Sept. 1, 1964 J. C. BONGIOVANNI 3,146,525

PRODUCTION OF STRIP OR SHEET STOCK FROM MOLTEN METALS

Filed Aug. 13, 1959 8 Sheets-Sheet 1

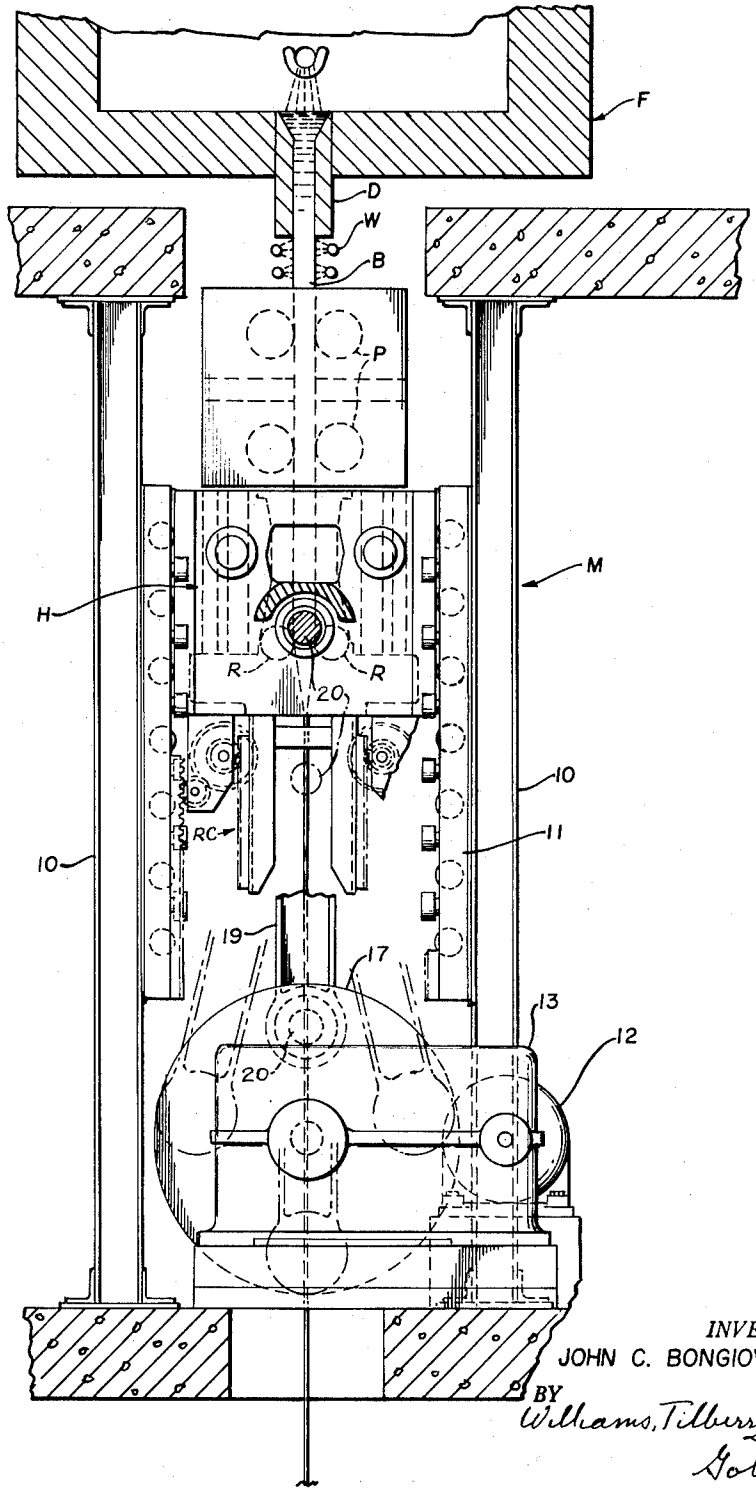


Fig. 1

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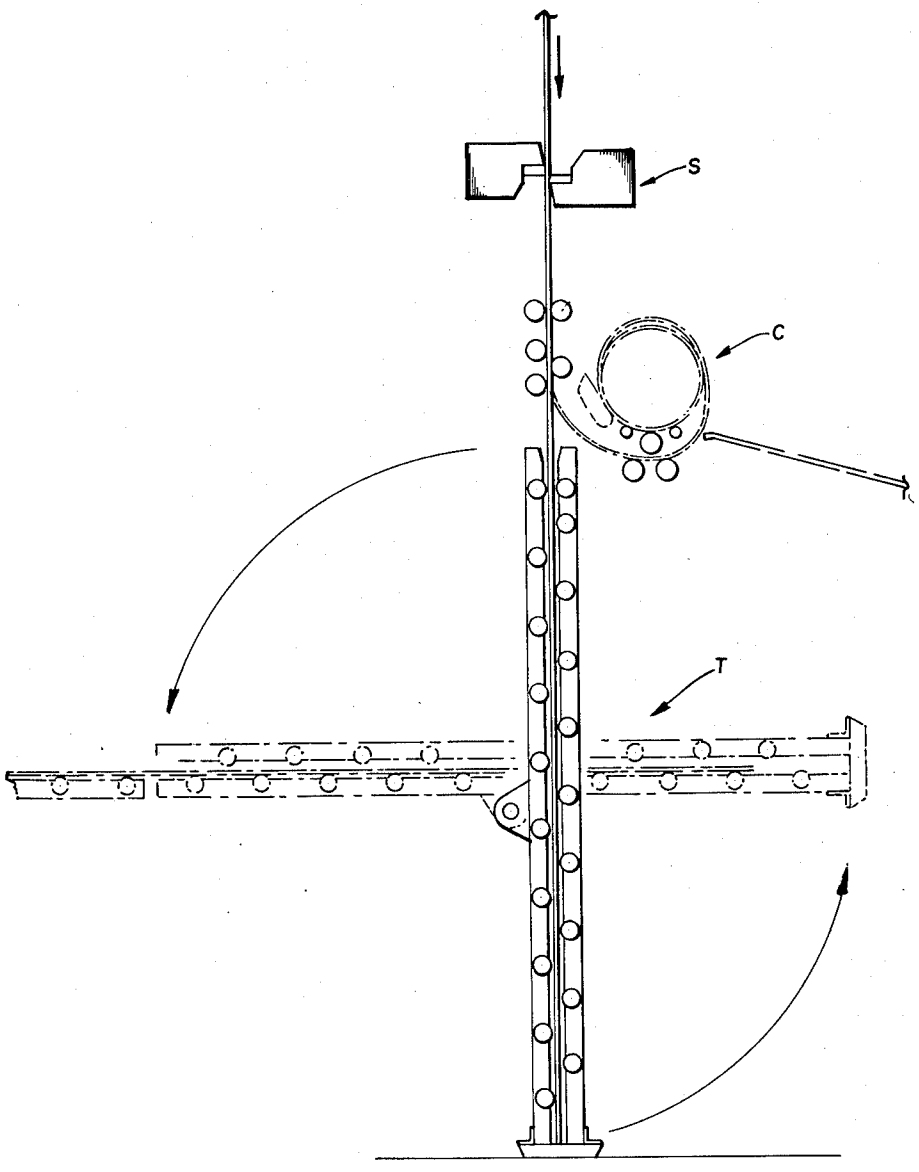


Fig. 1a

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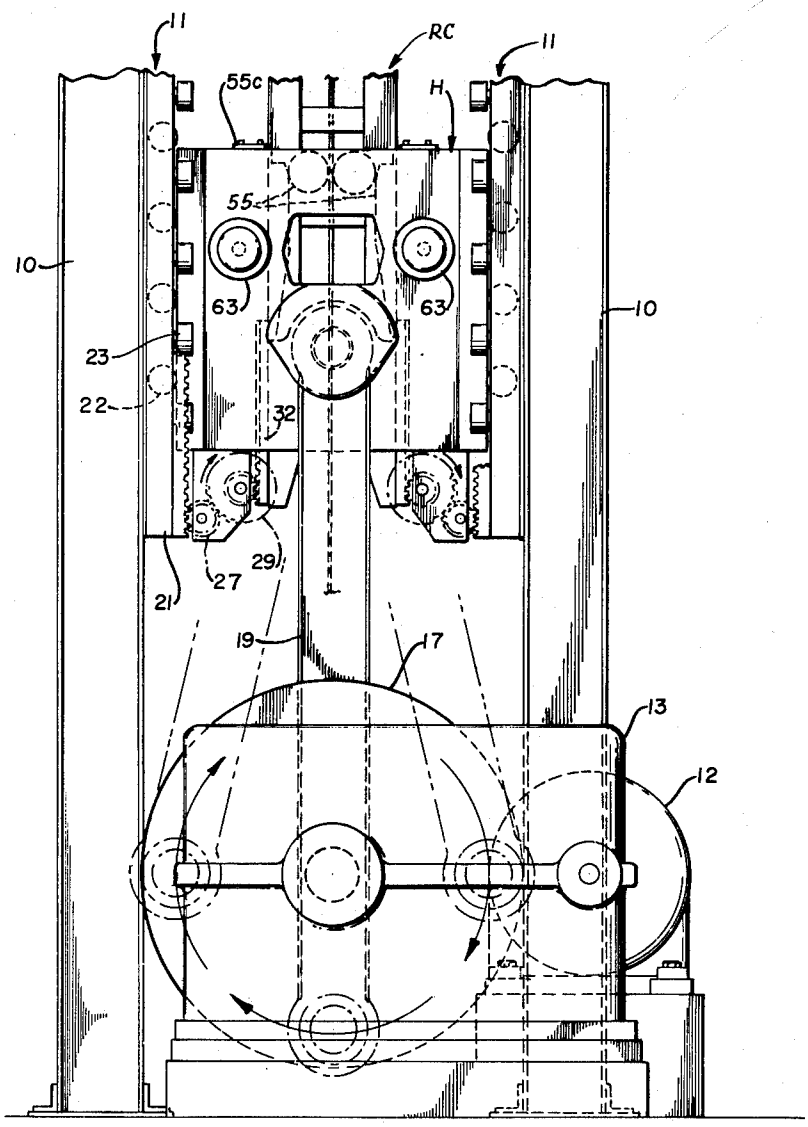


Fig. 2

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PRODUCTION OF STRIP OR SHEET STOCK FROM MOLTEN METALS

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Fig. 3

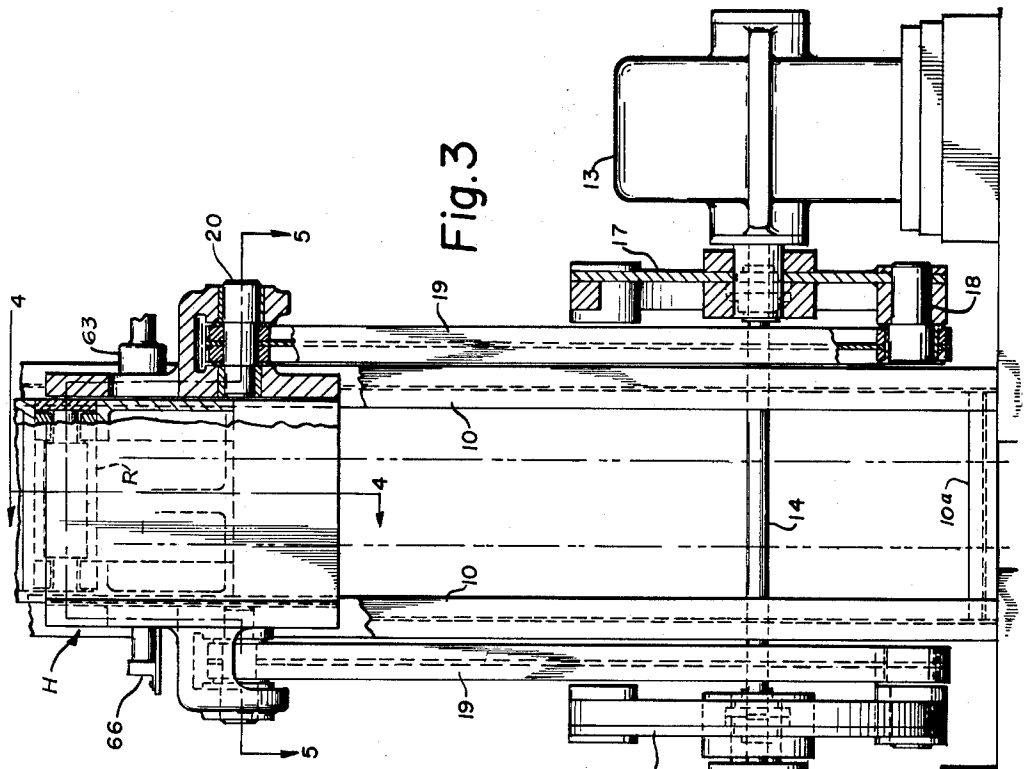
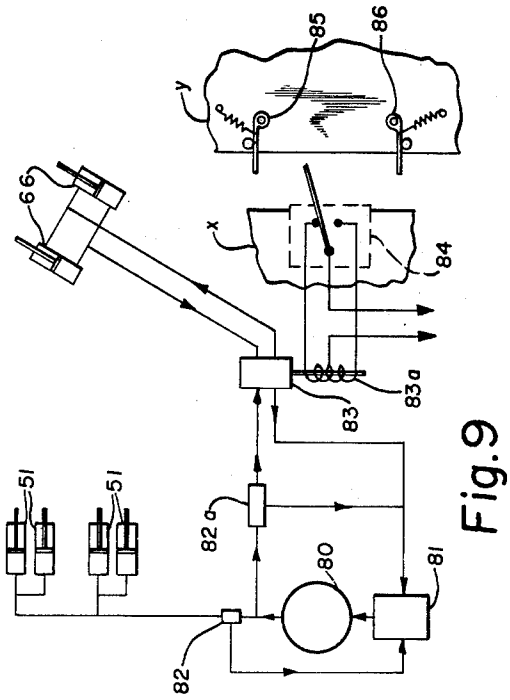


Fig. 9



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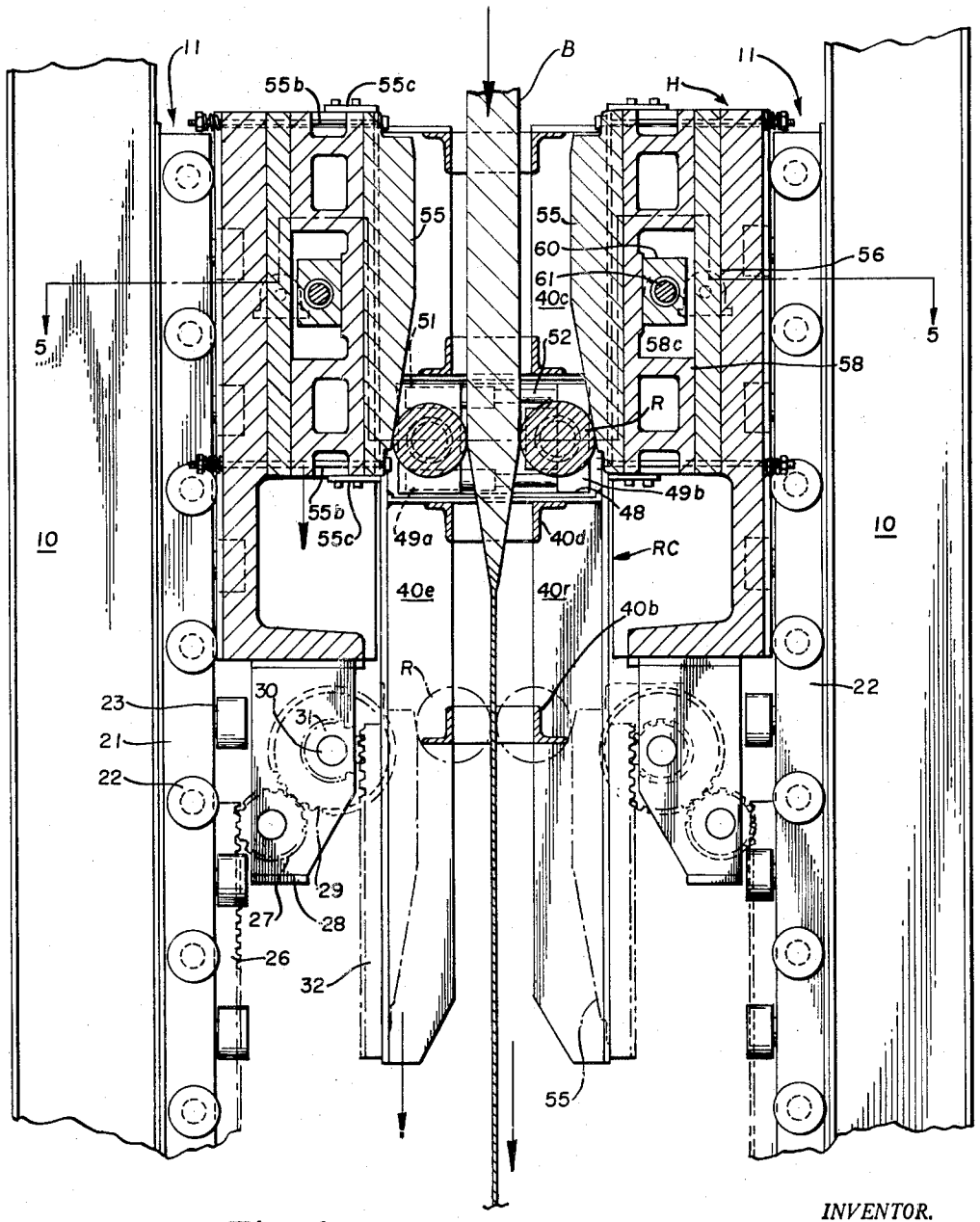


Fig.4

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PRODUCTION OF STRIP OR SHEET STOCK FROM MOLTEN METALS

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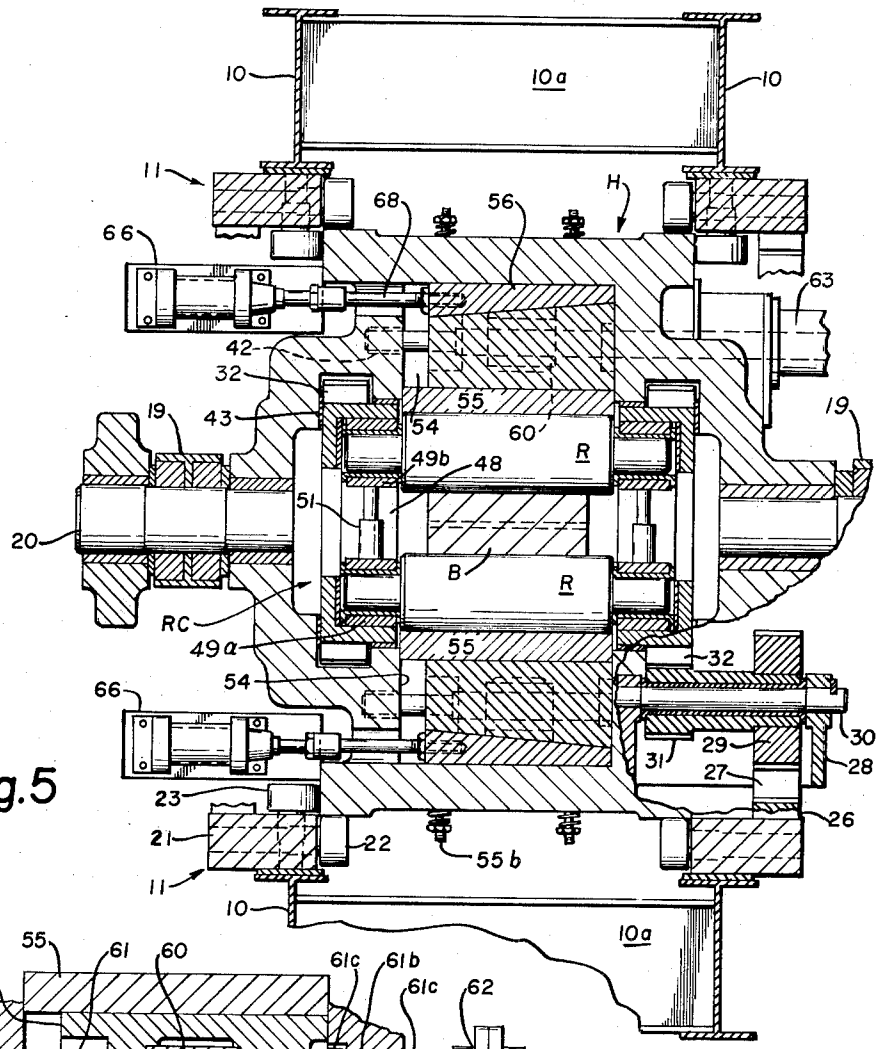


Fig.5

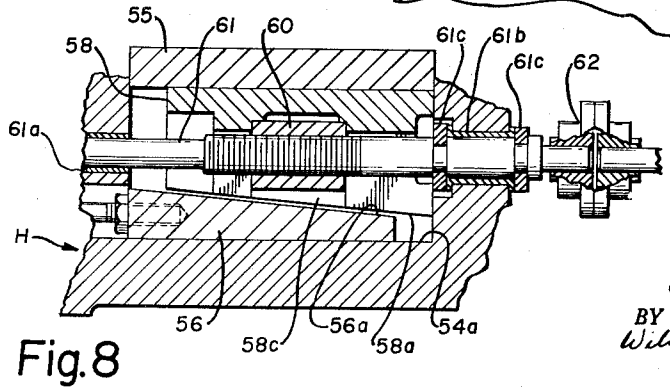


Fig.8

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PRODUCTION OF STRIP OR SHEET STOCK FROM MOLTEN METALS

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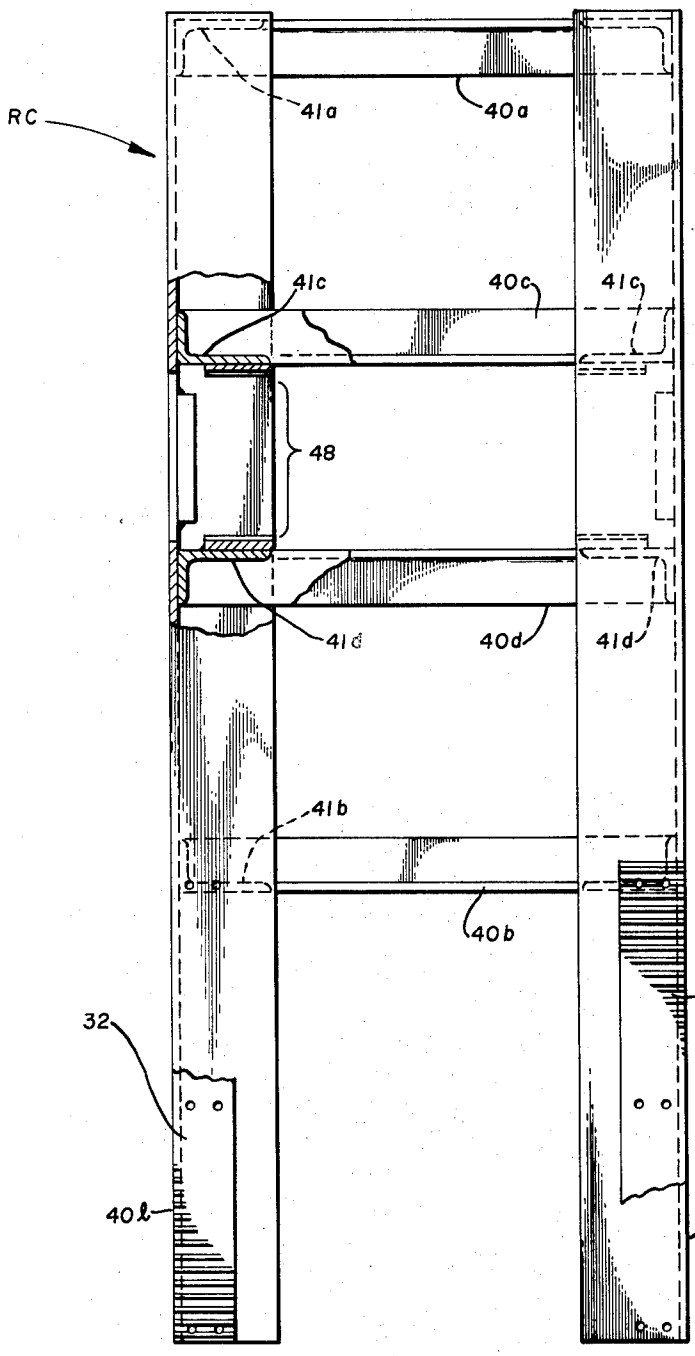


Fig.6

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PRODUCTION OF STRIP OR SHEET STOCK FROM MOLTEN METALS

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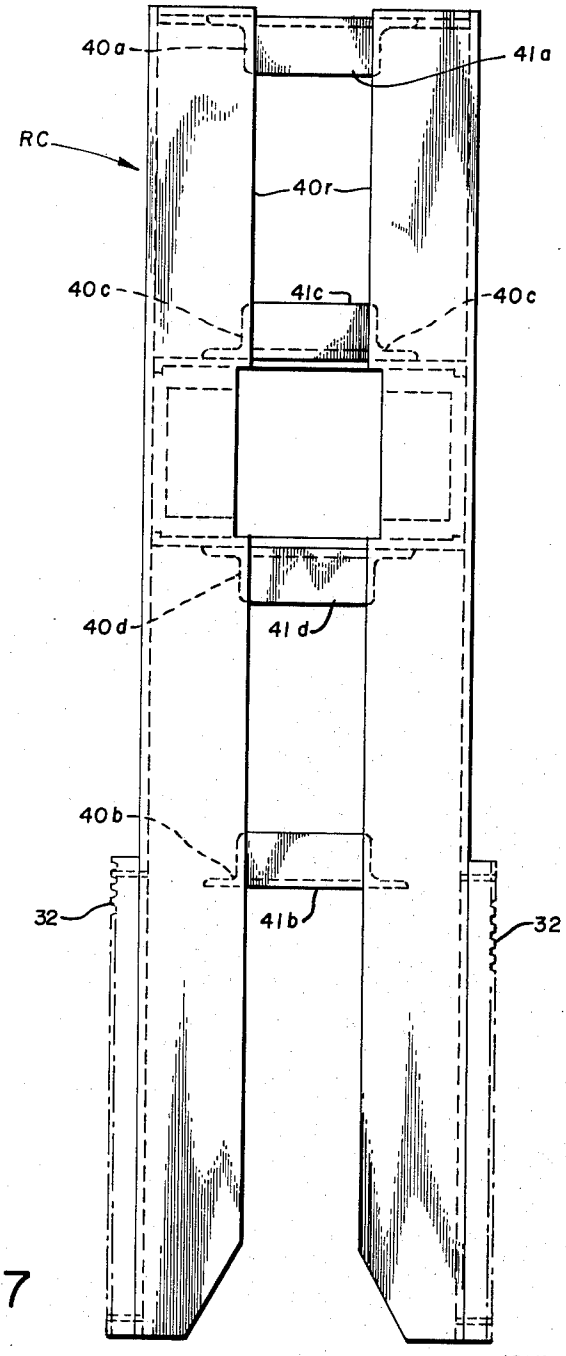


Fig. 7

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United States Patent Office 3,146,525 Patented Sept. 1, 1964

3,146,525

PRODUCTION OF STRIP OR SHEET STOCK FROM MOLTEN METALS

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Filed Aug. 13, 1959, Ser. No. 833,538
5 Claims. (Cl. 29—528)

The present invention is concerned with the direct production of sheet or strip stock from metals in a molten condition. Specifically the present invention is concerned with method and apparatus whereby a molten metal may be reduced directly to a sheet or strip form.

In broad terms, the present invention, insofar as method is concerned, is directed to the formation of a molten body of metal of desired composition, continuously casting the same into an endless slab or billet form, and rolling or reducing the slab while yet in a hot state into a continuous strip of desired gauge, the strip being then either cut into desired lengths of sheet or plate, or alternatively coiled and severed at desired coiled lengths.

With respect to the mill with which the invention is concerned, there is involved the combination of a direct casting apparatus—of which several types are types known to the art—for producing from continuously supplied molten metal a vertically descending slab in continuous form of approximately the desired final width of the strip or sheet stock; the molten metal being solidified in passing through the mold characteristic of such apparatus and partially cooled by water sprays or jets immediately beneath the mold, two sets of pinch rolls spaced below the nozzle serving not only for control of the casting speed for maintenance of the slab as a moving plug in the casting mold, but also partially reducing the slab and providing a reaction or anchor means for tension to which the slab is subjected in the heavy reduction; and a vertically reciprocating roller type mill for the heavy major reduction of the metal.

In the combination a vertically reciprocating pair of rolls on each downward stroke engage the slab and are cammed toward each other to produce a complete reduction to desired thickness of the hot cast slab feed; while on an upward stroke the rolls, first separated into a non-working relation for slab clearance, are returned into working spacing for re-engagement with the slab at about the top of the stroke. The main rolling portion of the apparatus—located directly below the casting mold so that the plane or centerline of movement of the metal from the mold, through pinch rolls and through the operating path of the mill rolls, is in a substantially vertical plane—is in effect a vertically disposed hot rolling mill; and the mechanism thereof generally of the type disclosed in the Krause Patent 2,161,064 or 2,161,065.

With this overall arrangement the energy required for the metal reduction is not absorbed from a power source only during the downward working stroke, for there is a considerable potential energy available for metal reduction in any practical mill at the beginning of any downward working stroke due to the elevation of the mass of the reciprocating rolls and their mounting or carriage structure; and, therefore, such potential energy is absorbed by or fed into the reciprocating system also on the non-working upward stroke of the rolls. Hence, the power requirements in the motor or prime mover for the rolling mill, and also the structural strength needed in elements of the power transmission system for the rolls, are lower for example than in prior horizontal Krause type mills.

In addition to the above-described features, there are here disclosed as located beneath the rolling mill a very economic means for cutting off and handling the finished strip, either in coil form or in flat sheets. For this purpose there is located immediately beneath the mill a power-operated shears for cutting the continuous product strip at appropriate points. Below the shears there are located, as alternative means of handling the finished strip, first a coiling apparatus for turning the strip length into say loose coil form; and therebeneath an "up-ender" device, a tilting sheet receiving and discharging mechanism. From the coiler there is provided a suitable coil ramp or other conveying means advantageously gravitational, whereby the final coils are directed to a point of loading or further handling. On the other hand, where the product is to be in sheet or plate form, the up-ender or tilting receiver accepting each length of material cut from the continuous strip in its vertically descending path is thereafter turned toward a disposition somewhat beyond horizontal to discharge the severed sheet onto a conveying system—again advantageously gravitational—for carrying the same to a final point of loading or other disposition; as for example to a point where the same are stacked and bailed or palletized.

The general object of the present invention is then the provision of a method and apparatus for the production of continuous strip metal from molten metal. Another object is the provision of method and apparatus for direct casting of metal into a continuous slab, and reducing the slab to strip, sheet or plate form. A still further object is the provision of a method and apparatus for achieving a low cost conversion of merchant metal or molten metal to strip, sheet or plate form, particularly non-ferrous metals such as copper and aluminum and alloys thereof, but also ferrous metals.

Other objects and advantages of the invention will appear from the following description and the drawings wherein:

FIG. 1 and FIG. 1*a* present in side elevation the relations of the principal parts of a plant or mill for carrying out the method or process of the present invention; certain parts being omitted in FIG. 1, and others being represented in generalized or outline form in FIG. 1*a* for overall clarity;

FIG. 2 is a somewhat enlarged side view of the principal part of the rolling mill proper;

FIG. 3 is a front view corresponding to FIG. 2;

FIG. 4 is a vertical sectional view taken generally as indicated by the lines 4—4 in FIG. 3 through the reciprocating housing and roll carriage contained therein;

FIG. 5 is an irregular transverse sectional view taken, however, substantially as indicated by the line 5—5 in FIGS. 3 and 4;

FIGS. 6 and 7 are front and side views respectively of the roll carriage frame;

FIG. 8 is a fragmentary detail of a roll camming wedge block adjustment means; and

FIG. 9 is a schematic representation of hydraulic and electric control circuitry for the rolling apparatus.

An overall view of a vertical hot rolling mill for production of strip, plate or sheet stock from molten metal according to the present invention is prevented by FIGS. 1, 1*a*. At a top floor of the mill, there is a furnace F for melting or holding in molten state metal continually poured from the nozzle thereof to be cast through a die-like direct casting mold D into a slab or billet-like continuous piece B; and immediately below D there are disposed the controlled continuous water-spray jets or cooling apparatus W, for partially cooling the slab and solidifying the metal while yet in the mold D. Below W are arranged in tandem two pair of pinch rolls, such as a conventional Horsburg & Scott pinch roll drive, driven at a selected rate to control the rate of casting or production of the slab at D, the rolls being located immediately below and in alignment with D and W. In general, the furnace or other means continually pouring metal to

the mold producing a slab of desired thickness and width, the cooling apparatus and the pinch rolls may be similar to those well known now in the art for direct casting processes. By way of example, an aluminum slab B may have dimensions on the order of 4 by 12 inches in leaving the mold.

For continuous reduction of the slab B to a plate, sheet or strip form, there is further provided on the next lower floor the reduction or rolling mill M located vertically below the pinch rolls P, the mill M effecting the major reduction of the slab thickness. Insofar as the reduction rolling apparatus itself is concerned, and its manner of operation, it may be said to be generally similar to that of the Krause Patent 2,161,065.

For handling the strip metal produced in the mill M, there are arranged therebeneath (see FIG. 1*a*) on a lower floor a shear device S, such as a Halden type shear, and for manipulation of the sheared product a three-roll up-coiler apparatus C into which the strip-like product may be directed and there formed into a loose coil; here again the apparatus being similar to prior well-known forms. With the coiling apparatus, for transport or conveyance of a finished coil of desired length away from the mill, there is also associated a conveying device such as an inclined guide ramp for directing the coils for example to a loading dock. Below the coiler, as an alternately available means of handling the product, there is disclosed a plate or sheet receiver mechanism or "up-ender" T, a roller lined elongated frame which, from a position vertically aligned with the path of the strip product to receive the same as it is cut off at appropriate lengths in sheet or plate form, by the shears, is tiltable to a position slightly beyond horizontal for gravity discharge of the received plate to a conveying system carrying the same to a bailing area or loading dock.

The mill M has a sturdy upright frame comprised of four rigidly parallel spaced and anchored vertical columns **10**, such as structural steel I-beams with transverse spacers **10***a*, wherein a heavy integrally cast hollow housing H is guided for vertical reciprocation by four guide roller assemblies **11** at each corner of the housing. A mill power and driving system comprises a prime mover **12**, such as a three-phase high voltage heavy duty motor; a pair of reduction gearing units **13**, **13** on opposite sides of the mill with input shafts coupled by a cross shaft **14**, and (at the left of FIG. 3) the motor being also connected to the input on one side of the unit **13** by a suitable coupling **15**. The output shafts of the reduction gearing units carry respective suitably counter-balanced fly wheels **17**, each having a crank pin **18** connected through a connecting rod **19** with the housing H through a wrist pin **20** journalled in bearings inserted in the housing. Suitable thrust washers are disposed between the inner faces of the wrist pin mounting formations of the housing and the adjacent faces of the connecting rod **19**.

The roller guide units **11** each comprise a spacer block or mounting bar **21** secured on a respective column **10** and having rotatably mounted on adjacent faces series of vertically equispaced rollers **22**, **23**. The rollers of one series are staggered relative to those of the other series and radially project beyond the face of the bar mounting the other series, so that each corner of the housing is embraced and guided by rollers **22**, **23**, bearing on respective vertical finished areas running from top to bottom of the housing.

The roll carriage RC is an elongated generally open frame (see FIGS. 6 and 7) here shown as formed by two pairs of joined corner angle irons **40***–l*, **40***–r* (left or right pair in FIGS. 5 and 6) connected by suitable cross struts or braces, such as **40***a*, **41***a* and **40***b*, **41***b* at the top and toward the bottom respectively, and **40***c*, **41***c* and **40***d*, **41***d* near the middle of the carriage, the front and back sides between respective members **40***–l* and **40***–r* being open and members **40***a–d* being set inwardly therefrom for clearance relative to the hereinafter described cam plates

55. The carriage also is guided and embraced at each corner on finished areas by bearing strip pairs **43** and **44** secured at corners in the hollow central space of the housing, there being also a vertical inward slot at each inside corner of the housing for accommodation of a corresponding vertical carriage rack **32**. As may be noted in FIGS. 4, 6 and 8 the racks **32** are carried on the lower end of the corner angles **40***–l* and **40***–r* which extend below the housing H even when the latter is in its uppermost position, at which time the carriage RC is in its lowermost position relative to the housing H, as in FIG. 4.

For effecting synchronized reciprocation of the roll carriage relative to the housing during reciprocation of the latter on the mill frame four rack and pinion mechanisms are provided. Each comprises a vertical fixed rack **26** mounted outboard of a roller support bar **21** and meshed with pinion **27** carried on a transverse shaft within a gearing housing or frame **28**, bolted or otherwise secured on a bottom surface of the main casting of the housing H. The pinion **27** is meshed in turn with a gear **29** carried on shaft **30** commonly with and rotatable with the pinion **31** meshing with a corresponding carriage rack **32**. The pitch diameter of **29** is twice that of **27** and **31**, whereby the movement of the roll carriage is half that of the housing H relative to the mill frame.

At opposite sides of the roll carriage RC, in the region between the respective middle vertically paired cross braces **41***c*, **41***c* and **40***d*, **40***d* there are formed corresponding parallel transverse slideways **48** for receiving in each a pair of opposed sliding bearing chock **49***a*, **49***b* for the roll neck bearings. Each chock is of a generally rectangular block form and has a large central aperture with a sleeve bearing journalling the roll neck of a corresponding roll R. The bearing chocks **49***a* for one working roll, at their upper and lower ends, each have blind bores or holes formed in parallel fashion to receive the ends of vertically spaced paired single acting hydraluic cylinder units **51**, with pistons **52** bearing against opposed shoulders on a corresponding one of the facing bearing blocks **49***b* supporting the other working roll. The cylinder units **51** hereinafter called balancing cylinders are constantly pressurized to extend the same in a dash-pot cylinder arrangement, and normally tend to spread the rolls from each other. Accordingly, each chock block **49***a* is provided with suitable passageways for hydraulic fluid leading to the balancing cylinders **51** from flexible hose connections pressured by hydraulic fluid supply system. There is a suitably sized window between the frame members opening into the slideway at each side of the frame, and also in the housing, which are alignable for removal and insertion of the rolls and chocks for servicing the assembled mill.

At the front and back sides (top and bottom of FIG. 5) of the vertical central opening of the housing H which accommodates the roll carriage, there are like opposed vertically extending channels or recesses wherein are mounted the cam plates **55** by bolts **55***b* to be vertically fixed relative to the housing H by thrust plates **55***c* but shiftable along bolts **55***b* toward and away from each other, and each cooperating with a respective one of the rolls R riding thereon. The shape (see FIG. 4) and function of the cam plates are hereinafter set forth. The cam plates are urged outwardly by compression springs interposed on each bolt between a nut thereon and the housing. Certain control and shiftable means for the respective cam plates are also mounted behind the latter in the channels, including an elongated rather thin wedge plate **56** with its outer flat face bearing upon a corresponding flat surface **54***a* of the channel; and a larger hollow wedge or taper block **58** having sloping face **58***a* complementary to and bearing on the inner sloping face **56***a* of the wedge **56** and an inner flat face in contact with the flat outer face of the cam plate **55**.

It will be noted that the widths of both **56** and **58** are less than the corresponding dimension of the channel or

recess whereby shifting of 56 and 58 from one side to the other, that is from left to right as viewed in FIG. 5, is permitted. The larger taper block 58 has a central recess 58c (see FIG. 8) with parallel vertical walls between which there is received a closely fitting nut block 60. A power driven lead or adjusting screw 61 engaged in block 60, journalled at its inner end by a sleeve bearing 61a in one wall of the recess 54, extends through and is axially fixed in a bearinged aperture 61b in the opposite wall by retainers 61c for coupling at 62 to the reversible drive motor and reduction gearing unit 63, bolted to the right side of the housing H.

The taper block 58 is transversely slotted in the region of the screw 61 to permit not only axial shifting of the block as it is carried by the nut 60 but also an inward and outward shifting as it is moved along the taper of the opposed small block 56. The blocks 56 and 58 are also slotted transversely at top and bottom for the cam plate bolts 55b therethrough to permit the in-and-out movement of the taper or wedge blocks.

On the side of the housing H opposite location of the motor 63 a double acting hydraulic piston unit 66, as a hydraulic reciprocating motor for a corresponding block 56, is mounted for reciprocation in direction transversely of the housing, that is, parallel to the direction of the lead screw 60 and to the axes of the rolls, and has its piston coupled to a stud 68 threaded into the broad side of the taper block.

Considering now the situation of FIG. 5, it is seen that one extreme working setting, a maximum spacing of the two cam plates from each other, and hence a maximum spacing of the rolls for any given position longitudinally of the cam plates is achieved under the conditions there appearing with 56 and 58 at the extreme right. However, upon withdrawal to the left of each block 56, as in FIG. 8, the blocks 58 and cam plates 55 actually follow so that the rolls immediately separate to clear the slab by action of balancing cylinders 51 upon the roll bearing chocks as in fact is intended to happen at the end of the downward housing or rolling stroke. However, upon simultaneous return of the two plates 56 by extending force of the units 66, the cam plates are then urged to return to the position of FIG. 5. However, when the power screws drive the blocks 58 to the left, the opposed tapers of 56 and 58 cause the blocks 58 and hence the cam plates 55 to move inwardly, thereby narrowing the roll spacing. Since the whole structure of the housing H, carriage RC and the other reciprocating components are in general symmetrical about the centerplane of the roll carriage, i.e., centerplane of the continuously cast slab and the product strip, the inward feed or retraction of the blocks 58 should normally be equal; and also the release and return of the same by operation of cylinders 66 should take place simultaneously.

Considering now a typical operation for conversion of aluminum to one-fourth inch plate 12 inches wide, the casting mold or die D of the furnace would be sized 4 by 12 inches to produce a hot billet of corresponding cross-sectional dimensions. With the slab entering the pinch rolls at a four inch thickness, and as a typical operating temperature at about 850° F., approximately a five percent reduction is effected at the pinch rolls. Therefore, the slab thickness would be 3.8 inches on entering the mill proper. Rolls, each six inches in diameter and sixteen inches long in the roll body, would be typically used in the roll carriage. With a 44 inch stroke of the housing, there is effected a corresponding relative upward movement of twenty-two inches of the roll carriage relative to the roll housing or a movement of only twenty-two inches of the carriage downward relative to the mill frame, by virtue of the rack and pinion gearing previously described. On the downward or working stroke of the mill this relative movement of the roll carriage relative to the housing is in a reverse direction, that is, there is a 22 inch vertically upward displacement of the roll carriage relative to the housing; in other words, on the downward stroke of the housing this travel being subtracted from the total travel of the housing, the carriage is carried downwardly only 22 inches.

In FIG. 4 the relative position of the elements at the extreme upward position of the housing is shown in full lines; while the corresponding relation of the elements at the extreme downward position at the bottom of the stroke is shown in dashed outline for certain elements such as the rolls and cam plates.

Consider now a typical installation utilizing a 200 horse power motor, rated for 1750 r.p.m. at 440 volts, three-phase 60-cycle power with 8 foot connecting rods, and a total mass of the reciprocating housing and all elements carried thereby of approximately 10,000 lbs., and 60 strokes per minute for the working rate. With a four inch thick "as-cast" slab reduced to 3.8 inches in the pinch rolls feeding at a rate of ⅜ inch for each working stroke cycle, in other words, about 1.9 feet per minute at 850° F. and with an elongation factor of 15.2 in the rolling, there is obtainable a delivery of 5.7 inches of the ¼ inch thick strip or plate per stroke or about 28.5 feet per minute or 1710 feet per hour. This would then represent a conversion of about 6480 lbs. per hour of aluminum.

Returning again to FIG. 4, the system is shown just as a downward stroke is about to begin. The cylinders 66 are under pressure to drive the wedges 56 inward and thereby to bring the cam plates to their fixed spacing predetermined by the adjustment of the system. As the housing starts downwardly, with the carriage lagging, the cam plates "over-run" the descending rolls R, so that sloping cam surfaces in engagement with the rolls not only rotate the rolls to cause the adjacent roll surface to move in an upward direction, but also urge the rolls inwardly. Hence, as the roll carriage descends, the rolls are squeezed inwardly, each "biting" into the metal and carrying or drawing downward a crest of metal on opposite sides of the slab. Over approximately the first half of the downward stroke, say 14 inches of roll descent, the rolls are being brought together. At about one-half of the downward stroke the rolls have reached the end of the inward cam slopes and there encounter straight parallel cam faces, and accordingly, over nearly the entire remainder of the stroke, the roll spacing is held constant at the actual spacing required by the thickness in the finished product. In this latter portion of the stroke, then, "crests" of metal advanced in the bite are rolled out into flat sheet form, the rolls continuing down even after the sheet has actually been formed in flat shape for a slight over-rolling portion of the stroke which may overlap say an inch or so of metal finished on the preceding stroke, to give a desired finished and flatness to the product. The tandem pinch rolls conventionally synchronous motor driven through a very high gear reduction restrain the slab, providing tension reaction to the downwardly applied forces of the rolls during the downward working stroke, permitting only the slab advance corresponding to the established casting rate and feed to which the pinch roll drive is set.

Just before the end of the stroke is reached, the cylinders 66 are actuated to retract the same and release the cam plates, and also as may be noted from FIG. 4, a very slight outward taper or cam relief is encountered by each roll; so that as the stroke is completed, a slight outward or roll-separating movement is permitted under the action of the balancing cylinders. Thus, even before the downward stroke is quite completed, the rolls are actually released from their rolling engagement with the finished sheet portion, so that the normal slab feed is not impeded. During the upward or return stroke, though the housing and cam plates actually will be overtaking the carriage and rolls, since the cam plates are spread and free, the rolls may pass therebetween without interference with the finished sheet metal. By the time the rolls would be encountering the tapered end of the partially reduced slab portion, the receding outward cam slopes are passing

the rolls permitting roll clearance with the increasing width of the tapered slab end. Just as the carriage is approaching the top of its stroke say one inch from the top, control means causes the cylinders **66** again to be pressurized for extension to drive the wedge plates **56** inwardly, thereby again restoring the cam plates to the original proper working spacing. The rolling cycle then begins again, in the meanwhile the slab or billet having continuously moved down by ⅜ of an inch from the position which it had at the beginning of the preceding working stroke.

In the aforedescribed apparatus, the mass of the metal involved in the moving system particularly the mass of the roll carriage, rolls and housing, along with the auxiliary equipment carried thereby such as the hydraulic pistons for the wedges and also the adjusting motors, represent a large moving mass elevated during the upward non-working stroke and thereby require a certain power input, not at that time used for metal reducing work. The elevation of this mass represents an increased potential energy of the system which reaches its maximum, of course, at the top of the upward stroke. As the downward stroke begins, this potential energy then becomes available as part of the working system expending energy upon the metal being worked. This accordingly lessens in some degree the load upon the driving system. In other words, there is an absorption of energy during the non-working stroke, that portion of the energy then being recoverable during the working stroke. Hence, the otherwise wide fluctuations in power demand at the input point are considerably minimized in contrast with a horizontal reciprocating mill. This then represents first a desirable general operation condition; secondly by virtue of the fact that the power demand is minimized for the working stroke, a smaller or lighter construction is possible in many of the working elements of the drive system. Furthermore, the very drive motor and other drive equipment are themselves reduced in size.

A generally conventional pressurized hydraulic system and components may be used to keep the balancing cylinders **51** pressurized continuously and to operate the double acting cylinders **66** to move the taper plates or blocks **56** in and out at the state appropriate points in each full cycle of housing reciprocation. Such a system, as schematically presented in FIG. 9, includes an electric motor driven pump **80** delivering fluid from a reservoir **81** through an adjustable pressure regulator **82**, with relief valve, through flexible hoses to the cylinders **51**; and also through a regulator and relief valve **82***a* to a two-way control valve **83**, which, selectively applies fluid under pressure to the outer ends of the cylinders **66** while opening the other ends to a reservoir return line for driving blocks **56** inward at one setting, and reverses the cylinder connections to withdraw the blocks on the other setting. The entire hydraulic supply system may be mounted on the moving housing with the pump motor energized through flexible electric cables, or alternatively the pump may be fixed, independent of the housing to which flexible hydraulic lines or hoses are run.

The control valve may be a solenoidally operated type shifted by solenoid **83***a* from one setting to the other, under the control of single control switch **84**, which is tripped or cammed to opposite settings by a set of spaced lugs **85**, **86**, the switch and lug set being on respective relatively moving members X, Y of which one is fixed, as the mill frame, and the other is the reciprocating housing. The lugs **85**, **86** for example, may be pivoted but spring biased against a stop so that each may engage an actuating element of the switch to trip the same near a respective stroke extreme, but slip past the switch in moving in the opposite direction. On the other hand, the control valve may be mechanically actuated or tripped to one or the other setting (at the times previously described for each cycle) by encountering vertically spaced dogs or lugs near opposite ends of the housing strokes, similar to **85**, **86**.

For the previously stated conditions in operations on aluminum of billet feed, stroke lengths, and delivery the roll supporting cam surfaces on a cam plate would have longitudinal dimensions, that is, as projected on a longitudinal line, as follows: a sloped surface of about seven and one-half degrees, 13.5 inches of the length; a straight position of 7.1 inches, with 5.7 inches thereof allotted to "delivery" or rolling out an accumulated "bite" or crest and 1.4 inches for over-roll of metal finished on a previous stroke; and a sharply sloped or "release" portion, of 1½ inches of the length. With one set of such cam plates as used for ¼ inch thick product obtained in the approximately 16 to 1 reduction from a four inch billet, a product range of 3/16 to ⅜ inch is practical from the stated size of billet. However, were it desired to hot roll with a greater reduction say from 4 inches to ⅛ inch, the billet feed rate would preferably be reduced and the cam slope increased.

With the previously described cam plates, and the same feed rates, a 2 inch billet thickness would be preferred to produce ⅛ inch product thickness, representing the reduction ratio for which the cams were specifically designed.

Generally, it may be said that the common metals of ductile character or capable of normal hot rolling are susceptible to operations as here contemplated excepting of course certain special alloys thereof, and the same cam plates and billet size (therefore direct casting mold) may be used therewith as for aluminum by varying the rate of billet feed and the final thickness produced. Of course the temperature of the billet in arriving at the reciprocating rolls is selected according to the hot rolling temperature requirements of the particular metal, e.g. 2000–2200° F. for a 1020 or mild steel; 1800° for copper. Even for these metals, where the same reduction ratio of approximately 16 to 1 is used as first described for aluminum, about the same cam configuration and feed would be used, the specific energy requirements merely demanding varied power.

The temperature of metal actually being cast into the mold will, as well known to the art, depend upon the specific metal composition and mold environment; for example with various aluminum alloys requiring temperatures over a range easily as broad as 1200°–1500° F.

I claim:

1. A method for producing metal in a rolled form comprising: forming a body of molten metal, pouring the molten metal into an inlet of a mold having a vertical die-like downward discharge opening normally closed by metal solidified therein as a plug, continuously withdrawing the plug of metal downward from said opening at a controlled linear rate corresponding to the rate of solidification of metal on the upper end of the plug thereby providing a continuous vertical billet of cross-section determined by said mold operating, rolling the billet to a final dimension with opposed rolls vertically oscillating longitudinally of the billet by bringing the rolls into engagement with the billet and thereafter forcing the rolls toward each other to a predetermined spacing during a first part of a downward stroke with the rolls maintained at such spacing substantially to the end of the stroke to produce rolled metal of the desired form.

2. A method for producing metal in a rolled form comprising: forming a body of molten metal, pouring the molten metal into an inlet of a mold having a vertical die-like downward discharge opening normally closed by metal solidified therein as a plug, continuously withdrawing the plug of metal downward from said opening at a controlled linear rate corresponding to the rate of solidification of metal on the upper end of the plug thereby providing a continuous hot billet of cross-section determined by said mold opening, passing the billet through pinch rolls driven and maintained at a constant speed to control the casting rate and simultaneously to effect a partial rolling reduction of the billet cross-section; hot rolling the hot billet to a final dimension with opposed

rolls vertically oscillating longitudinally of the hot billet by bringing the rolls into engagement with the billet and thereafter forcing the rolls toward each other to a predetermined spacing during a first part of a downward stroke with the rolls maintained at such spacing substantially to the end of the stroke to produce rolled metal of the desired final form.

3. A method for producing metal of a rolled form comprising: forming a body of molten metal, direct casting the molten metal into a downwardly moving straight continuous hot billet, controlling the rate of direct casting by passing the billet through fixed paired constantly driven cooperating rolls, hot rolling the billet by successively engaging like increments of the billet length between opposed rolls having a principal movement in the direction of billet movement, said opposed rolls after engagement with each increment also being moved toward each other to a predetermined final spacing to pick up and draw work downwardly in the direction of billet motion respective accumulating bite portions on the billet and thereafter maintaining said spacing to roll out the accumulated bite portions to produce a rolled shape corresponding to the form and final spacing of the opposed rolls.

4. A method for producing metal of a rolled form comprising: forming a body of molten metal, direct casting the molten metal into a vertically downwardly moving continuous hot billet, controlling the rate of direct casting

by passing the billet through fixed paired constantly driven cooperating rolls and thereby also partially reducing the billet, hot rolling the billet by successively engaging like increments of the billet length between opposed rolls having a principal movement in the direction of billet movement, said opposed rolls after engagement with each increment also being moved toward each other to a predetermined final spacing to pick up and draw-work downwardly respective accumulating bite portions on the billet and thereafter maintaining said spacing to roll out the accumulated bite portions to produce a rolled shape corresponding to the form and final spacing of the opposed rolls.

5. A method as in claim 4 wherein the opposed rolls in rolling out bites of one increment are caused to overroll finished metal corresponding to a preceding increment.

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