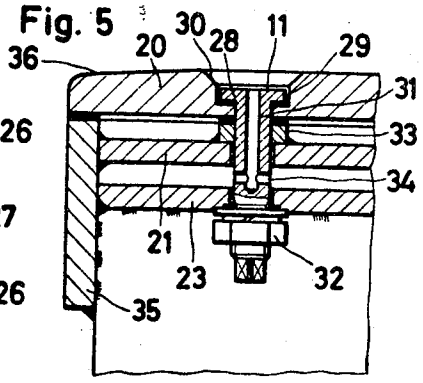


Fig. 5



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METHOD FOR COOLING HOT METAL, ESPECIALLY CONTINUOUSLY CAST METAL
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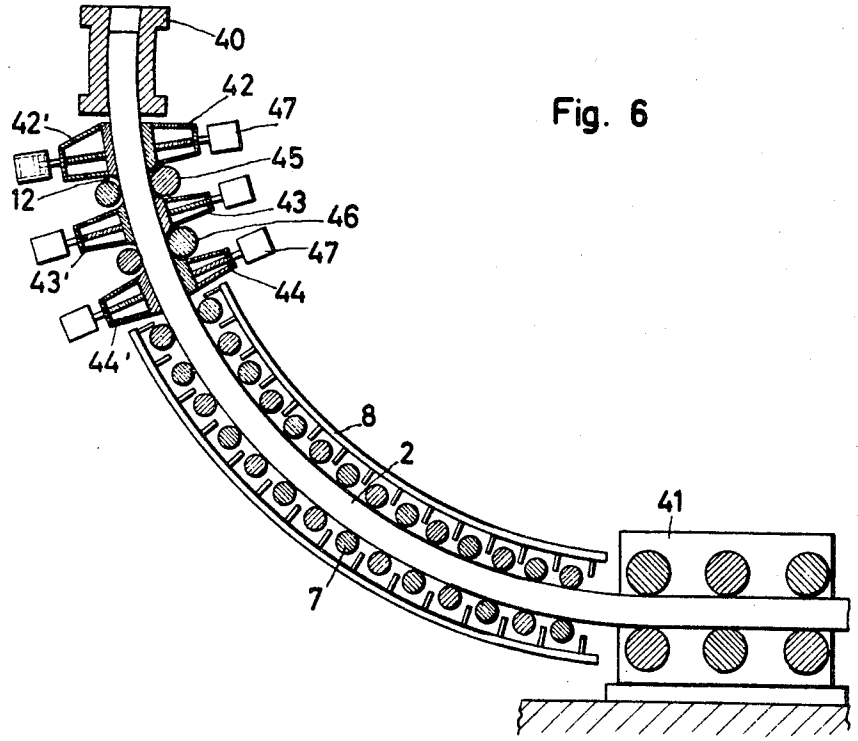


Fig. 6

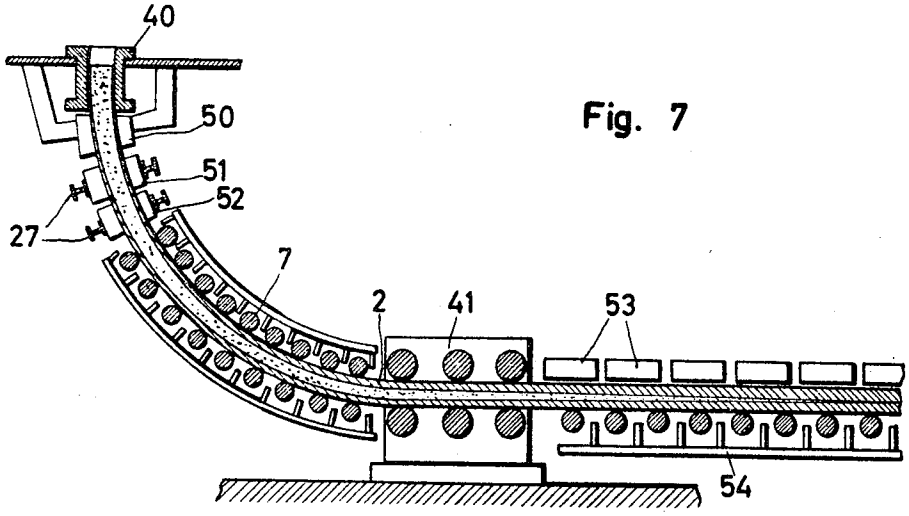


Fig. 7

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METHOD FOR COOLING HOT METAL, ESPECIALLY CONTINUOUSLY CAST METAL

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14 Claims. (Cl. 164—89)

ABSTRACT OF THE DISCLOSURE

Hot metal, such as a strand of metal emerging from a continuous casting mold, is cooled by positioning a cooled surface adjacent a surface of the metal with a gap between the surfaces. A liquid coolant under controlled pressure is circulated through the gap and turbulence is generated in the flow of coolant in the gap to penetrate a film of vaporized coolant that forms on the surface of the metal to extract heat from the film by intimate contact with it. The turbulence and resultant cooling effect is controlled by varying the pressure of the coolant in the gap.

This invention relates to a method of and to apparatus for cooling hot metal, particularly a continuously cast metal, comprising at least one cooling element for cooperation with the metal that is to be cooled.

The cooling of hot metal is a particularly important aspect of continuous casting because the performance of the casting plant depends upon the rate at which the heat can be extracted from the metal. The extraction of the heat is governed by a variety of factors. For example, the thickness of the solidified external skin of the strand issuing from the mold substantially affects the output of the plant and the casting rate. If this external skin is thin, it tends to fracture and to bulge under the effect of internal pressure. In order to avoid damage to the plant and to the casting itself from such causes, the rate of casting must be reduced sufficiently to permit a solidified external skin of appropriate thickness to form.

During the solidification of the molten metal and the further cooling of the outer crust inside the mold, the casting contracts and usually pulls away from the wall of the mold at a point below the surface of the liquid metal level. The gap thus formed impedes the transfer of heat from the surface of the casting through the mold wall. Shrinkage therefore retards the rate of growth of a solid crust. Only by slowing down the casting rate the consequent risk of a breakout of molten metal be reduced.

In order to eliminate the drawbacks of a lower casting rate, it has already been proposed to provide a combination mold. This consists of a mold followed in alternation by cooling slippers and guide rollers which support the thin crust and further cool the same. These guiding and cooling elements are supported by yielding support means which improve the cooling effect by pressing the cooling elements against the cast surface. However, the unevenness of the surface of the casting does not permit contact to be maintained everywhere and the effect of such a mold extension is therefore only limited. In order to reduce the drawbacks involved in the creation of a shrinkage gap inside the mold, it has been proposed to introduce a coolant into the gap. In this arrangement, flow channels for cooling water are provided in the form of grooves in the bottom part of the wall of the mold. However, in order to avoid the formation of stress cracks due to the direct contact between the cooling water and the surface of the casting and in order to moderate the intensity of the cooling effect, a gas is introduced into the grooves under pressure.

However, the cooling water itself results in a heat insulation barrier of steam on the surface of the casting due to the Leidenfrost phenomenon. The water flowing in the grooves of the casting is not turbulent due to the groove depth and contacts only the steam film. Thus, cooling of the casting takes place primarily by radiation reducing the rate of heat transfer from the casting surface to the mold wall.

In order to improve the transfer of heat across the gap inside the mold, it has been proposed to spray the casting inside the mold with a coolant liquid. The sprayed coolant is intended to evaporate when it touches the surface of the casting. In order to prevent bubbles of steam from rising in the direction towards the liquid metal level, means for the withdrawal of the steam from the gap by suction are provided. This proposal does not recognize that the generation of steam must be suppressed so far as is possible if the transmission of heat from the surface of the casting to the mold is intended to be improved. The formation of the steam in this proposal is in fact promoted by the reduced pressure in the gap due to the suction means, since the reduced pressure lowers the boiling point of the liquid coolant and, thus, causes even more steam to be generated which then impedes the transfer of heat from the surface of the casting to the wall of the mold.

The method and apparatus proposed by the present invention seeks to extract a maximum of heat from the film of vapor which worms on the surface of a metal that is being cooled and to retard, limit and maintain at a desired level the generation of vapor which inhibits the transmission of heat to the cooling elements.

According to the proposed method, this is achieved by the introduction of a coolant under controlled pressure into the gap between the metal that is being cooled and the cooling element and by the generation in said gap of turbulent coolant flow to cause the coolant to penetrate the vapor film on the surface of the metal that is being cooled and to extract heat from the vapor by intimate contact therewith.

For example, in continuous casting the gap between the surface of the strand and the cooling element is principally determined by inequalities of the cast metal surface. According to the factors which are governed by the casting conditions and other parameters, such as quality of the cast metal, casting rate, width of gap, surface roughness and so forth, a suitable degree of turbulence is created in the gap by adjustment of the pressure. Consequently the penetration of the coolant into the vapor film caused by the Leidenfrost phenomenon causes the required heat to be extracted from the vapor principally by convection. By measuring the surface temperature and examining the quality of the metal, it is possible to check whether the desired degree of cooling has been achieved.

According to a particular feature of the invention, the turbulence generated brings the individual coolant particles which have a higher enthalpy into close contact with the cooling element so that they transfer a portion of their heat to the cooling element, a process which retards the evaporation of the particle when it picks up

more heat in the vapor film. The turbulent flow conditions push the particles to and fro between the metal surface and the cooling element, heat being thus transported from the metal surface to the cooling element as is desired.

The above mentioned explanations based upon the movements of the coolant particles due to turbulence are, of course, merely symbolic. In practice, the totality of the coolant particles make up the coolant.

Nevertheless it is impossible to prevent the temperature of the coolant particles from rising whilst they are being thrown to and fro in the gap and the particles themselves from eventually turning into vapor. In order to deal with this situation, another feature of the invention proposes to remove the coolant from the gap before so much vapor is generated as to inhibit the further flow of heat from metal surface to cooling element to an undesirable extent. In order to provide a more moderate cooling effect, it may occasionally be even desirable to have a major proportion of steam in a water-steam mixture.

It has been found that by the provision of two pairs of cooling elements following the mold on the longer sides of a continuously cast slab, the coolant in the cooling element will extract up to 30% of the heat dissipated in the mold. The heat carried away by the coolant leaving the clearance gap may even be substantially higher. These decisive improvements in heat extraction permit the casting rate to be considerably increased.

According to another feature of the invention, the cooling element is principally defined by a plate which faces the metal to be cooled, and the side of the plate of the cooling element facing away from the metal is cooled by a flowing coolant.

The resultant external and internal cooling of the plates of the cooling elements by the coolant prevents the plates from heating up unevenly, from distorting and thereby changing the gap width and the cooling effect.

The time which elapses before the evolution of vapor in the gap becomes undesirably high depends upon the rate at which heat is delivered by the coolant to the cooling element. This heat transfer in turn depends upon the thermal conductivity of the plate of the cooling element. According to a feature of the present invention, the length of the cooling elements is reduced when the thermal conductivity of the plates is low. This obviates an excessive period of dwell of the coolant in the gap and a corresponding temperature rise followed by increased evolution of vapor.

As already mentioned, the magnitude of the induced turbulence decides the rate at which heat will be extracted from the metal. According to another inventive feature, this turbulence of the flowing coolant and hence its cooling effect on the metal can be varied by changing the width of the gap. The adjustability of the gap width should preferably be variable from direct contact with the surface that is to be cooled to a width of 1 mm. The width depends upon the nature of the surface of the metal that is to be cooled.

For example, if the cooled metal is a flat steel section that is to be hardened, then an excessively rapid cooling effect may cause thermal stress cracks at the edges. By suitably shaping the surface which cooperates with the metal, more particularly by reducing the thickness of the plate towards the edges by say 0.5 mm., the width of the gap is correspondingly affected. This reduction in the width of the plate may begin in the middle of the plate or near the edges, as may be desirable. The wider the gap, the less intense is the cooling effect.

The surface roughness of a steel workpiece that is to be hardened is usually very slight and the turbulence in the gap as well as the resultant cooling effect are therefore low. However, the turbulence can be increased by increasing the roughness of the surface of the cooling element which cooperates with the metal, for example, by providing it with grooves extending across the direction of coolant flow, for example, the kind of grooves that are formed by roughing a surface on a planer.

In the continuous casting of steel to which the invention may be applied, the continuous casting issuing from the mold has a thin solidified external skin of limited mechanical strength. In order to avoid inward collapse of this skin due to the pressure of the coolant inside the gap, particularly when the coolant is introduced through openings in the plate, the pressure may be controlled, preferably between 0.5 and 2.5 atm. gauge, in such a way that the thin skin is not inadmissibly stressed and thus damaged. Such damage may appear in the form of a crack in the skin through which the liquid coolant could penetrate into the liquid core of the casting, possibly leading to an explosion.

It has been found that when applying the proposed method to continuous casting, the intensity of the cooling effect of several consecutive plates on steel castings which are liable to form cracks is too high to avoid the appearance of cracks even if the coolant is introduced into the gap at low pressure. In order to overcome this particular difficulty, another feature of the invention consists in providing an uncooled zone or a zone of weaker cooling effect, for example, a spraying zone, behind each zone cooled by the described cooling elements. If this is done, the relatively thin excessively cooled layer of metal has time to extract more heat from the interior of the continuous casting to raise its temperature sufficiently for the avoidance of a major temperature gradient such as might lead to thermal cracks.

When producing continuous castings in such curved strand casting machines, the liquid core of the casting may extend into its horizontal part if the casting rate is fairly high. Further cooling of this horizontal part of the casting is therefore required. If this cooling effect is provided in conventional manner by sprayers, it is impossible to ensure that the water sprayed on the top of the casting will trickle quickly enough down the sides. The layer of water which then forms on the top of the casting is insulated from the metal surface by a Leidenfrost film of steam. This film of steam prevents effective cooling of the casting. The kinetic energy of the individual droplets of water issuing from the sprayers is destroyed in the layer of water and no effective contact of the water droplets with the film of steam actually takes place. The greater proportion of the heat dissipated from the top of the casting, therefore, leaves in the form of radiation. On the underside of the casting, the heat can be carried away by radiation as well as convection because a covering pool of water cannot form in this region. The casting is, therefore, unevenly cooled, with all the drawbacks this is known to entail.

According to another feature of the invention, this difficulty can be overcome by cooling at least the top of the casting by cooling elements of the proposed kind.

Having briefly described this invention, it will be described in greater detail along wtih other objects and advantages in the following portions of the specification, which may best be understood by reference to the accompanying drawings, of which:

FIG. 1 is a sectioned elevation view in schematic form of a vertical continuous casting installation employing the present invention;

FIG. 2 is a cross sectioned view taken on the line II—II of FIG. 1;

FIG. 3 is a cross sectioned view of another embodiment of the invention;

FIG. 4 is a cross sectioned view of still another embodiment of the invention;

FIG. 5 is a sectioned view of an admission device through which the coolant is admitted into the gap;

FIG. 6 is a sectioned elevation view of a curved strand casting plant employing the present invention; and

FIG. 7 is a sectioned view of a curved strand casting

plant equipped with cooling elements for cooling the top of the horizontal leg of the casting.

In FIG. 1, a strand **2** is continuously withdrawn from an oscillating mold **1** by withdrawal rolls **3**. Upon leaving the mold, the metal is first guided between pairs of box-like secondary cooling elements **4**, **4'**, **5**, **5'**, **6**, **6'** and then enters a secondary cooling zone comprising guide rollers **7** and cooling means **8**.

Moreover, sprayers **9** are located between the mold **1** and the first pair of cooling elements **4**, **4'**. These sprayers cool the metal immediately as it leaves the mold and prevent outward bulging in the gap which must be provided between the mold and the cooling elements **4**, **4'** to allow for mold oscillation. The amplitude of oscillation is small to reduce the length of this gap within which the metal casting is unsupported. The sides of the cooling elements facing the mold **1** carry deflector shields **10** which may be of copper or some other material that is a good conductor of heat for the purpose of deflecting the molten steel, if there is a breakout, to protect the equipment below from damage. A coolant, such as water, is introduced between the cooling elements and the surface of the casting through admission devices **11**.

In order to provide an easy route of escape for the water introduced between the cast steel surface and the cooling elements as well as for the steam-water mixture which gradually forms, the cooling elements are short in the direction of travel of the steel casting, preferably less than 300 mm. in length. The travelling casting assists the ejection of steam-water mixture. An outlet is formed by spacing the cooling elements sufficiently far apart, as indicated at **12**. For example, when casting a slab, 1500 x 250 mm. in size, the length of each cooling element in the direction of the casting axis may be 160 mm. and the intervals between consecutive elements may be less than 30 mm. Each cooling element is provided with thirty admission devices **11** distributed over its surface. The top coolant admission devices **11** are so disposed as to permit ecape of the liquid from the top of the cooling element in a direction opposite to that of casting movement.

The limited evaporation of the water also ensures that sufficient lubrication is available between the surface of the casting and the surface of the cooling element, since besides its cooling and heat conveying functions, the water also has a lubricating effect.

FIG. 2 illustrates the construction in greater detail of a pair of cooling elements for a cast slab. A metal plate **20** facing the casting, such as a plate made of copper, guides and locates the casting and, together with an intermediate partition **21**, forms a cooling channel through which water entering via branch pipes **22** circulates at high speed, i.e., at a velocity of 6 metres/second. This partition **21** in conjunction with an outer plate **23** at the same time forms a distributor supplied wiht water from a pipe **24** for feeding the admission devices **11** that will described in detail by reference to FIG. 5. These admission devices **11** also constitute fastening means for holding plate **20** which is replaceable. The cooling elements are secured by bolts **26** to beams **27** of a supporting structure. If desired, the cooling elements may be mounted for limited movement to permit them to yield to motions of the casting across the longitudinal casting axis.

In order to reduce the increased risk of breakout in the gap required between the mold and the first cooling element to permit the mold to oscillate, at least one cooling element may be attached to the mold in a manner already known in the art so that the necessary wider gap can be shifted to the zone where the crust is already thicker and the risk of breakout is less.

FIG. 3 illustrates an embodiment of a cooling element for casting bars. In order to avoid an excessive cooling effect at the edges and at the same time in order to facilitate the escape of the water and steam, the cooling elements are narrower than the length of the sides of the casting cross section and so disposed that intense cooling is provided only in the region where it is desired. The other parts of the cooling elements correspond to those already described by reference to FIG. 2.

FIG. 4 is an embodiment of the cooling elements intended for castings of smaller cross-section, in which each cooling element completely embraces the casting. Recesses **25** are formed at the corners of the casting to prevent excessive cooling at those points and at the same time to provide outlets for the water-steam mixture.

FIG. 5 shows a device **11** for admitting the water and for securing the metal plate **20** in greater detail. The external plate **23** and the central partition **21** are secured, as by welding, to a cross member **35** which on its edge carries the plate **20**. The admission device **11** is in the form of a bolt comprising a flange **28** located in a countersink **29** in the plate **20**. The countersink is outwardly flared as shown at **30** to facilitate entry of the water into the gap between the surface of the casting and the surface of plate **20**. The water is admitted through a duct **31** which communicates through transverse channels **34** with the water distributor. A nut **32** which pulls the admission device **11** into the countersink thus also pulls the plate **20** onto the cross members **35** and a spacing member **33**.

In order to reduce the cooling effect on the strand **2** near the edges, the width of the clearance gap is increased in these regions at **36** by a reduction of the thickness of the plate **20**.

Instead of feeding the water through plate **20**, nozzle-shaped openings may be provided to introduce the water at the end of the plate from which the casting enters.

FIG. 6 illustrates a curved strand casting plant with a curved mold **40**, guide rollers **7**, cooling means **8** and a withdrawing and straightening assembly **41**. Located below the outlet end of the mold **40** are cooling elements **42**, **42'**, **43**, **43'**, **44**, **44'**. Moreover, supporting rollers **45** are located between the cooling elements **42** and **43** and further supporting rollers **46** are provided between the cooling elements **43** and **44**. The cooling elements conform with the circular periphery of the supporting rollers and are spaced in relation thereto to form intervening gaps **12**. These gaps which are 8 mm. wide provide an escape route for the water-steam mixture from between the casting and the cooling elements. Small intervening outlet gaps have the advantage that the crust cannot be substantially forced outward by the ferrostatic pressure if a crack should appear and that any bulges in the crust will be pushed back into shape in the following cooling element where the steel which tends to break through a fracture will be solidified by the cooling medium. This self-healing effect on fractures considerably reduces the number of breakouts.

Nevertheless, the gap **12** may be made appreciably wider to provide a zone of reduced cooling by the escaping coolant behind a zone of intense cooling by a cooling element.

All the cooling elements **42**, **43**, **44** are movable perpendicularly to the surface of the casting. This movement can be produced by plungers **47**, the purpose being as follows: When the casting operation begins, chips and scrap are first placed in the dummy bar to ensure rapid cooling of the steel adjacent the dummy bar. However, the presence of the chips has the drawback that they impart a rough surface to the solidified casting and that this roughness tends to score the plates of the cooling elements, particularly if they are copper plates. When this rough surface travels along the cooling elements, the latter are, therefore, kept in retracted position until the rough portion of the casting has cleared the region of the cooling elements.

As known, in the event of a breakout, liquid steel will not weld to the copper plates. Consequently, the

cooling elements are still retractable after breakouts so that the damaged casting can be further withdrawn.

Furthermore, the plungers **47** can be used for adjusting the width of the gap, the supporting rollers **45, 46** ensuring the maintenance of the width of the gap since it is these rollers which are principally responsible for guiding the casting.

As has been mentioned, the cooling effect of the water is greater in narrow gaps. For casting large dimensions, slight bulges are known to occur in the solidified crust. Instead of providing for mobility of the cooling elements by plungers **47**, they may be urged against the casting by spring means, creating only a very small clearance gap which is determined by the unevenness of the surface of the casting and the plate of the cooling element. Places where bulges tend to form are cooled very much more intensely than the corner regions where a thicker crust has already formed. This step reduces the formation of curves in the surface of the casting.

FIG. 7 illustrates another curved strand casting plant. The first pair of cooling elements **50** following the mold is here attached to the mold **40** and participates in its oscillations. The unsupported region necessitated by the oscillating movement is thus shifted into a zone where the thickness of the crust is already greater and the risk of rupture is thus considerably less.

Moreover, the attachment of the cooling elements to the mold also permits the length of the mold to be reduced, causing the inhibitory effect of the shrinkage gap in the mold on the cooling rate to be reduced, and permitting the casting rate to be raised in relation to continuous casting processes known in the art. Preferably, the cooling elements are arranged to be short, i.e., 60 mm. in length, the spaces between consecutive cooling elements being 2 to 3 mm.

The casting rate in a plant according to FIG. 7, is high, so that the liquid core in the casting will extend into the horizontal part of the casting where further cooling is therefore required. In order to avoid the previously mentioned drawbacks of unequal cooling from above and below, the top of the strand **2** emerging from the withdrawing and straightening roller assembly **41** is cooled by cooling elements **53**, whereas its underside is cooled by a spraying device **54**.

Since the solidified zone in this region contains less heat, the plates of the cooling elements **53** may consist of a material of low thermal conductivity, such as steel. In zones containing such heat, for example, immediately after the casting has emerged from the mold, the plates may consist of a material of high thermal conductivity, such as copper. For the reduction of wear, it may be necessary to construct the plates of the cooling elements **51** and **52** of steel and these plates should then be shorter to prevent the volume of steam generated in the clearance gap from having an undesirably high insulating effect upon the transfer of heat from the casting to the cooling element.

In a curved strand casting plant comprising a straight mold and an assembly for guiding the casting along a curved path, the freshly cast steel directly below the mold is bent by one of the first rollers of the guiding assembly. If this operation of bending the casting is performed in a plant in which the casting rate is very high, the risk of crack formation is considerable on the side of the casting which is under tension. Cracks often lead to breakout of the steel. In order to prevent breakouts, cooling elements may be provided in the region of the bend to prevent the steel from flowing out and to heal cracks that may occur.

When solidifying flat sections or in other fields of application, it may be best to keep the body that is being cooled rigid and to move the cooling elements instead.

This invention may be variously modified and embodied within the scope of the subjoined claims.

What is claimed is:

1. The method of secondary cooling of hot continuous castings having a molten core, which comprises the steps of positioning a cooled surface adjacent said metal with a gap between said cooled surface and the surface of said metal, circulating a liquid coolant under controlled pressure through said gap, generating in said gap a turbulent flow of the coolant causing it to penetrate a vapor film of coolant formed on the surface of said metal and to extract heat from said vapor film by intimate contact therewith, and controlling the turbulence of the coolant and the resultant cooling effect on the metal by varying the pressure of the liquid coolant in the gap.

2. The method in accordance with claim **1** which includes the step of delivering the extracted heat to the cooled surface by the coolant and thus retarding a heat-transfer-inhibiting formation of vapor by said coolant in the gap.

3. The method in accordance with claim **1** which includes the step of replacing the coolant in the gap before the transfer of heat between the metal surface and the cooled surface is undesirably inhibited by the formation of an increasing volume of vapor.

4. The method in accordance with claim **1** which includes the step of continuously cooling said cooled surface.

5. The method in accordance with claim **1** which includes adjusting the pressure between 0.5 and 2.5 atm. gauge.

6. The method in accordance with claim **1** in which one of said surfaces of the metal and said cooled surface moves generally parallel relative to the other, and which includes positioning at least one additional cooled surface adjacent said metal, said cooled surfaces being positioned in line, and spaced apart, in the direction of said relative movement for providing an area of reduced cooling between the adjacent ends of the cooled surfaces.

7. The method in accordance with claim **1** in which the pressure of the liquid coolant in the gap is varied by varying the width of the gap.

8. The method in accordance with claim **1** which includes varying the cooling effect on selected portions of the surface of the metal by varying the width of said gap at said selected portions.

9. The method for cooling the strand in a continuous casting machine, in which molten metal is poured into a cooled mold to solidify on the periphery of said mold into a skin enclosing a molten core and defining a strand which issues continuously from said mold, comprising the steps of positioning at least one cooling element adjacent the surface of said strand skin with a clearance gap between said element and said surface, introducing a liquid coolant under controlled pressure into said clearance gap, generating in said gap a turbulent flow of the coolant causing said coolant to penetrate a vapor film of coolant formed on the surface of said strand and to extract heat from said vapor film by intimate contact therewith, and controlling the turbulence of the coolant and the resultant cooling effect on the strand by varying the width of the clearance gap.

10. The method in accordance with claim **9** which includes the step of varying the width of the clearance gap from direct contact between strand and cooling elements to a width of 1 mm.

11. The method in accordance with claim **9** in which the width of said cooling element is less than the width of said strand and said cooling element is positioned adjacent the mid-portion between opposite edges of the strand whereby the edges are cooled less than the mid-portion.

12. The method in accordance with claim **9** in which a portion of the length of the strand is in a horizontal position and in which a cooling element is adjacent the upper surface of said portion.

13. The method in accordance with claim **12** in which the lower surface is cooled by spraying coolant thereon.

14. The method of claim **9** in which said cooling ele-

ment is less than about 300 mm. long in the direction of travel of the strand and which includes replacing the coolant in the gap before the transfer of heat from the surface of the strand to the cooling element is undesirably inhibited by the formation of an increasing volume of vapor.

References Cited

UNITED STATES PATENTS

3,237,251	3/1966	Thalmann	164—89 X
3,358,744	12/1967	Rossi	164—282
2,698,467	1/1955	Tarquinee et al.	164—283 XR
2,895,190	7/1959	Burgereth et al.	164—282
3,015,862	1/1962	Rustemeyer et al.	164—283 XR

FOREIGN PATENTS

152,036	6/1953	Australia.
594,346	3/1960	Canada.
759,290	10/1956	Great Britain.
762,513	11/1956	Great Britain.
814,435	6/1959	Great Britain.

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