

July 6, 1954

I. HARTER, JR

2,682,691

CONTINUOUS CASTING PROCESS AND APPARATUS

Filed July 9, 1949

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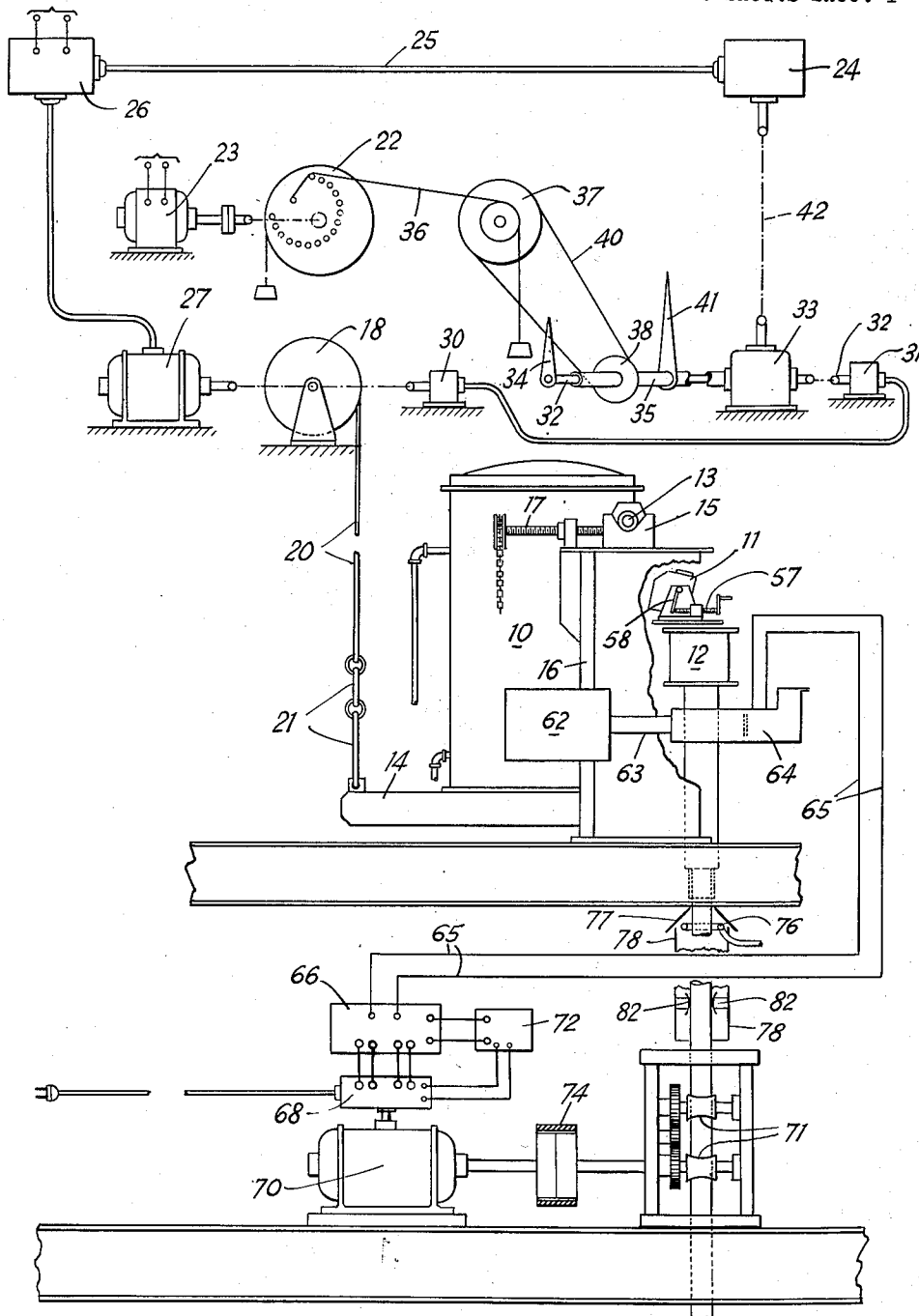


FIG. 1

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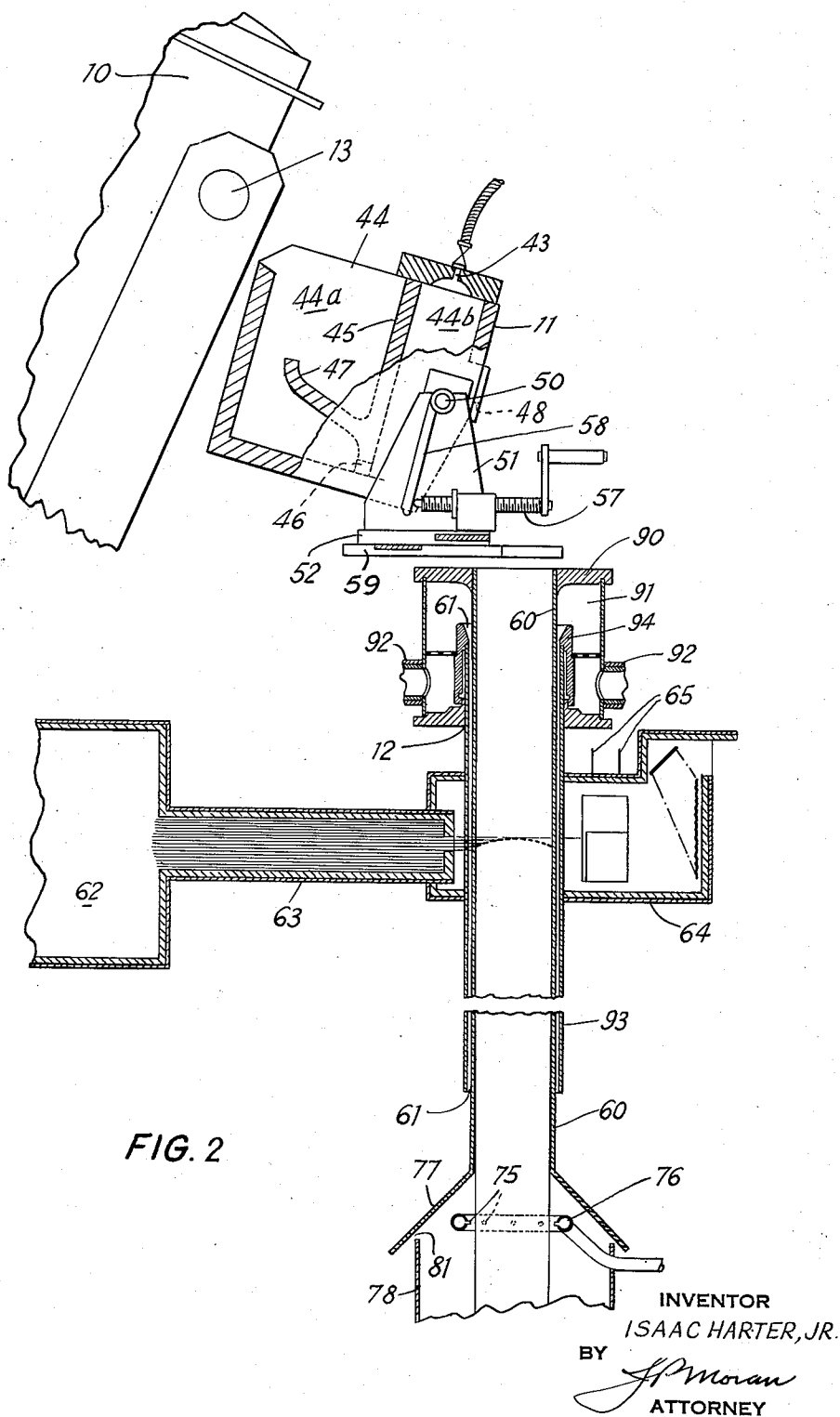
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CONTINUOUS CASTING PROCESS AND APPARATUS

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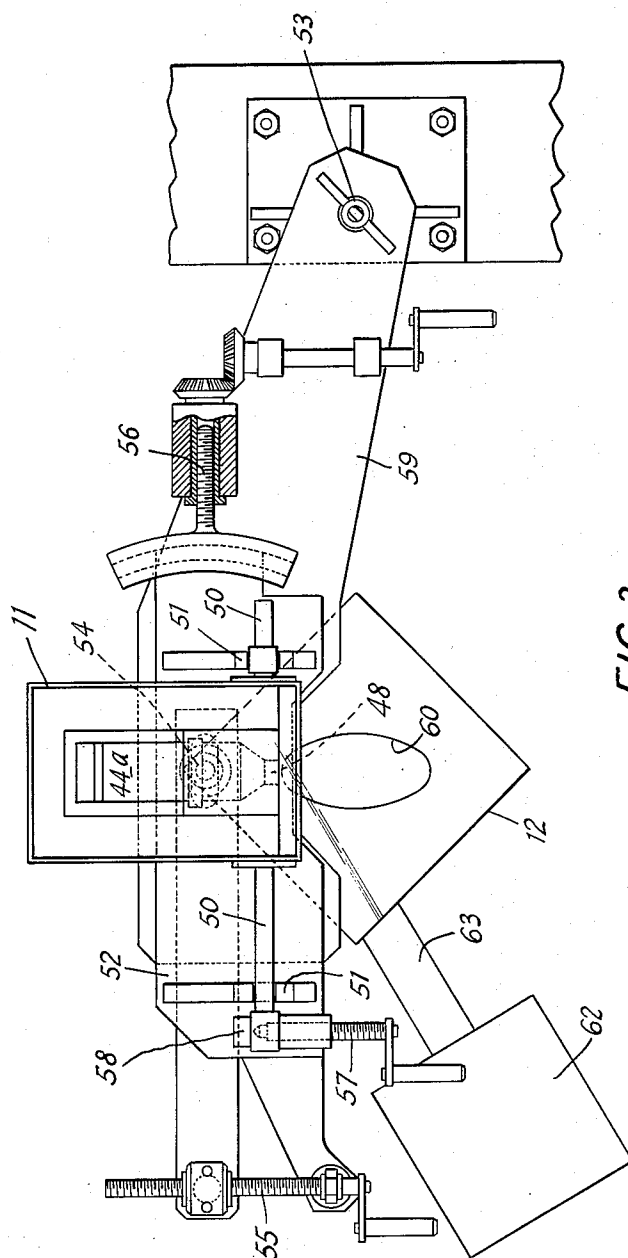
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CONTINUOUS CASTING PROCESS AND APPARATUS

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5 Sheets-Sheet 3



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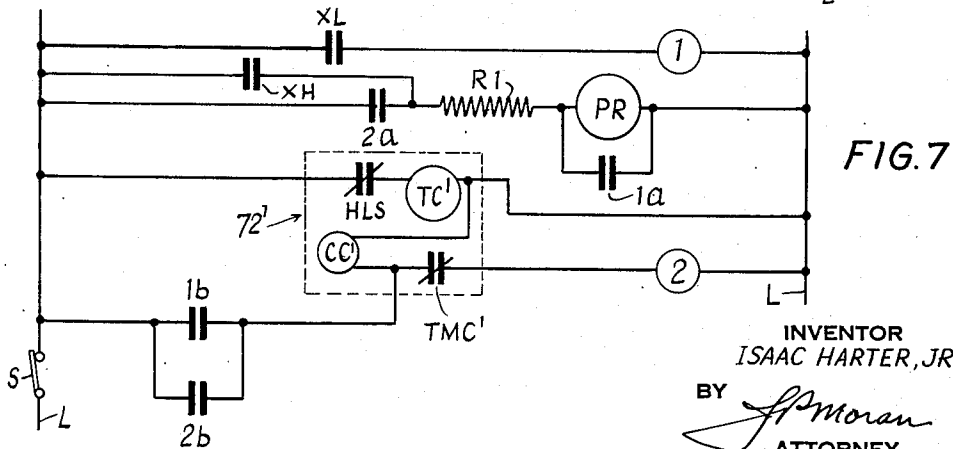
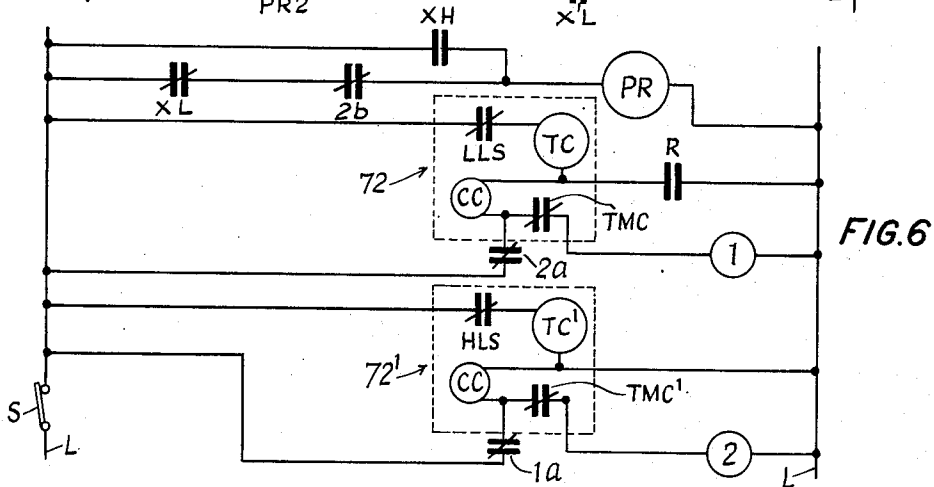
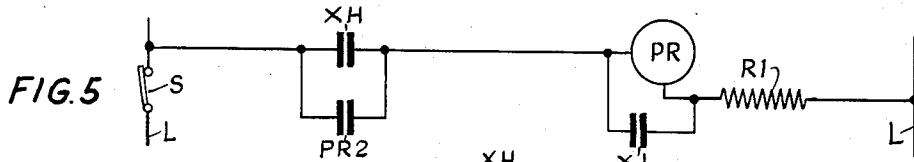
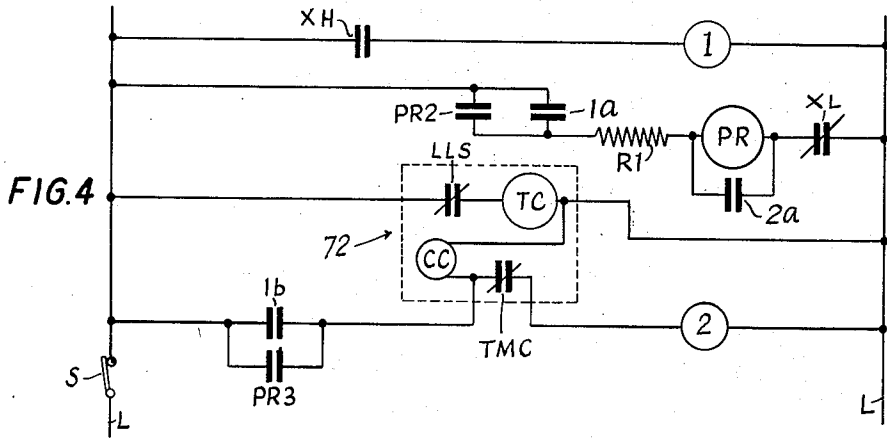
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CONTINUOUS CASTING PROCESS AND APPARATUS

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CONTINUOUS CASTING PROCESS AND APPARATUS

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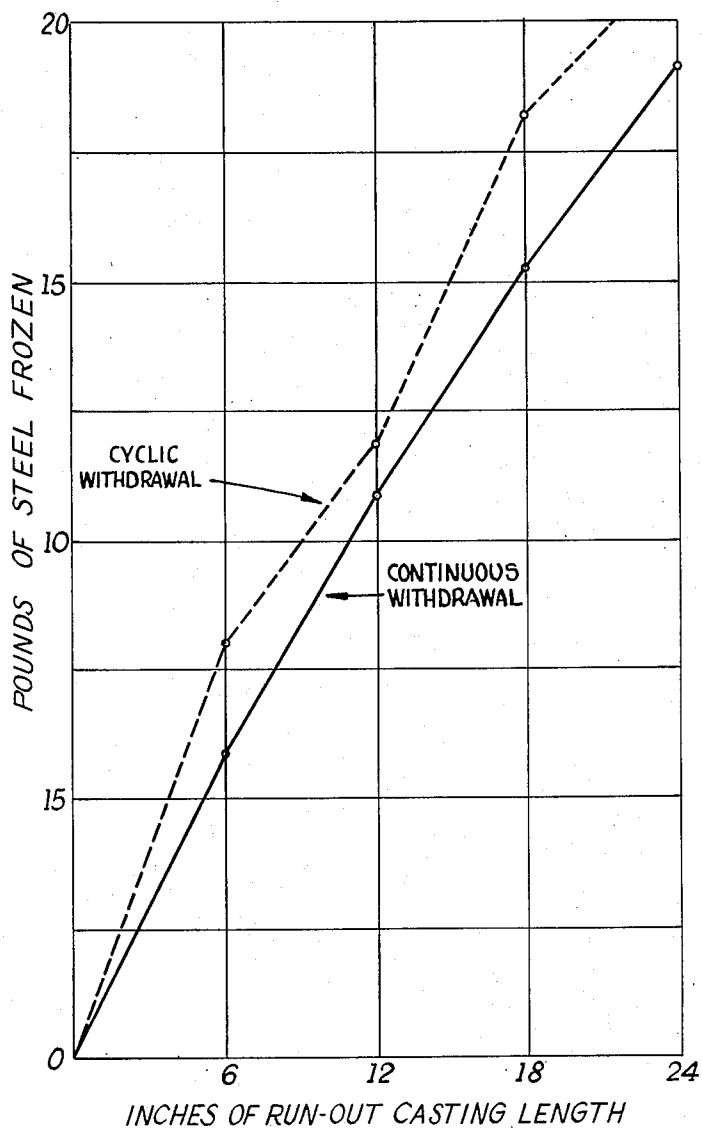


FIG. 8

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2,682,691

CONTINUOUS CASTING PROCESS AND APPARATUS

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Application July 9, 1949, Serial No. 103,901

8 Claims. (Cl. 22-57.2)

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The present invention relates in general to the continuous casting of metal products, and more particularly to a process of and apparatus for the continuous casting of high melting temperature metals, such as ferrous metals and alloys, in semi-finished and/or finished products of indeterminate length and various cross-sections.

In a related copending application of Harter et al., Serial No. 10,956, filed February 26, 1948, now Patent No. 2,590,311, dated March 25, 1952, it is disclosed that processes and apparatus have been in successful commercial use for years for the continuous casting of non-ferrous metals, such as copper and aluminum, having relatively low fusion temperatures and high thermal conductivities, but that such prior apparatus and processes have heretofore failed to result in a single installation in commercial production for the continuous casting of steel/or alloy steel products.

The principal object of the present invention is the provision of an improved process of and apparatus for continuously casting metal in semi-finished or finished products of a commercially uniform and acceptable quality at a commercially economical rate of production, which process and apparatus are particularly characterized by the maintenance of more effective heat transfer conditions in the mold, the production of a metallurgically sound casting having improved surface conditions, and greater ease of control of the casting operation. Further and more specific objects are the provision of a process of and apparatus for continuous casting of the character described in which molten metal is delivered at a substantially constant rate and temperature to an open-ended liquid-cooled stationary mold, subjected in the form of an embryo casting to alternating rates of heat absorption while in the mold, then withdrawn from the mold as a self-sustaining casting by a cyclic on and off or high and low speed movement of the withdrawal mechanism. A further specific object of the invention is the provision in a continuous casting process and apparatus of the character described of a fluid cooled mold having an inner wall or liner formed of metal with a relatively high thermal conductivity and of a thickness providing a substantial heat storage capacity. A further specific object of the invention is the provision of mechanism for automatically controlling the rate of molten metal delivery to the mold in correlation with mechanism for automatically controlling a cyclic operation of the

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casting withdrawal mechanism in response to time and/or molten metal level change.

While the process of the present invention can be used for the continuous casting of non-ferrous and ferrous metals and alloys, it is particularly designed and especially useful for continuously casting ferrous and other high melting point alloys to produce semi-finished and finished castings, each of commercially acceptable quality and of a substantially uniform metallurgical structure throughout its length. In the continuous casting of steel, for example, steel of the desired composition is first melted in accordance with good steel making practice in or delivered to a suitable heating and/or pouring vessel, such as a ladle. Ladle heating means insure that during the time of pouring, the metal temperature will be within an optimum temperature range, which, while varying with the metal composition, will normally be enough above the liquidus temperature of the metal to insure the desired fluidity of the metal. As much as possible of the slag present in the charge is separately removed from or retained in the ladle. A tilt-able ladle having mechanism for controlling the rate of tilt is preferably employed to insure an approximately constant rate of pour of the molten metal. To minimize the amount of slag in the charge, the refractory linings of the apparatus parts which contact the molten metal are constructed of the same or compatible ceramic composition, as disclosed in said copending Harter et al. application.

A special stationary casting mold assembly is employed which is constructed to permit and maintain the desired high rate of heat absorption from the molten metal and embryo casting. The casting mold itself is upright and open at both ends, and the delivery rate of molten metal to its upper end and the rate of withdrawal of the casting from its lower end are coordinated to maintain in normal operation a varying level of molten metal not exceeding a predetermined value within and below the upper end of the mold. The maximum molten metal level should not be too close to the top of the mold due to possible metal oxidation because of exposure to the atmosphere. The stream of molten metal delivered is also regulated by adjusting the position of tundish, to enter the molten pool with a minimum of splashing against the mold and of turbulence in the molten metal pool in the mold.

Complete elimination of oxygen from the mold atmosphere above the molten metal is highly desirable to prevent formation of metal oxides.

This is accomplished by the continuous introduction of an inert gas, preferably heavier than air and non-soluble in the metal, into the top of the mold to displace any lighter gas, such as air, therefrom and also the introduction of a substance which will consume any oxygen and/or deleterious reactive gases that might remain in the mold. The combined effect produces a substantially oxygen-free atmosphere in the mold space immediately above the molten metal level.

The present process of continuous casting of ferrous and other high melting point alloys is particularly distinguished by the extremely high rate of heat transfer effected between the solidifying metal and the mold cooling liquid. This is attained by employing an extremely high rate of mold cooling, as set forth in said copending Harter et al. application, in conjunction with an improved method of withdrawing the solidified casting from the mold assembly in a cyclic on and off or high and low speed movement.

As disclosed in said copending Harter et al. application, it has been found that for a commercially acceptable ferrous alloy casting process a rate of heat transfer from the portions of the mold effective in the formation of the embryo casting is required which is at least several times over the maximum cooling rate heretofore proposed in the prior art for casting ferrous alloys. This extremely high cooling rate is attained by the introduction of the cooling water into the stationary mold assembly in a manner and in quantities insuring the entry and maintenance of a solid stream of cooling water throughout the mold cooling passage at a velocity having a calculated Reynolds number for highly turbulent flow conditions, with pressure and flow so combined that far greater heat transfer rates than have been achieved in any other known system are obtained.

In contrast to the substantially uniform rate of withdrawal of the casting from the mold assembly disclosed in said copending Harter et al. application, the present invention involves a controlled cyclic operation of the withdrawal mechanism, whereby the casting is alternately subjected to periods of high rates of heat absorption while stationary or substantially stationary in the mold and periods of lower rate of heat absorption while moving downwardly in the mold.

The combination of a substantially constant molten metal delivery to the stationary mold with a cyclic on and off or high and low speed movement of the casting withdrawal mechanism results in a varying molten metal level in the mold between predetermined limits, whereby the section of the mold liner within the molten metal level limits is alternately in contact with the metal and exposed to the mold atmosphere. During the exposure period this mold liner section continues to be cooled at the same rate by the contacting cooling water, reducing the mold liner metal temperature in this section substantially below its temperature when in contact with molten metal. As the molten metal level again rises, the heat storage capacity of the mold metal results in an initial chilling effect on the contacting molten metal. If the mold liner is made as thin as structurally permissible, the heat storage effect would be insignificant. In accordance with the present invention, the mold liner is preferably made of a metal having a relatively high thermal conductivity and of sufficient thickness to provide a substantial heat storage capacity sufficient to give a substantial initial chilling ef-

fect on the molten or partially frozen metal over and above the equilibrium heat extraction from the molten metal. The maximum thickness of the mold liner is limited only by the necessity of maintaining the maximum metal temperature of the wall within safe limits.

The amount of heat transfer by conduction per unit area between any two surfaces in contact is dependent upon the closeness of contact, i. e. the degree of conformity of the surfaces, the time in which the contact is maintained, and the temperature difference therebetween. This temperature difference in casting is primarily dependent upon the pouring temperature of the metal. The necessary higher pouring temperature and inherently higher heat content per cubic inch of ferrous metals and alloys make it more important in continuous casting thereof to maintain close intimacy of contact between the casting and mold in order to obtain rapid solidification, and consequently increase the problems of mold design, mold cooling, and method of operation, in order to transfer the greater total amount of heat from the casting to the cooling liquid. Where freezing metal is continuously moved downwardly in the mold, the degree of conformity of the molten metal will be high initially, due to the inherent property of any liquid to conform to the wall of its container, but as the peripheral shell of frozen metal is formed and thickened, the degree of conformity decreases due to contraction of the shell and deviations in the cross-sectional dimensions of the subjacent portions of the mold. In view of the substantially greater contraction of ferrous alloys as compared to most non-ferrous metals, a partial "gap" heat barrier is almost instantaneously introduced between an embryo ferrous casting and the mold wall. When this gap develops, the rate of heat transfer to the mold decreases and this lower rate of heat transfer continues until the internal reheating of the casting and ferrostatic head causes the shell to expand to reduce the gap. In some cases it has been found that the expansion of the casting reestablishes contact with the mold wall, but obviously the degree of conformity will never be as high as the initial contact between the molten metal and mold wall. The cycle of shell freezing and contraction, reheating and expansion continues during the downward movement in the mold. This "breathing" of the casting is repeated a number of times, dependent upon the time required for reheating, the rate of withdrawal of the casting, and the axial length and cross-sectional shape of the mold. After sufficient shell thickness is attained, further freezing and contraction of the casting are simultaneous. The contact time for any substantial amount of heat transfer between the moving casting and mold will ordinarily be short.

The present process of cyclically withdrawing the casting is designed to substantially increase the time and number of heat transfer contacts per unit of mold length between the casting and mold, with a consequent gain in overall heat transfer efficiency of the mold assembly and improved metallurgical properties of the casting. For this purpose, in the preferred normal operation the casting withdrawal mechanism is operated with an "off and on" cycle to first hold the casting stationary in the mold during a varying period controlled by the rise in level of the molten metal in the mold to a predetermined extent. During this period an extremely close contact is maintained between the molten metal and

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mold wall, causing the metal in the contacting outer rim portion to solidify at a very rapid rate due to the high rate of heat absorption of the mold and the stationary intimate contact of the metal. The controls, generally speaking, are set to maintain the "off" period of the withdrawal mechanism, or "dwell" of the casting, for a time interval sufficient to permit the formation of an appreciably thick shell around the molten metal and a slight contraction of the shell away from the mold. This time interval is coordinated with the rate of supply of molten metal to the mold and when the rising level of molten metal during the dwell of the casting reaches a predetermined level, the withdrawal mechanism is put into operation to permit the casting to move downwardly a predetermined increment of its length or period of time.

During the dwell period additional metal is poured into the mold at a substantially constant rate. This additional metal is subjected to the high rate of heat absorption of the mold and a shell tapering upwardly in thickness to a lace-like formation is formed thereon. On the subsequent withdrawal movement of the casting, the lowermost portion of this shell stays joined to the shell on the metal present at the start of the dwell and tears away from the remaining weaker section of the shell, the upper lacy portion of which, now unsupported by molten metal, tends to fall inwardly into the metal pool. The submerged intermediate section appears to remain on the mold wall, because sufficient contraction has not yet occurred, until the molten metal present fills and heals the breach and is solidified during the withdrawal and subsequent dwell period.

The decreased rate of heat absorption by the mold due to the gap heat barrier permits the casting shell to be reheated by the enclosed core of molten metal and expand towards the mold wall under the ferrostatic head of molten metal. According to the present invention, this fluid pressure is increased at the end of each "on" period by rapidly decelerating the speed of the withdrawal mechanism, causing the inertia of the core of molten metal to exert a "hammer" effect on the surrounding shell. The added expansion so given to the shell substantially re-establishes the mold to shell contact and consequently a high rate of heat transfer between the casting and mold. The expanded shell is thickened during the dwell of the casting and contracts by the time the withdrawal mechanism is again operated to repeat the cycle. As the casting proceeds downwardly through the mold, each successive increment of withdrawal is less affected by the hammer effect until the increasing thickness and strength of shell is sufficient to withstand the combined action of the ferrostatic head and hammer effect, and this point determines the optimum length of mold for a particular casting rate as a self-sustaining shell will now exist.

As the casting is withdrawn from the mold, it usually contains a V-shaped core of liquid metal. To solidify the core more rapidly and reduce shrinkage voids, the casting is preferably subjected to a substantial liquid cooling effect close to the bottom of the mold. The rate and amount of casting cooling in this zone is selected in accordance with good metallurgical practice for the type of metal or alloy being cast to produce a completely solidified casting at a desired temperature. The casting can be subsequently re-

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heated and recooled alternately to satisfy any particular metallurgical requirements. From this core solidification zone, the casting continues downwardly through a suitable guide and enclosing tube which serves to keep mold cooling water from the casting. Below the lower end of the enclosing tube the casting is engaged by the withdrawal mechanism, and proceeds downwardly to the cutting and handling apparatus.

The hammer effect of the enclosed core of molten metal at the end of each cycle has the further result of insuring a period of forced feed of molten metal into any piped area in the casting, thus insuring the metallurgical soundness of the casting product by eliminating voids. This hammer effect is also believed to have the further advantage of offsetting the necking of the casting which is believed to principally occur during the reheating cycles of the casting, i. e. when the shell has contracted out of contact with the mold, in a continuous withdrawal process. The force causing the necking is the pull of the withdrawal mechanism when the friction in the mold is sufficient to become a holding force.

It is a fact that the refractory lining of steel holding or heating vessels is subject to erosion and/or build up, thus causing change in internal contour. This changing contour causes difficulties in any programed pouring control, especially for the nose tilting type of pouring ladle. The required degree of precision of pouring from a ladle is advantageously less for an intermittent withdrawal of the casting than for a continuous withdrawal. According to the present process, variations in the rate of molten metal supply to the mold are readily compensated for by changes in the frequency of operation of the withdrawal mechanism. The duration of the casting dwell period part of the cycle, i. e. the time required for the incoming molten metal to reach a predetermined height in the mold after each withdrawal period, affords an effective check on the ladle control system. For example, if the duration of dwell periods continually decreases, it signifies that the incoming metal rate is too fast; if the duration of dwell periods continually increase, the incoming metal rate is too slow. In either case, the ladle tilt control can be manually adjusted in accordance with the indications of dwell time duration to provide a substantially constant average withdrawal rate from cast to cast.

In spite of the best known methods and apparatus for the elimination of slag or lightweight impurities, some slag may enter a casting mold with the molten metal. Whenever a comparable amount of slag is present in either a continuous or intermittent withdrawal casting process, the latter process advantageously minimizes the amount of slag contained in each patch of slag entrapped on the surface of the finished casting. With the intermittent withdrawal process, the regulated changes in the molten metal level encourages the entrapment of accumulated slag during each cycle of operation. On the other hand, with the continuous withdrawal, nominally constant molten metal level process, the slag generally accumulates during a much longer timed period per entrapment. The greater slag accumulation leads to an entrapped slag mass sufficient to form an appreciable heat barrier on the surface of the casting which results in interior slow cooling and creates casting defects.

The various features of novelty which characterize my invention are pointed out with par-

ticularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, its operating advantages and specific objects attained by its use, reference should be had to the accompanying drawings and descriptive matter in which I have illustrated and described a practical embodiment of my invention.

Of the drawings:

Fig. 1 is a partial side elevation of a continuous casting apparatus constructed in accordance with the present invention, including a diagrammatic illustration of the metal pour rate control and the control means for regulating the casting withdrawal mechanism;

Fig. 2 is an enlarged elevation view of the pouring means and a sectional elevation view of the mold shown in Fig. 1;

Fig. 3 is a plan view, partly in section, showing the tun dish and the upper portion of the mold;

Fig. 4 is a wiring diagram showing the control circuit for the withdrawal mechanism shown in Fig. 1;

Figs. 5, 6 and 7 are wiring diagrams showing other control circuits for regulating the withdrawal mechanism shown in Fig. 1; and

Fig. 8 is a graphical representation of the pounds of metal frozen in a continuous casting mold operated in accordance with the present invention as compared with the pounds of metal frozen in the same mold under substantially identical conditions, except for a substantially uniform casting withdrawal rate.

The embodiment of the present invention illustrated in the drawings is somewhat similar in general physical arrangement to the disclosure of the previously mentioned copending applications, now Patent No. 2,590,311. In the following description, the term "continuous casting" is used to generically signify the formation of a cast metal product having a length greater than that of its mold.

As shown in Fig. 1, the metal pouring means includes a vessel 10 arranged for lip pouring, and a tun dish 11 arranged to receive molten metal from the vessel and to deliver a substantially slag-free stream of metal to a selected position in the open upper end portion of a continuous casting mold assembly 12. The vessel 10 may be a melting furnace, or a holding and pouring ladle arranged to be charged with molten metal as delivered thereto by a transfer ladle. Advantageously the vessel 10 is heated, so that the molten metal poured therefrom is delivered to the mold at a substantially uniform temperature.

The vessel 10 is arranged for tilting movement about a transverse horizontal axis defined by trunnions 13 extending outwardly on opposite sides of an L-shaped frame 14 supporting the vessel. The trunnions are supported in trunnion bearings 15 each of which is mounted on a pedestal 16 and arranged for sliding movement in a horizontal direction normal to the axis of tilting movement. The transverse position of the vessel 10 relative to the tun dish 11 is regulated by means of gear motors (not shown) connected to the adjusting screws 17. The tilting movement of the vessel is obtained by any suitable method, such as the operation of a motor driven drum hoist 18. The hoist is connected to the vessel 10 by a cable 20 and a yoke 21 which is attached to the platform of the frame 14 supporting the vessel.

The pour rate from a lip pour type of container, such as the vessel 10, is not uniform during a uni-

form angular rate of its tilting movement. To attain pour rate uniformity the vessel must be tilted through a pattern of a changing rate of angular movement. This preferred pattern of tilting movement can be determined experimentally or by calculation for any specific internal shape of vessel. A tilting control system for a pouring vessel utilizing a pattern of angular rate of movement for a substantially uniform rate of pour is disclosed and claimed in the copending application of T. W. Ratcliffe and S. O. Evans, Ser. No. 107,506, filed July 29, 1949, and is shown schematically in Fig. 1 of this application.

As shown, a pin cam 22 is driven at a uniform angular velocity by a synchronous motor 23 through an adjustable speed reducer (not shown). The cam contour is adjustable so that it can be correlated for an optimum tilting rate of the pouring vessel 10 to obtain the desired uniform metal pouring rate. The substantially uniform angular velocity of the cam shaft is converted to a selected varying angular movement in a manner hereinafter described, and an indication resulting from a comparison of such varying angular movement with the actual movement of hoist 18 is transmitted to a speed and direction control unit 24 connected through an electrical cable 25 to a motor driven rheostat 26 controlling the motor 27 of the hoist 18.

A continuous indication of such actual movement of hoist 18 is provided by a self-synchronous motion transmitter 30 driven by the drum and electrically connected with a self-synchronous receiver 31. The actual rotation of the hoist, reproduced by the rotation of the shaft 32 of the receiver 31, is fed to a differential comparator 33, and to an indicator arm 34. The comparator 33 is also fed by a shaft 35 rotated by movement of cam 22 through a chain 36 riding on the cam contour through the toothed pulleys 37 and 38, and the chain 39. An arm 41, mounted on the shaft 35 indicates the movement of the shaft. The input driving gears of the gear box 33 are separately connected to the shafts 32 and 35, and are arranged so that any differential movement of the shafts effects rotation, in one direction or the other, of the differential output shaft 42 which in turn actuates the control unit 24. Thus the speed control device 26 will regulate the drum hoist motor in accordance with the comparative movements of actual tilt rate and the optimum pattern of the cam contour so as to maintain the actual tilting movement of the vessel 10 at an optimum metal pour rate.

The tun dish 11, as shown particularly in Figs. 2 and 3, is disclosed and claimed in a copending application of I. Harter, Jr. et al., Serial No. 2114, filed January 13, 1948, now Patent No. 2,571,033, dated October 9, 1951, and a division thereof, Serial No. 209,164, filed February 2, 1951, and is formed with a refractory lined rectangular cavity 44 divided by a transverse partition 45 having a port or ports 46 in the lower end thereof for the passage of molten metal therethrough. Molten metal from the vessel 10 enters the receiving chamber 44a of the tun dish cavity, with the entering stream of metal deflected through an angle of substantially 180° by a submerged baffle 47. Any slag tends to accumulate on the surface of the molten metal in the receiving chamber 44a, and can be removed as it accumulates. The metal receiving chamber is provided with a longitudinal dimension sufficient to permit a slight variation in the delivery position

of the entering molten stream without altering the relative horizontal position of either the vessel 10 or the tun dish 11 or adversely influencing the slag separating effect of the baffle 47. Molten metal passing through the port or ports 46 in the partition 45 fills the discharge chamber 44b to the level of the discharge lip 43 and thence discharges into the open upper end of the mold assembly 12.

Advantageously the tun dish 11 is mounted for a plurality of adjustments, so as to insure the delivery of molten metal into a preferred location in the mold. To insure a desirable fluidity of the molten metal passing through the tun dish, a suitable fuel burner 43 is installed in the top of the discharge chamber 44b. The gaseous products of the fuel burned in the chamber discharge through the molten metal discharge lip above the molten metal level maintained therein and thereby tend to maintain the fluidity of the metal passing through the V-notch of the pouring lip. The tun dish is provided with trunnions 50 supported in trunnion bearings 51 carried on a base plate 52. The plate 52 is supported upon a plate member 59 which is pivotally supported at one end, as at 53, with the plate 52 also mounted for horizontal movements on the plate member 59. The horizontal movements of the plate 52 and tun dish 11 relative to the member 59 are obtained by an angular movement about a vertically arranged pin 54 affixed to the member 59 and a transverse movement shifting the plate 52 relative to the pin 54. These movements are obtained through the screw-cranks 55 and 56 respectively. In addition, the tun dish is arranged for tilting motion about the trunnions 50 with the tilted position of the tun dish adjusted by the screw crank 57 and arm 58 shown in Figs. 1, 2, and 3. The adjustments in the positioning of the tun dish are intended to permit the directing of the flow of the molten metal stream so that it will enter the mold at a preferred location.

The mold assembly 12 is described in considerable detail in the Harter et al. application, Serial No. 10,956 and is shown in Figs. 2 and 3. As disclosed and claimed therein, a stationary mold wall or molding tube 60 is formed from brass, copper, or other suitable material selected with a thermal conductivity and wall thickness sufficient to attain a satisfactory heat flow there-through. The molding tube is open at both ends and is vertically elongated to provide a confining wall surface for the formation of an embryo casting therein. The molding tube 60 may be of one piece or segmental construction, and is exteriorly cooled by a high velocity confined stream of cooling water. To attain a satisfactory commercial metal casting rate, the cooling water velocity must be such as to insure highly turbulent flow along the exterior surface of the molding tube. As disclosed and claimed in the I. Harter, Jr. et al. application Serial No. 44,654, now abandoned, the tube 60 and its surrounding cooling water passageway 61 are advantageously formed with an "oval" cross-section shape, where "oval" is defined as a figure by-symmetrically formed about perpendicularly intersecting major and minor axes. A typical mold cross-section and its relationship to the tun dish 11 is shown in Fig. 2.

The upper open end of the molding tube 60 is supported in a top plate 90, whereby the tube is free to expand axially therefrom. The plate 90 forms the top wall of an annular chamber

91, which is supplied with a flow of cooling water through a plurality of inlet pipes 92. A metallic skirt 93 of corresponding cross-sectional shape surrounds the molding tube 60 to define the cooling water flow passageway 61 and to confine the high velocity stream of cooling water against the surface of the tube substantially throughout its length. The upper end portion of the skirt 93 fits into a corresponding recess in a surrounding sleeve 94 extending into the chamber 91, and defining a discharge weir from the chamber 91. The weir section of the sleeve 94 is shaped to form an anti-cavitation entrance nozzle to the passageway 61 and to substantially uniformly accelerate and distribute the flow of cooling water in its contact with the exterior surface of the molding tube.

As indicated in Fig. 3, the tun dish and oval mold are relatively arranged so that the stream of molten metal will enter the open upper end of the molding tube in a trajectory in a vertical plane containing the major axis of the oval mold internal cross-section and impinge upon the molten metal therein at or slightly beyond the intersection of the mold minor axis. The resulting surface eddy currents cause any slag or ferric oxides which may be floating on the surface of the molten metal to collect in the quiescent area behind the point of impingement of the delivered stream and adjacent to the end of the mold nearer the tun dish.

In starting a casting operation, the usual sectional dummy is inserted in the mold with its upper end positioned at the expected minimum liquid level of molten metal therein and with its lower end engaged by the casting withdrawal mechanism, which, as shown in Fig. 1, consists of vertically spaced pairs of pinch rolls 71 driven through suitable gearing by a variable speed electric motor 70. The initially poured metal freezes around a projection on the dummy end to form the connection for effecting the casting movement.

The main feature of the present invention is the controlled cyclic multi-change operation of the casting withdrawal mechanism whereby the molten metal and embryo casting are subjected to periods of high rates of heat absorption while stationary or substantially stationary in the mold and periods of lower rates of heat absorption while moving downwardly in the mold, i. e. the withdrawal mechanism is operated in cycles with each cycle comprising a "dwell" period and a "run" period. As compared to the heat absorption rate in such a mold with a continuous supply of molten metal and uniform rate of withdrawal of the casting, the present operation of the withdrawal mechanism to include a dwell period in which the casting is stationary or substantially stationary relative to the confining wall of the mold produces a substantially higher rate of heat absorption due to the extremely close contact maintained between the molten or partly frozen metal and mold wall, particularly in the initial freezing zone, and secondly, due to the heat storage property of the molding tube in conjunction with a varying molten metal level in the mold. This varying molten metal level is attained by the continuous substantially uniform delivery of molten metal to the stationary mold throughout each cycle. The level drops during the run period of the casting and rises during the dwell period between predetermined limits, whereby a longitudinal section of the molding tube is alternately exposed to the mold atmos-

sphere and covered by molten metal. With the tube formed of a high thermal conductivity metal, the continuous cooling action of the contacting cooling water results in the rapid lowering of the wall temperature in this section to a value approaching the cooling water temperature. The subsequent contact of molten metal with this relatively cold molding tube wall section produces a "shock" cooling effect on the contacting metal depending upon the heat storage capacity of the tube.

In accordance with the present invention, this shock cooling effect is made substantial by forming the molding tube 60 of metal having a relatively high thermal conductivity and of a wall thickness sufficient to provide a substantial chilling effect on the molten or partly solidified metal in addition to the normal heat absorption by the mold cooling water. The maximum molding tube wall thickness is limited only by the necessity of keeping the maximum metal temperature of the tube within safe temperature limits during operation. For example, a molding tube of copper of approximately one-half inch thickness would be satisfactory for casting steel in accordance with the present process.

In carrying out this cyclic operation, the casting withdrawal mechanism can be regulated in response to measurements of time, indication of changes in the molten metal level within the mold, or by a combination of time measurement and level indication. With a selected casting average withdrawal rate and a substantially uniform rate of pour, the extent of molten metal level change is determined by the duration of the run and dwell periods.

The position of the molten metal level within a casting mold can be determined by the use of any suitable mechanical or electrical level indicating means, such as, for example, the radiation type of molten metal level indicator disclosed in a copending application of T. W. Ratcliffe et al., Serial No. 107,506, filed July 29, 1949, now U. S. Patent 2,586,713. Such an indicator utilizes the difference in radiation penetration through a casting mold with and without the intervention of the molten metal level within the mold. As disclosed and claimed in said copending application of T. W. Ratcliffe et al., the radiation type of molten metal level control is used in combination with a pattern control of a tilting ladle to maintain a constant molten metal level in a casting mold by regulation of a continuous withdrawal rate. Thus, the level control is utilized as a vernier regulation to compensate for any non-uniformity of molten metal pour rate to the mold. Such non-uniformity in pour rate can occur by reason of changes in the internal dimensions of the pouring vessel due to erosion or build up of its lining in contact with molten steel.

As shown schematically in Figs. 1, 2 and 3, a penetrating radiation molten metal level indicator, constructed in accordance with said T. W. Ratcliffe et al. copending application, is arranged in the present cyclic type of casting withdrawal control circuit to control the upper limit of the molten metal level variation, and effect the start of the run period of the cycle. A source of penetrating radiation, such as an X-ray tube, is provided within a shielded container 62, with a stream of penetrating rays therefrom directed through a shielded conduit 63 across the rear portion of the mold at the selected level for maximum molten metal level in the molding tube. At

the opposite side of the mold an ionization chamber 64 receives any penetrating radiation passing through the mold. An electrical means measures the conductivity of the ionization chamber 64, so that a predetermined change in the conductivity thereof will indicate the presence of molten metal at the level of the stream of penetrating rays passing through the mold. As shown in Fig. 2, the transverse dimension of the stream of penetrating rays passing through the mold is limited so that a relatively small change in the molten metal level will cause a measurably large variation in the conductivity of the ionization chamber 64. Changes in the conductivity of the ionization chamber are transmitted electrically through the leads 65 to an amplifying circuit (not shown) and thence to a relay PR in a control box 66. The relay is connected into an electrical control circuit regulating the controller 68 of the pinch roll drive motor 70. The motor 70 is of the variable speed type, with its speed of rotation regulated by any of the customary electric control systems.

In the apparatus shown in Fig. 1, the penetrating radiation level control is utilized to limit the maximum rise of molten metal level in the mold by initiating the operation of the pinch roll motor to withdraw the casting from the mold at a rate in excess of the molten metal input rate. The fall in molten metal level continues during a predetermined period of time as regulated by an adjustable timer 72. At the end of a selected time period the pinch roll motor is stopped, or its speed reduced to permit the molten metal level to rise in the mold. When the molten metal level within the mold again occludes the penetration radiation stream of the level control, the described withdrawal cycle is repeated.

The control circuit for regulating the described cycle of pinch roll motor operation is illustrated in Fig. 4, where control circuit power is obtained through the lines L. The customary manual switch S is provided in the power line L so that the control system may be disconnected when not in use. The contacts XH are closed by the penetrating radiation relay when the molten metal reaches its highest level position in the casting mold. This energizes the relay 1 closing the contacts 1a and 1b starting the timer clock cc and energizing the relay 2. With the contact 1a closed the pinch roll motor relay PR is energized, starting the pinch roll motor through the controller 68. In energizing relay PR, the contacts PR2 and PR3 are closed. The contacts PR2 and PR3 are arranged in parallel relationship with contacts 1a and 1b respectively so that as the molten metal level falls in the mold with a resultant opening of the contacts XH the pinch roll motor relay will remain energized and the casting withdrawal will continue. When the desired time has elapsed, as regulated by adjustment of the timer element TC, contacts TMC open to deenergize relay 2 and close contact 2a. With the contact 2a closed, the pinch roll motor relay PR will stop the motor 70 and open the contacts PR2 and PR3. The resistance R1 in the feed line to relay PR will limit the load through the shunt line, including the contact 2a, until the contacts PR2 open.

The described "off and on" operation of the withdrawal mechanism is preferably carried out with a dwell period of greater duration than the run period for maximum production capacity. With the described high rate of heat absorption in effect during the dwell period of the cycle, the

initial freezing of the molten metal to form the embryo casting, particularly when casting ferrous alloys, causes the metal to contract and move out of contact with the confining wall of the mold. With the formation of this air gap barrier, there would no longer be any advantage in continuing the dwell period, and as the molten metal level will then have reached approximately the desired level, the controls are set to start the pinch rolls for the run period.

In one illustrative example of the described "off and on" operation of the casting withdrawal mechanism, molten steel of a common mild carbon analysis was delivered to the upper end of an "oval" mold having interior major and minor axis dimensions of $9\frac{1}{4}$ and $4\frac{1}{4}$ inches respectively. The molten metal pour rate was equivalent to an average casting production rate of approximately 39 inches per minute of cast product, of approximately this cross-section. During the cyclic intermittent withdrawal of the casting as described, the "off" or "dwell" period averaged 8.2 seconds and the "on" or "run" period averaged 11.0 seconds, with a molten metal level change of 5.2 inches during each operating cycle of the casting withdrawal mechanism.

The described "off and on" operation of the pinch rolls may be modified in certain instances to use a slow speed operation of the pinch rolls instead of bringing the rolls to a complete stop, during the "off" or "dwell" period of the cycle. For such modified operation, the timer control 72 would be set to maintain a predetermined high speed of withdrawal above the rate of delivery of molten metal for a definite period and then to actuate the motor speed control device to operate the pinch rolls at a speed producing a casting movement substantially below the rate of delivery of molten metal. With the resultant rise in metal level, the level control mechanism will subsequently operate to restore the speed control to its high speed operation and repeat the cycle.

The pinch roll and drive gear mechanism are of such construction that when the drive motor is stopped or its speed suddenly reduced at the end of each "on" or "run" period, the withdrawal speed of the casting will be rapidly decelerated, causing the core of molten metal in the upper end of the casting to exert the described "hammer" effect on the surrounding embryo shell. The rapid deceleration can be increased by any suitable means, such as for example by the operation of a brake 74 mounted on the shaft connecting the drive motor 70 and the pinch rolls 71. The brake can be of any suitable mechanical or electrical type actuated in coordination with the stoppage or change in speed of the motor 70.

Alternately, as shown in Fig. 5, the casting withdrawal cycle may be regulated by a pair of level controls of the penetrating radiation type described. In such an arrangement the level controls are spaced longitudinally of the mold and electrically connected to the control box 66 to cause the pinch rolls 71 to start to operate at a high speed when the molten metal level reaches the position of the upper level control. This high speed casting withdrawal continues until the molten metal level falls to the position of the lower level control. At this position the pinch rolls are stopped or caused to withdraw the casting at a low rate, causing a rising molten metal level in the mold. As shown in the wiring diagram of Fig. 5 the contact XH is closed when the molten metal level rises to its upper position in the mold and occludes the radiation of the level control. Closing contact XH energizes the relay

PR to start the pinch roll motor 70, and to close the contact PR2. As the molten metal level drops the contacts XH will open, but the pinch rolls will continue to operate until the molten metal level falls to the level of the lower level controller. At this lower level, the change in penetration radiation measured in the ionization chamber will close the contacts XL, deenergizing the relay PR to stop the pinch roll motor.

When the molten metal pour rate can be maintained uniform, it is possible to regulate the cyclic withdrawal of the casting by means of timers alone. Under such circumstances the high speed casting withdrawal period can be regulated by a timer, while the stopped or low speed withdrawal period can be regulated by a second timer, such timers being of the type of the timer 72 indicated in Fig. 1, and arranged in the control circuit of the motor 70. The control circuit of pinch roll control of this type is shown in Fig. 6, wherein the circuit is energized, by closing the manual switch S at the beginning of the "dwell" period, i. e. the period of rising molten metal level. This energizes the dwell timer 72' and the relay 2, to open the contact 2a and 2b. The pinch roll relay PR is not energized during this timed period and the pinch roll motor will not run. At the end of the timed dwell period determined by adjustment of TC' the contacts TMC' open to deenergize relay 2 and close contacts 2a and 2b. Closing the contact 2b starts the pinch roll motor while 2a starts the run timer 72, and energizes relay 1. With the relay 1 energized contact 1a is opened to reset the dwell timer circuit 72', so that the cycle may be repeated when the "run" timed period has elapsed as determined by the adjustment of TC, and the contacts TMC have opened to deenergize relay 1.

With a uniform molten metal pour rate, the casting withdrawal mechanism can also be regulated by the use of a molten metal level indicator of the penetrating radiation type positioned at the lower end of the desired molten metal level range within the mold, in conjunction with a timer for regulating the time during which the withdrawal mechanism is stopped or operated at a low speed, thus permitting the molten metal level to rise within the mold, and then starting the high speed operation of the pinch rolls which is subsequently terminated by the level control. The control circuit for this mode of operation is shown in Fig. 7. This circuit is substantially the same as that shown in Fig. 4, except actuation of the penetrating radiation control at the lower limit of molten metal level in the mold stops the operation of the pinch roll motor. This permits the molten metal level to rise during a timed period as determined by the adjustment of the timer element TC'. At the end of the timed "dwell" period the deenergization of relay 2 closes the contact 2a to cause a fall in molten metal level through operation of the relay PR, and the pinch roll motor.

As a safety measure when the duration of the run or dwell periods is governed by a timer of the character described, it is usually desirable to supplement the timer control by a molten metal level control, such as of the penetrating radiation type described, to avoid any change in the molten metal level beyond a predetermined limit established by the level indicating device. The use of the level controller as a safety limit switch is illustrated in Figs. 4, 6 and 7.

In Fig. 4 the contacts XL and LLS are opened when the lower molten metal level is reached, stopping the pinch rolls until the molten metal rises beyond the control level when the contacts are again closed and the normal cycle is continued. In Fig. 6 both a high and low level safety controller are used, with the high level controller closing the contact XH and opening contact HLS to operate the pinch rolls to lower the molten metal level within the mold. The low level controller opens the contacts XL and LLS to stop the pinch roll motor to raise the molten metal level in the mold. In Fig. 7, the upper level controller is shown as a safety control, where a rising molten metal level reaching the level of the controller causes contacts XH and HLS to close, operating the pinch rolls to lower the molten metal level within the mold.

As the embryo casting leaves the mold in its cyclic downward movement, the casting passes through a core solidification zone in which it is subjected to a supplementary cooling effect to reduce the casting temperature at least to a value at which the casting will be completely solidified. Various cooling means can be employed for this purpose, but I prefer to use cooling water sprays in direct contact with the casting. As shown in Fig. 2, spray nozzles 15 are peripherally spaced on the inner side of a horizontally arranged manifold 76 encircling the casting. The lower end of the molding tube 60 carries a frusto-conical member 77 enclosing the manifold 76 and arranged to deflect the cooling water flowing downwardly through the passage 61 away from the casting. Beneath and within the periphery of the member 77, a vertically elongated tubular shield 78 encloses the casting so as to further protect the casting from the excessive cooling effects of the mold cooling water. A gap 81 is provided between the upper end of the shield 78 and the member 77 for the escape of steam resulting from the evaporation of the water sprays contacting the casting. Ordinarily the amount of water sprayed against the casting will be only a small fraction of the amount of cooling water passed through the mold passageway 61, and is completely evaporated on contact. However, the amount of spray cooling water used may be substantially increased, depending upon the composition of the metal being cast and the effect of such rapid cooling on its metallurgical quality.

To insure peripherally uniform cooling of the casting in the mold and the spray cooling zone, it is desirable to provide a guide or guides above the pinch rolls 71 to maintain the vertical alignment of the casting. A pair of stationary guides 82, shown in Fig. 1, are mounted within the shield 78. These guides may be water cooled and restrain any tendency for transverse movement of the hot casting which might cause the emerging casting to bear upon one side of the lower end portion of the molding tube 60.

In operation, molten metal is delivered to the upper end of the mold 12 at a substantially uniform temperature and rate, and with the embryo casting withdrawn from the lower end of the mold in a controlled cycle of downward movement. With the described cyclic withdrawal of the casting, the increased amount of heat extracted from the hot metal within the mold is illustrated in Fig. 8. The solid line indicates the progressive freezing of steel in the mold under continuous withdrawal conditions while the dotted line indicates the progressive freez-

ing of steel in the same mold with a cyclic "off and on" operation of the casting withdrawal mechanism according to the present invention. The values indicated in Fig. 8 were obtained by molten metal run-out procedure, where an oxygen lance was used to burn a hole through the side wall of the casting at a position immediately below the lower end of the molding tube 60 to permit the molten metal core to run out, and simultaneously stopping the molten metal delivery to the upper end of the mold. When all of the casting variables are comparable, i. e. metal analysis, temperature of delivery, rate of delivery, and cooling fluid flow to the mold are substantially equal, the weights of solidified metal in the run-out section of the casting would be equal, unless the casting withdrawal method is changed. The increased metal freezing rate within the mold attained by the cyclic casting withdrawal system of the present invention is apparent by a comparison of the curves shown in Fig. 8.

While in accordance with the provisions of the statutes I have illustrated and described herein the best forms of the invention now known to me, those skilled in the art will understand that changes may be made in the form of the apparatus and method of manufacture disclosed without departing from the spirit of the invention covered by my claims, and that certain features of my invention may sometimes be used to advantage without a corresponding use of other features.

What I claim:

1. The process of continuously casting molten ferrous metal in an open-ended vertically elongated stationary mold liner made of high thermal conductivity metal and having a laterally confined space around said mold liner for the flow of a liquid coolant therethrough and a casting withdrawal mechanism spaced below said mold liner which comprises continuously supplying a stream of molten metal to said mold liner from a discharge point above the normal maximum molten metal level therein, maintaining a non-oxidizing atmosphere within said mold liner above the molten metal level therein, circulating a liquid coolant at a high velocity through said space in heat absorbing contact with said mold liner to form an embryo casting within said mold liner, discharging a cooling liquid against the casting on issuing from said mold liner, guiding and restraining said casting between said mold liner and said withdrawal mechanism, and cyclically varying the molten metal level in said mold liner by starting said withdrawal mechanism when the molten metal level rises to a predetermined position within said mold liner, and stopping said withdrawal mechanism after a predetermined downward movement of said casting.

2. Apparatus for continuously casting molten ferrous metal comprising means forming an open-ended vertically elongated stationary mold liner of high thermal conductivity metal, means forming a laterally confined space around said mold liner for the high velocity flow of a liquid coolant therethrough, means for circulating a liquid coolant through said space in heat absorbing contact with said mold liner, means for supplying a stream of molten metal to said mold liner from a discharge point above the normal maximum molten metal level therein, means for maintaining a non-oxidizing atmosphere within said mold liner above the molten metal level

therein, a casting withdrawal mechanism spaced below and in vertical alignment with said mold liner and arranged to engage the casting discharged from said mold liner, spray means between the lower end of said mold liner and said withdrawal mechanism and arranged to discharge a cooling liquid against the casting on issuing from said mold liner, casting guide means positioned between the lower end of said mold liner and said withdrawal mechanism, and means for cyclically varying the molten metal level in said mold liner including means for starting said withdrawal mechanism when the molten metal level rises to a predetermined position within said mold liner, and means operable to stop said withdrawal mechanism after a predetermined downward movement of said casting.

3. Apparatus for continuously casting molten ferrous metal according to claim 2, wherein the means for starting the withdrawal mechanism comprises molten metal level responsive means positioned externally of the mold liner and connected to said withdrawal mechanism for starting said withdrawal mechanism in response to the presence of molten metal at an upper position within said mold liner.

4. Apparatus for continuously casting molten ferrous metal according to claim 2, wherein said means operable to stop the withdrawal mechanism comprises a timer arranged to start with the operation of said withdrawal mechanism and operatively connected to stop said withdrawal mechanism at the end of a predetermined timed period.

5. Apparatus for continuously casting molten ferrous metal according to claim 2, wherein the means for starting the withdrawal mechanism comprises a timer arranged to start when the withdrawal mechanism stops and operatively connected to start said withdrawal mechanism at the end of a predetermined timed period, and said means operable to stop the withdrawal mechanism comprises a timer arranged to start with the operation of said withdrawal mechanism and operatively connected to stop said withdrawal mechanism at the end of a predetermined timed period.

6. In continuous casting apparatus for high melting temperature metals, the combination including an upright elongated molding tube open at both ends, means for cooling the exterior of said molding tube by heat exchange with a cooling fluid, means for delivering molten metal to the upper end of said molding tube at a substantially uniform rate, a withdrawal mechanism spaced below and in alignment with said molding tube arranged to engage the casting formed within said tube, a drive for said withdrawal mechanism, means for cyclically varying the molten metal level in said molding tube comprising molten metal level responsive means externally of the molten metal space and connected to said withdrawal mechanism for starting said withdrawal mechanism in response to the presence of molten metal in an upper position within said molding tube, a timer arranged to start with the operation of said withdrawal mechanism and operatively connected to stop said withdrawal mechanism at the end of a predetermined timed period, and said molten metal level responsive means including means for continuing the operation of said withdrawal mechanism beyond the end of said timed period if the molten metal level in the molding tube is then not below a predetermined upper level position.

7. A continuous casting apparatus for high melting temperature metals, the combination including an upright elongated molding tube open at both ends, means for cooling the exterior of said molding tube by heat exchange with a cooling fluid, means for delivering molten metal to the upper end of said molding tube at a substantially uniform rate, a withdrawal mechanism spaced below and in alignment with said molding tube arranged to engage the casting formed within said tube, a drive for said withdrawal mechanism, means for cyclically varying the molten metal level in said molding tube comprising molten metal level responsive means externally of the molten metal space and connected to said withdrawal mechanism for starting said withdrawal mechanism in response to the presence of molten metal at an upper position within said molding tube, a timer arranged to start with the operation of said withdrawal mechanism and operatively connected to stop said withdrawal mechanism at the end of a predetermined timed period, and separate molten metal level responsive means positioned above said first means and operatively arranged to continue the operation of said withdrawal mechanism beyond the end of said timed period if the molten metal level in the molding tube is then not below the upper level position of said separate molten metal level responsive means.

8. Apparatus for casting metals comprising a thick-walled upright molding tube formed of a metal having a high thermal conductivity and open at both ends, means for cooling the exterior surface of said tube, a pouring vessel arranged to deliver molten metal at a substantially uniform rate into the upper end of said tube for the formation of an embryo casting therein, a set of pinch rolls arranged to withdraw the embryo casting from the lower end of said tube, a motor arranged to drive said pinch rolls, means for cyclically changing the molten metal level within said mold comprising means positioned externally of the molten metal space of said molding tube and operatively connected with said motor to cause operation of said rolls at a casting withdrawal rate in excess of said pouring rate when the molten metal rises to an upper level within said mold, and separate means positioned externally of the molten metal space of said molding tube and below said first means and operatively connected with said motor to stop said motor when the molten metal level within said molding tube falls to a lower position corresponding to the level of said separate means.

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