

June 14, 1955

T. SENDZIMIR

2,710,550

PLANETARY REDUCING APPARATUS AND PROCESS

Filed June 7, 1954

4 Sheets-Sheet 1

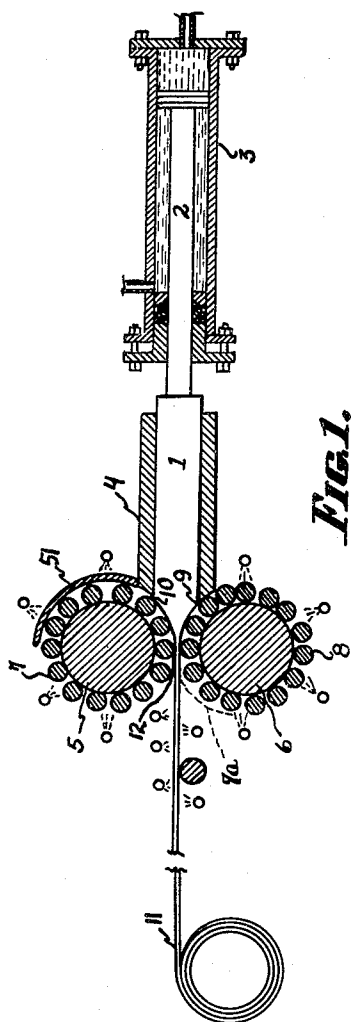


Fig. 1.

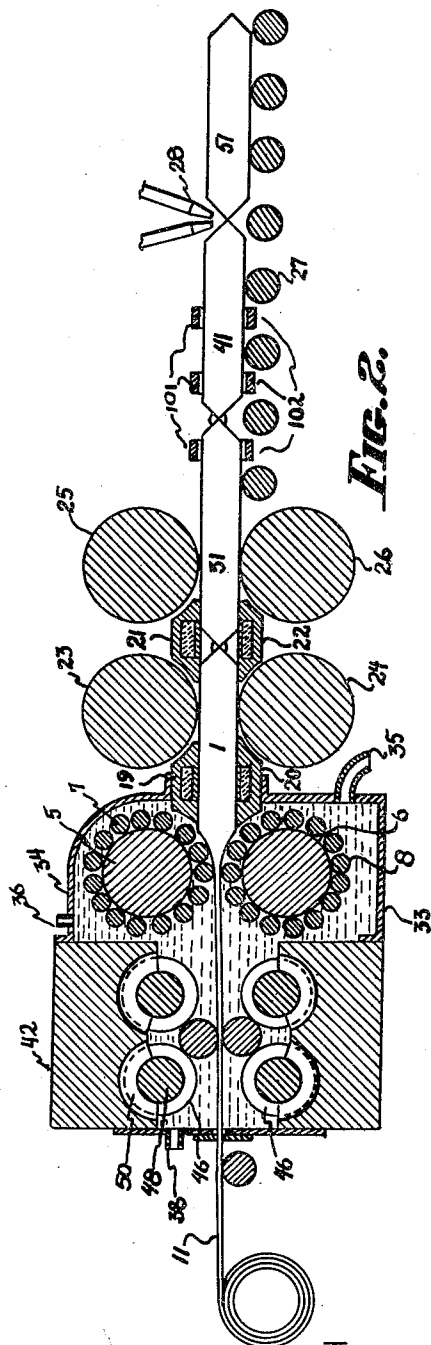


Fig. 2.

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4 Sheets-Sheet 2

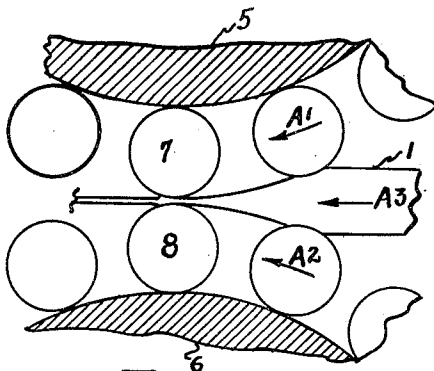


FIG. 3.

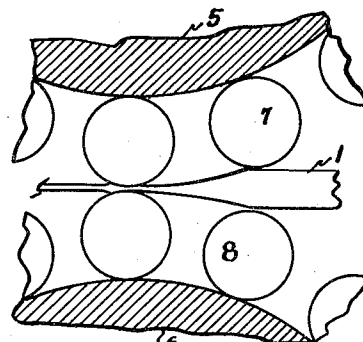


FIG. 4.

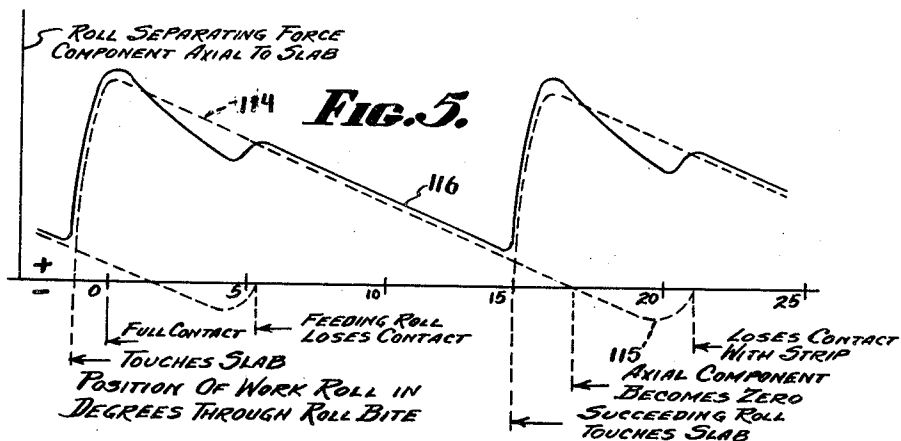


FIG. 5.

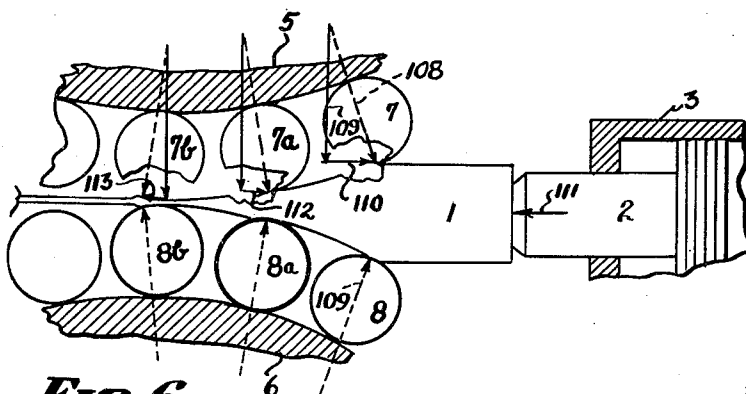


FIG. 6.

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4 Sheets-Sheet 3

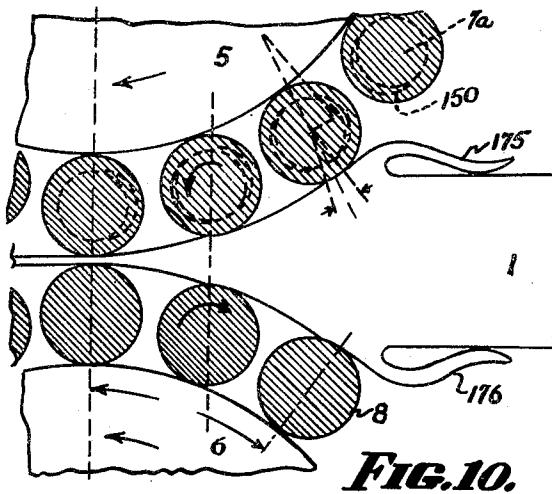


FIG. 10.

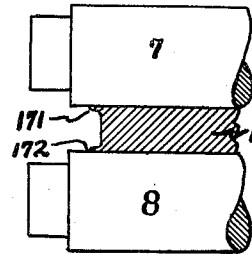


FIG. 7.

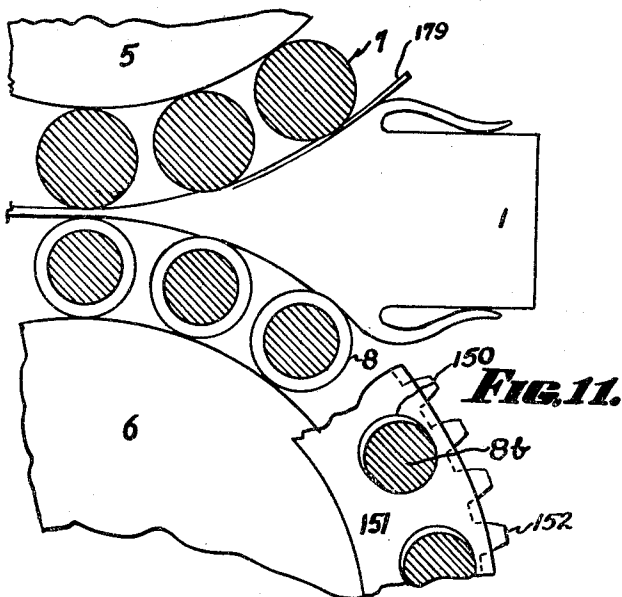


FIG. 11.

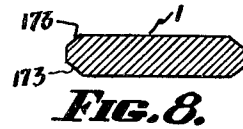


FIG. 8.

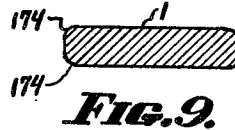


FIG. 9.

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PLANETARY REDUCING APPARATUS AND PROCESS

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Application June 7, 1954, Serial No. 434,698

13 Claims. (Cl. 80—31.1)

Ordinarily the slabs are reduced on the hot continuous mill to an intermediate gauge, from which subsequent reduction to sheet gauge is accomplished on a continuous cold mill, also representing a large investment.

A primary object of the present invention is the provision of a method of producing metallic strips with very much less costly equipment, although with a lesser productive capacity.

It is also my object to provide a new apparatus and process which is simpler and requires less skill to operate, but gives a superior product and possesses other advantages, as will hereinafter be set forth.

It is an object of my invention to provide for the use of an apparatus in which very great reductions in the thickness of the piece being operated upon may be effected in a single passage of the piece through a single reducing apparatus. It is my object to provide both an apparatus capable under many conditions of reducing an easily obtainable slab, billet or the like to finish gauge sheet all in one stage or part, and a process of rolling which makes possible the accomplishment of such a result with the apparatus involved.

My preferred process comprises providing a slab,—in certain instances even a cast slab instead of a rolled slab may be employed,—preheating it to a temperature preferably at which a thin oxide coating is formed thereon but below the scaling range, then passing it through a reducing instrumentality which effects the desired reduction all in one pass. Thus, I take advantage of the deformation heat which raises the temperature of the metal within the bite of the rolls, so that the bulk of the reduction takes place in a hot state, while at the same time a certain measure of self-annealing takes place. Finally, I cool the strip, preferably under non-oxidizing conditions. The force and effect of the process hereinabove referred to, and the manner in which it enables a particular result to be obtained from the apparatus, will hereinafter be outlined.

The general objects of my invention as well as more specific ones which will be referred to later or will be clear to the skilled worker in the art upon reading these specifications, I accomplish by that process and in that construction and arrangement of apparatus elements of which I shall now describe certain exemplary embodiments. Reference at this point may be made to the drawings forming a part hereof, and in which:

Fig. 1 is a longitudinal sectional view of diagrammatic character of one embodiment of apparatus used to carry on my process.

Fig. 2 is a longitudinal section of another apparatus embodiment of the same general type.

Fig. 3 is a diagrammatic view showing the engagement of reducing rolls with the work piece in one type of operation.

Fig. 4 is a diagrammatic view showing the engagement of reducing rolls with the work piece in a modified operation.

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Fig. 5 is a diagram showing the components of the planetary rolling forces axial of the slab.

Fig. 6 is a diagrammatic view of reducing rolls in contact with a slab showing the force components acting upon the rolls and slab.

Fig. 7 is a partial view showing a slab in section and illustrating the formation of side fins.

Figs. 8 and 9 are sectional views of slabs treated to prevent side fin formation.

Fig. 10 is a partial sectional view showing the formation of back fins.

Fig. 11 is a partial sectional view illustrating a mode of making clad metal.

Fig. 12 is a sectional view of one form of mill taken along the section line 12—12 of Fig. 13.

Fig. 13 is also a sectional view of the same mill taken along the section line 13—13 of Fig. 12.

In accordance with this invention, I provide an instrumentality capable of making extremely heavy reductions in metal in a single pass and in a relatively short space, so that an unusual quantity of mechanical energy is being applied to a localized portion of the work piece at any one time. The work piece is initially heavy in cross-section and hence more stable as to temperature changes by radiation. In view of these factors, I am enabled to reduce the metal in accordance with new techniques.

General features of the apparatus

A planetary type of apparatus is employed in the practice of the invention, by which is meant that a typical mill comprises a pair of relatively large diameter backing rolls, which are driven, and which are provided with screwdown means, i. e. means to regulate and adjust their axial spacing from each other. Around the periphery of each backing roll, a plurality of working rolls are arranged as satellites. In a preferred type of structure, the working rolls are driven by frictional contact with the backing rolls, but it is necessary that a work roll of each planetary assembly contact the work piece at the same instant, forming a simultaneously acting pair, to which end, in the preferred embodiment, the work rolls have necks which are journaled in rings. These rings may be geared together in such fashion as to insure simultaneous contact of the work roll pairs with the work piece.

The backing rolls are so driven that the work rolls roll forwardly on the work piece. Means are provided to feed the work piece into the zone of action of the work rolls and, if desired, to withdraw it therefrom.

Certain planetary arrangements have hitherto been suggested for swaging tubular blanks and the like; but these are not effective for the purposes of this invention.

In the diagrammatic illustration of one embodiment of my apparatus, as shown in Fig. 1, 1 is the preheated slab, 2 is the plunger of an hydraulic ram, the cylinder of which is indicated at 3. The hydraulic mechanism is employed to feed the slab into the reducing instrumentality with a considerable force and at a predetermined rate of speed, to which end the cylinder may be connected with a constant feed pump or pressure mechanism (not shown). Guides 4 are provided to prevent buckling or deflection of the slab, or even the upsetting of it, under the high pressure conditions. At least the upper guide is removable for insertion of the next slab 1.

The reducing instrumentality comprises two cylindrical backing rolls 5 and 6, each surrounded by a series of rotating and revolving cylindrical work rolls 7 and 8. The ends of these work rolls are carried in suitable roll retainers or rings (one of which is indicated in dotted lines at 7a in Fig. 1) which are geared to each other, preferably through outside idling gears. A specific structure for this purpose will be described hereinafter, including

means for obtaining and adjusting synchronization. The reason for this is to insure a perfectly symmetrical movement of the group of work rolls 7 around the backing roll 5 on one side, and the group of work rolls 8 around the backing roll 6 on the other side, so that when one particular work roll 7 first comes in contact with the slab 1 at line 9 on the bottom face of slab 1, the corresponding work roll 8 simultaneously comes in contact with the symmetrically opposite line 10 on the top face of the slab.

The backing rolls 5 and 6 are preferably driven through suitable spindles, not shown, so that the planetary work rolls 7 and 8, which are successively fed in by the retainers, are wedged between the backing rolls 5 and 6 and the corresponding side of slab 1, at the lines marked 9 and 10. From those points on they are driven by friction, by the backing rolls 5 and 6, and perform a rotating and progressive movement around the circumferences of rolls 5 and 6 respectively, while at the same time rolling against and reducing in thickness the corresponding portion of slab 1. This movement continues until the work rolls 7 and 8 reach line 12, at which they leave the strip 11 and continue their movement around the backing rolls 5 and 6 out of contact with the work piece, only their ends being carried in suitable holes in the roll retaining rings.

The making of heavy reductions in a slab

By the term "slab" is meant a heavy gauge piece of metal of a width several to many times its thickness, of a thickness several to many times the ultimate sheet gauge to which it is to be reduced, and of finite or indefinite length. Since the mills of this invention may be made in various sizes for various purposes, it is not possible to specify a particular slab thickness or width. In general, slab thickness will vary from, say, ½ in. or thereabout, especially for cast slabs of special alloy materials up to perhaps 10 or 12 inches for low carbon steels or other basic materials. There will generally be a relationship between the width and thickness of the slabs; but the width of the slabs may vary from a few inches in a small mill to 100 inches or more in a large mill designed to produce sheet materials of the greatest commercial widths.

The invention contemplates the making of heavy reductions. Here again, the specific reduction is variable; but the economy of the use of the apparatus of this invention dictates the production of such reductions as will result in an elongation of the work piece of at least about ten-fold and extending to elongations of 75-fold or greater. In an exemplary average operation, an elongation of 50-fold or more may be produced. The reductions are normally far greater than could be taken without slippage by any single pair of rolls mounted on stationary axes in a mill housing.

Such elongations are made at one station or position in the apparatus where the metal of the slab is being repeatedly rolled by successive pairs of the planetary work rolls until the desired elongation is produced. The speed of translation of the work rolls with respect to the work piece can be controlled and varied for different purposes, as hereinafter set forth; but all of the reduction produced by the mill occurs at the single station aforesaid, and the speed at which any given reduction in any given slab occurs will depend (with suitable apparatus) on the rate at which the slab is fed into the working zone of the mill. For a given reduction in a given slab in a given mill, a variation in the speed of translation of the work rolls will result in a variation of the amount of metal displaced by a given pair of work rolls during a single planetary traverse; but the actual reduction will be determined by the screwdown or setting of the mill. For these reasons it becomes possible to control the temperature of the work piece throughout the entire reduction, i. e. to keep the temperature the same, or to cause it to rise or fall.

From the practical standpoint, it is necessary that the

diameter of the planetary assemblies and the spacing of the work rolls in each planetary assembly be so related to the actual reduction being produced in the slab that at least one work roll of each planetary assembly can be in contact with the work piece in the active zone at all times. It is preferable that the construction and arrangement of parts be such as to permit at least two rolls of each planetary assembly to contact the metal in the active zone at all times.

From the accompanying drawings, it will be evident that these conditions will be met when the diameter of the planetary assemblies and the diameters and spacings of the work rolls are so related to the thickness of the slab and the actual reduction being made therein that the successive pairs of work rolls initially contact the slab at a relatively high angle to the longitudinal slab axis, rolling forwardly on an arcuately disposed portion of the slab portion in the active zone of the mill.

For a given setting in a given mill producing a given reduction in a given slab, so long as the feeding rate is not varied, an increase in the speed of translatory movement of the work rolls will result in each pair of work rolls displacing less metal per transverse, and vice versa. At the same time, since the rolling of the metal is ordinarily accomplished while its plasticity is affected by heat, the speed of traverse of the work rolls must at least be so great as to produce the desired reduction in the slab since otherwise the metal will tend to extrude between the rolls of each planetary assembly. Beyond this, however, the speed of translation of the work rolls may be increased for various purposes hereinafter set forth.

Precession of the work rolls

The slab will enter the mill at one speed; but the reduced strip will leave the mill at a different and much greater speed, depending upon the extent of the reduction. Consequently, from point 9 or 10 to point 12 there will be a progressive increase in the speed of movement of the surface of the metal. The work rolls are driven by frictional contact with the backing rolls, so that their speed of translation tends to be one-half the rotary speed of the backing rolls. This does not take into account the progressive increase of the speed of movement of the work piece in the active zone of the mill. In order to permit the work rolls to follow the increased speed of the work piece, provision is made for precession of the work rolls in each planetary assembly, i. e. the work rolls are so mounted that they can roll ahead of their normal radial or planetary positions in the active zone.

A way of accomplishing this is to mount the necks of the working rolls in circumferentially extending slots in the roll retaining rings, instead of in round holes, so that the precessional movement of the work rolls can take place. This in turn necessitates the provision of means to insure that each work roll contacts the back side of its slots when it reaches points 9 and 10, so as to maintain the symmetry of feeding of the work rolls as described above. Such means may be, for example, a friction brake 51 pressing the work rolls just strong enough to preserve their contact with the back sides of their respective retainer slots, in spite of the force of gravity, and effective just before the work rolls come into contact with the slab. In a vertical type mill, as illustrated in Figs. 18 and 19, gravity may act to position the work roll ends in the slots as the rolls approach the work piece.

The roll retainers with their gears as well as the driving mechanism of the backing rolls 5 and 6 are not shown in the diagrammatic view for the sake of clearness. But in Fig. 11, I have shown how reduced ends or necks 8b on the work rolls 8 may be engaged in slots 150 in the roll retaining ring 151, having gear teeth 152 by which it may be driven. It will be understood that a similar construction is provided for work rolls 7. In Fig.

10, where the slots in the roll retainer are shown in the dotted lines 150, I have illustrated the rolling ahead or precessional movement of the work rolls and the progressive movement of the necks 7a in the slots.

The effect of mounting the work roll necks in circumferential slots rather than in round holes is that of providing for the work roll necks circumferentially movable bearings rather than bearings which have a fixed radial position in the retaining rings. Thus, more elaborate constructions may be adopted, in which the retaining rings are provided with bearings which have a play or movement circumferentially thereof. Preferably, fixed abutments are provided at one side of each such bearing to determine the radial position at which each work roll first contacts the work piece, the bearings being resiliently urged toward the abutments, but capable of moving away from them to permit precession of the rolls.

Rolling action in the active zone

In a planetary mill of the type referred to herein, and producing a heavy reduction as described, the direction of movement (Figure 3, arrows A₁ and A₂) of the reducing rolls is initially oblique to the direction of movement of the slab (arrow A₃) because of the converging paths of the reducing rolls in the several pairs. The wedge-shaped portion of the slab undergoing reduction is subjected to the two-directional compression, one component being normal to the direction of slab motion and arising from the pressure exerted upon the slab by the opposed reducing rolls, and the other component being axial and arising from the forward thrust of the feeding means, applied against the rearward thrust exerted by the reducing rolls.

This condition gives to the operation of the planetary mill an important advantage over the kind of plastic reduction produced by conventional rolling means wherein a stationary pair of reducing rolls engages the work piece and exerts vertical pressure thereon. Within the roll bite in conventional rolling means, there will be a no-slip point at which the speed of travel of the work piece is equal to the speed of travel of the surface of the work rolls. Ahead of this point the reduced piece travels faster than the roll surfaces, while behind it the work piece is retarded. Hence, tension is produced within the area of plastic deformation; and because of this tension, materials which are not highly ductile tend to crack and may even disintegrate.

By way of example, a cast slab or ingot of a low carbon steel heated to a proper rolling temperature of, say, 2220° F. must be rolled on a conventional blooming mill with great care and initially with very small reductions until the brittle cast structure or dendritic structure of the ingot is gradually transformed into a forged structure which is more ductile. The same cast slab or ingot, when rolled on a planetary mill, can be carried down to strip gauge in a single pass without cracking, providing this is done under a proper correlation of the forces in a two-directional compression system, since it is possible to cause all grain slippage and flow to take place under conditions of compression rather than tension. Moreover, the slab does not need to be heated to so high a temperature, and can be reduced drastically at a heat as low as 1500° F.

Referring to Fig. 6, I have shown a slab 1 engaged by pairs of planetary work rolls 7, 7a, 7b, 8, 8a and 8b. The slab is being forced into the operating zone of these pairs of work rolls by a powered feeding device diagrammatically represented as the piston rod 2 of an hydraulic cylinder. The work rolls of each pair are shown as backed by rolls 5 and 6 turning respectively in clockwise and counter-clockwise directions in the diagram. The respective work rolls roll upon the surfaces of the backing rolls which thus not only sustain the forces of operation imposed upon the work rolls, but also drive the work rolls by frictional contact forwardly in the

direction of motion of the slab 1 and at a substantially higher speed.

As any one pair of rolls, such as the pair 7, 8, enters the operating zone, a force 108 is set up against the slab. This force is not a single force, but rather the sum of many forces acting as pressure and distributed over the whole area of contact between the work rolls of the pair and the slab 1. The force 108 is thus a resultant force which comprises a vertical or normal component 109 and a horizontal or axial component 110. The vertical component 109 of the work roll 7 is resisted through the slab 1 by the vertical component 109 of the opposing work roll 8. But the horizontal component 110 of both work rolls must be resisted by a force 111 supplied by the feeding mechanism. It will now be clear why the portion of the slab between the work rolls 7 and 8 and between this pair of work rolls and the feeding mechanism is in a state of two-directional compression.

The rolling action of the planetary work rolls as they pass through the active zone is such that each roll effects a relatively light reduction at the thick portion of the slab. The large number of such light passes, each producing a small individual plastic deformation, is of further benefit in producing a heavy total reduction without the danger of internal cracks. In effect the slab is subjected to a large number of light passes over its cast or dendritic structure, while the deformation is caused to take place in the absence of tension but rather under compression. Beyond the first major portion of the active zone, the central portion of the slab 1 will be found already to have acquired a forged structure and hence greater ductility. From this point on through the roll bite, the slab is subjected to increasingly higher reductions percentage-wise up to the point at which the final strip gauge is established, beyond which point the rolls of each pair follow divergent paths.

Remembering that the pairs of work rolls move ahead in the direction of motion of the slab, it will be seen that the rearward thrust component diminishes with their movement. When the rolls have attained the positions shown at 7a, 8a, a substantially smaller rearward thrust is indicated at 112. When the rolls have attained the positions shown at 7b, 8b, the horizontal thrust component 113, while still small, is in the reverse direction thus tending to pull the slab forward instead of resisting its forward motion. Tensional stresses thus exist between the rolls 7b, 8b and the nearest member or members resisting the forward motion of the slab, in this example, the work rolls 7a, 8a; but since the dendritic structure of the metal has already been broken down in the earlier portion of the roll bite, the tensional stresses cause no trouble and instead assist in leveling out the strip, reducing the roll-separating forces as is understood in the art.

In Fig. 6 I have shown an operation in which the maximum number of roll pairs in contact with the slab at any one time is three, and the minimum two. Fig. 3 shows an operation with a maximum of two and a minimum of one pair of rolls in contact with the work piece. Fig. 4 shows an operation in which one pair of work rolls only is in contact with the work piece at any one time, but an interval occurs between the departure of a pair of work rolls from the work zone and the entrance of the next pair into the work zone. Operations are, of course, possible in which larger numbers of pairs of work rolls are in simultaneous engagement with the slab than illustrated in Fig. 6. It will be understood that the number of pairs of work rolls simultaneously engaging the work piece can be varied for slabs of any given thickness by using mills differing from each other in the spacing of planetary rolls in the two orbits and in the diameters of the orbits themselves.

In Fig. 5 I have made a diagrammatic showing of the magnitude of the total feeding force required in relation to the positions of pairs of work rolls. For an exemplary bite angle, the dotted curves show the feeding

forces required for one pair of work rolls. If a single one of these dotted curves, say, the curve 114 is considered, it may be taken as representing the force required for a pair of work rolls which is the only pair of work rolls in contact with the work piece at any given instant. This condition is illustrated in Fig. 4. It will be noted that the rearward force indicated by the plus sign increases very rapidly to a maximum at the instant of full contact of the roll pair with the work piece and then gradually diminishes to zero, ending in a reversed or forward force in the area 115.

When more than one pair of work rolls is in contact with the work piece, the forward force exerted by the pair of work rolls which is about to leave the surface of the slab is counterbalanced by the rearward thrust of another pair or pairs. The solid line 116 in the diagram of Fig. 5 is the resultant of the various forces in a system of this kind. It will be noted that it varies in magnitude but lies continuously to the positive side of the zero force line. The greater the number of pairs of rolls contacting the work piece at any given time, the flatter will be the curve 116.

It will be understood that the vertical component of the forces exerted by the work rolls on the piece also fluctuates during each cycle, and that there is relatively a great difference between the magnitude of the maximum and minimum of the total roll separating forces. It will be seen that so long as the work piece is contacted by at least one pair of the work rolls at all times, and so long as the feeding pressure is maintained, there will be two-directional compression on the work piece.

Feeding the work piece

The work piece may be fed forwardly in various ways, as for example by the hydraulic feeding means shown in Fig. 1, by rolls as hereinafter described in connection with Fig. 2, or by gripping means or shoes, arranged in pairs laterally of the slab, and acting, in individual pairs, to engage the slab, move it forward under power, release it, and move back to a starting position. More elaborate feeding means may be adopted, designed to produce a constant forward speed of the work piece irrespective of variations in the backward thrust of the work rolls. Thus, where feed rolls are employed, these may be connected to heavy fly-wheels through speed-increasing gearing.

Exemplary apparatus embodiment

Fig. 2 shows diagrammatically another embodiment of the process and apparatus, differing from Fig. 1 in that the slabs 1, 31, 41, 51 are fed into the reducing instrumentality comprising work rolls 7 and 8, not by an hydraulic ram, but by a plurality of very heavy feeding rolls 23, 24, 25 and 26, which may, if desired, have some reducing function, but not necessarily so. Other continuous pressure-feeding means may be employed.

With this arrangement, it is possible to join or weld the slabs 1, 31, etc., as for instance, by a gas or electric welding unit 28, and feed the mill continuously as will be clear. For this purpose the slabs are preferably beveled off at their ends as shown, because it is easier to weld the relatively thin section produced by such beveling, rather than the whole thickness of the slab, although wherever cost is not the object it is possible to resort to such methods of welding as Thermit welding, where a relatively large section of weld may be obtained quickly and unfailingly. On the other hand, if slabs are joined together only in order to insure continuous operation of the unit and not necessarily for producing a continuous strip, even mechanical joints on an abutting relationship of slabs with suitably squared ends may be employed.

I prefer to clean the welded seam by sand blasting or other means, before it reaches the roll bite.

Slabs may be deposited on the roll bed 27, ahead of the welding instrumentality 28, in a preheated condi-

tion. Preheating to such temperatures as 400 or 500° C. can readily be accomplished economically in a gas-heated or radiation furnace or in a furnace where hot air is circulated, or again in a lead bath.

Fig. 2 illustrates still another mode of heating, namely, by electric induction. 19, 20, 21 and 22 are suitable electric coils conveniently built into the guides which prevent buckling of slab 1. For ferrous magnetic metals, the heating of the slabs to my desired rolling temperatures takes place entirely within the magnetic range of the metal, and is therefore very much more simple than if the higher temperatures had to be obtained. With preheated slabs it may be convenient to dispose electric or other heating elements in the guides to maintain the temperatures of the slabs. On large units it is more practical to arrange the preheating coils, whether induction or resistance radiating type, ahead of the mill, as at 101, 102, and use heaters 19, 20, 21 and 22 only to maintain the temperature of the slabs.

Again, for some metals with no "blue brittleness" range, usually of the softer, lower melting point type, it may be preferable to insert the slabs at room temperature and have all the heating take place within the roll bite.

It is within the scope of my invention to pass the strip 11, right after it leaves the reducing instrumentality, through a plain rolling mill of some kind capable of reducing its gauge by another 10 to 30% approximately, and at the same time, capable of ironing out the "scallop" left on the surface of strip 11 by each successive pair of revolving rolls 7 and 8.

A rolling mill such as disclosed in my Patent No. 2,169,711 is very suitable for such reduction owing to the high precision in supporting the relatively small diameter work rolls and the extreme rigidity of the one-piece housing. This enables me to remove in one pass the little unevennesses or scallops left by the mill hereinabove described and produce strip of very uniform gauge and good surface and shape. Fig. 2 shows such a final rolling mill comprising a heavy one-piece housing 42 in which are located, in suitable bores and channels, a plurality of saddles 50 carrying in their bores, shafts 48 upon which are rotatively mounted, bearing rings 46, a plurality for each of the four supporting shafts 48. The bearing rings 46 support the work rolls 43 and 44, which can be driven or not, depending on the degree of reduction required.

The rolls and backing elements of such mill may be conveniently submerged in a bath of coolant-lubricant such as oil or soluble oil, and in such case the first mill and its rolls 5 and 6 may also be submerged in the same cooling lubricant as by connecting the housing of this reducing instrumentality by means of a continuous watertight shield or apron 33 and 34 opened to the subsequent rolling mill at the left and having only small clearances in the direction of guides and coils 19 and 20 where a slight leakage may be tolerated.

The lubricant should be supplied, for instance, through the pipes 36 and 38 and escape through the pipe 35, in a controlled manner so as to leave the inside of the mill at all times filled with lubricant, and so as to circulate it at a rate sufficient to carry away heat from the working elements.

The distance between the two reducing instrumentalities, the analysis, and the temperature of the lubricant should preferably be so chosen that as the scalloped strip 11 reaches the reducing instrumentality 42, it has cooled down just enough to maintain a temperature difference between the thicker portion of the scalloped strip and the bottom of the scallop so that the hotter crest portions will be in a condition to reduce easier than the cooler, thinner portions, thus helping to produce a rolled product of even gauge.

Since as explained, the strip 11 is quite suitable for further cold reduction at this stage, after the reducing mill 42, my procedure and apparatus assembly lends

itself very well to the employment of further cold reducing mills in a tandem arrangement so as to bring the strip down to the final thin gauge, all in one operation. Thereafter the strip can be coiled, preferably under tension, as by coiler 17.

In Figs. 12 and 13 I have shown a vertical mill. This embodiment is preferred wherever a planetary mill is coupled in tandem with a continuous slab casting machine and at least in part the original heat is utilized. The backing rolls 5 and 6 lie side-by-side with their axes in a horizontal plane. The necks of these rolls are mounted in suitable bearings with respect to the mill housings 153 and 154. For simplicity, sleeve bearings have been shown at 157 and 158; but it will be understood that other types of bearings may be used, including roller- and oil-film-type bearings. One of the necks of each backing roll is provided with a coupling, as at 6c, so that power may be transmitted to each backing roll by means of spindles from a pinion stand or the like.

The backing rolls 5 and 6 must also be mounted in such a way that their distance from each other can be varied, even under full rolling pressure, in order to control the thickness of the strip 11. The "screwdown" mechanism should include means not only to move one of the rolls toward and away from the other, but to move both in symmetry and equally toward and away from each other.

Exemplary mechanism for this purpose is illustrated in Figs. 12 and 13 and involves the provision of eccentric bushings 155 and 156, free to rotate in corresponding bores of the mill housings 153 and 154, and containing the bearings 157 and 158 for the necks of the backing rolls 5 and 6. The gauge of the strip 11 may thus be controlled by varying the angular position of these eccentric bushings. I may thus provide the eccentric bushings 155 and 156 with teeth 159 along a portion of their circumference, which teeth are engaged by racks 160 and 161 slidably mounted in the mill housings. The racks may be moved by screws or other mechanical means, or preferably, may be connected to an hydraulic cylinder, not shown. I prefer this latter embodiment because, with the use of well-known hydraulic control means, the position of the pistons can be held automatically within very close limits, e. g. within an accuracy of .001 inch, and at the same time, by the use of equally well-known "flow-control" valves a symmetry of angular movement of each pair of opposite eccentric bushings 155, 156 can be automatically obtained.

In comparison to a purely mechanical connection such as might be accomplished by extending the gear teeth 159 far enough so that the bushings 155 or 156 in each pair are positively geared together, the hydraulic control above referred to has the additional advantage of permitting individual control of rotation of each eccentric bushing, i. e. of providing for differential screwdown to correct inaccuracies in the mill itself.

On supplementary necks, such as 6d and 6e, of the backing rolls, I mount rotatably the roll retainers or rings 151, the necks of the work rolls 7 and 8 being engaged in slots in these retaining rings as has been explained above.

The retaining rings are provided with gear teeth 152 which mesh with the teeth of gears 162 and 163 affixed respectively to shafts 164 and 165 journaled in fixed bearings on the mill housings as shown. The work roll retaining rings on each end of each backing roll are thus geared together which insures that the work rolls belonging to each backing roll stay parallel at all times. Adjustment of this alignment may be had by varying the position of one of the gears on shafts 164 and 165.

The gears 162 and 163 on the shafts 164 and 165 are in mesh with each other, as shown in Fig. 13, and this arrangement, properly designed, insures synchronization of the work rolls belonging to opposite backing rolls especially as to the coincidence of their first con-

tact with the slab 1. The positions of opposite pairs of work rolls are determined by the slots 150, as explained above, so that a gearing together of the roll retaining rings of opposite backing rolls will produce the desired synchronization, as will be clear.

The gearing arrangement above described permits the backing rolls 5 and 6 to be moved symmetrically toward and away from each other for screwdown purposes without disturbing the accuracy of the meshing of the gears, as might be the case if the roll retaining means of opposite backing rolls were directly in mesh with each other. The movement of the axes of the respective backing rolls during the screwdown is so nearly radial with respect to the axes of shafts 164 and 165 that the meshing of the teeth of gears 162 and 163 is not substantially disturbed; and gears 162 and 163 remain in mesh with each other because their shafts are mounted in fixed bearings on the mill housings.

It is true that the size and disposition of the teeth 152 on roll retaining rings on opposite backing rolls may be such that at certain screwdown positions the teeth will come partially in mesh, as is shown in Fig. 13. But the pitch contours may be so selected that there is ample clearance between the teeth of opposite roll retaining rings even with the screwdown adjusted for minimum strip thickness.

The work rolls, as has been explained, roll in frictional contact both with a backing roll and with the work piece. Hence the work rolls have a planetary movement about the backing rolls at a speed of revolution less than the speed or rotation of the backing rolls. This speed of revolution will have a fixed relation to the speed of rotation of the backing rolls because the matter of precession of the work rolls, as explained above, occurs within the scope of and is accommodated by the slots in the work roll retaining rings. Hence, I prefer to drive my work roll retaining rings at a speed bearing a fixed relation to the speed of rotation of the backing rolls. Assuming the driven backing rolls to be rotating equally and oppositely, as may be determined by the pinions in the pinion stand mentioned above (it is also possible to gear the backing rolls together in the mill if desired), driving of the work roll retaining rings is readily accomplished by gearing one of the shafts 164 or 165 to one of the backing rolls in a suitable ratio. For reasons hereinafter set forth, it may also be desired to provide for adjustment of the work roll positions with respect to the surfaces of the backing rolls. In the arrangement shown in Fig. 12, I have included such an adjustment means. A gear 166, having a wide face is affixed to the neck 6a of the backing roll 6 by clamping means such as shown at 166a, so that the torque exerted upon it by the driven roll 6 can be controlled by adjustment of the screws of the clamping means. A gear 167 having a narrower face is mounted upon the shaft 164. The gear 167 has a hub grooved as indicated at 168. The gear 167 is mounted upon the shaft 164 by means of a spline 169 which has a helical conformation, the hub of the gear having a corresponding helically formed groove to accept the spline. Thus by moving the gear 167 axially of the shaft 164, its rotative position with respect to the shaft may be changed within the limits of the length and pitch of the spline. The position of the gear 167 along the axis of the shaft may be adjusted in a variety of ways. I have indicated means 170 which will be understood as rolls or fingers engaged in the groove 168 and mounted on a forked lever which, in turn, is pivoted on the mill housing and is provided with adjustment means which may be in the nature of a screw. By such means the angular position of gear 167 on shaft 164 may be adjusted while the mill is either running or at rest.

Surface effects

Since in the practice of the invention a work piece of

substantial thickness is being subjected to a heavy reduction while its plasticity is affected by heat, some lateral expansion of the work piece as it is being reduced is to be expected. However, the reduction is being performed along arcuate surfaces of the work piece by pairs of working rolls which successively traverse those surfaces. Thus, the greater part of the heat of deformation of the metal is generated at the arcuate surfaces of the slab in the active zone of the mill, so that especially where these surfaces diverge and are more widely separated from each other, the surface metal becomes hotter and more plastic than the metal in the interior of the slab. Thus, a tendency for the formation of side fins 171 and 172, as illustrated in Fig. 7, may be noted. The formation of such side fins can be alleviated or prevented by beveling the lateral corners of the slab, as shown at 173 in Fig. 8, or rounding them, as shown at 174 in Fig. 9.

Where a heavy reduction is being taken, with the work rolls initially encountering the slab at a high angle to the longitudinal axis of the slab, the surface heating and softening effect heretofore mentioned may result in the formation of back fins such as are shown at 175 and 176 in Fig. 10. Under some circumstances the formation of such back fins is highly desirable, for the reason that a surface layer of metal is progressively removed from the faces of the slab and a scarfing effect is obtained in addition to the heavy reduction. In some operations, however, the formation of back fins is undesirable, as diminishing the production of useful reduced stock and involving a disposal problem. The formation of back fins can be prevented by the application of surface cooling to the slab in the active zone in such fashion as to prevent the softening of the metal at the surface with respect to the metal underneath. This can be accomplished by the application of coolants; but I have discovered that it is more conveniently prevented by making a large increase in the speed of translation of the work rolls. It has been explained above that the speed of reduction of the work piece is not dependent upon the speed of translation of the work rolls, but rather on the speed of feeding, all other conditions remaining the same. If the speed of translation of the work rolls is very greatly increased, the individual pairs of work rolls not only produce less deformation of the metal per cycle of translation, but also tend to abstract some of the heat produced by the deformation of the metal. Thus, it is possible by selecting a speed of translation to avoid the formation of a back fin even where very heavy reductions are being taken.

Increasing the speed of translation of the work rolls has yet another valuable effect in eliminating or diminishing scallops. By speeding up the work rolls for a given reduction, the length of finished strip for each cycle of translation of the coating pairs of work rolls can be diminished so that the scallops become of less and less length in the direction of movement of the finished material. In this way it is readily possible to produce a material which is visually devoid of scallops.

Cladding

The apparatus and procedure described in the present specification are of particular value in the making of clad structures, i. e. structures in which dissimilar metals are joined. It is old in the art to make clad structures by joining dissimilar metal strips and subjecting them to simultaneous reduction or by passing dissimilar metal strips at welding temperatures simultaneously through a rolling instrumentality. Under such circumstances, however, the dissimilar metal layers are reduced proportionately, and the bond between them is dependent either on the strip of a previously effected bond (as by welding, brazing or the like), or on the attainment of welding temperatures during the reduction, in the absence of oxides or other intervening films which would prevent satisfactory bonding. When using the apparatus of the present invention, it is possible to run a preformed strip

of metal 179 (Figure 11) into the active zone of the mill on one or both sides of the slab 1. Where the strip or strips 179 are of a metal substantially less readily deformable than the metal of the slab 1 (as for example, in joining stainless steel to iron or mild steel), or where the strip can be maintained at a lower temperature than the metal of the slab in the active zone of the mill, relatively little reduction will take place in the strip while a very large reduction takes place in the slab. Not only, therefore, are any oxide films on the slab broken up and elongated so as not to interfere with bonding, but there is relative movement of the surface of the slab and the strip which greatly promotes bonding. To obtain these effects it is ordinarily sufficient merely to run a relatively thin cold strip into the mill along with the very much hotter slab. Since the strip is not elongated or is elongated very much less than the slab, it will pass through the active zone at a speed much more nearly equivalent to the speed of exit of the composite product which in turn helps to maintain the desired temperature differential.

Moreover, when the slab 1 is reduced under conditions to form the back fins 175 and 176 as illustrated in Fig. 11, the slab will itself be continually scarfed ahead of the lines of juncture between it and the strip or strips 179, as will be clear.

Modifications may be made in my invention without departing from the spirit of it. Having thus described my invention in certain exemplary embodiments, what I claim as new and desire to secure by Letters Patent is:

1. A strip mill having a pair of backing rolls, and sets of work rolls arranged about the surfaces thereof, roll retaining rings associated with said backing rolls, means gearing said rings together, means mounting said work rolls in said roll retaining rings so that said work rolls are free to rotate on their axes with respect to said backing rolls and so that successive opposed pairs of said work rolls engage the work piece substantially simultaneously, said work rolls having a driving connection with said backing rolls whereby said backing rolls can drive them with respect to the work piece, and means for driving the backing rolls, the mounting of said work rolls in said retaining rings including means permitting limited movement of the rotational axis of the work rolls relatively to each other and relative to said rings in a direction circumferentially of said rings such that said work rolls are free to adopt the surface speed of the strip at the point where they contact it so that said rolls can move ahead of their normal position during rolling and advance with said work piece without substantially diminishing said driving force and maintain therewith a no-slip line during working.

2. The structure claimed in claim 1 in which said retaining rings are driven.

3. The structure claimed in claim 1 in which said retaining rings are driven through a mechanical connection with said backing rolls including an adjustable slipping clutch.

4. The structure claimed in claim 1 in which said retaining rings are driven through a mechanical connection with said backing rolls including an adjustable slipping clutch, said mechanical connection also including means for adjusting the angular positions of said rings.

5. A method of reducing flat thick slabs to flat thin strips, the slab thickness being a very high multiple of the thickness of the strip, which comprises force feeding the slab at a slow constant speed through a rolling zone the length of which is determined by the sharp evolution of the slab thickness down to the thin strip, wherein the slab is equally reduced at opposite sides and said zone is observed as a wedge shaped transition in the slab, subjecting the opposite face of said slab to the full width thereof, while passing through said zone, to a high speed succession of a multitude of rolling operations for the incremental reduction of said slab to thin strip which leaves said zone at high speed, whereby each increment

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of reduction starts at the beginning of said zone, produces a slight reduction in relation to the total reduction and constitutes a rolling action passing along the aforesaid wedge transition to the exit end thereof, and controlling the heat loss due to radiation and conduction as compared with the heat gain due to deformation to maintain the slab at proper working temperature at said zone.

6. The process of claim 5 in which the controlling of the heat loss is accomplished by controlling the feeding speed in relation to the speed of said succession of rolling operations and thereby controlling the magnitude of the rolling operations in the said succession.

7. The process claimed in claim 5 wherein said slab is a slab of ferrous metal, wherein said slab is heated to a temperature above the blue brittleness range but below the active scaling temperature, and wherein the rate of feeding is controlled to maintain the temperature of the work piece within the said limits throughout the entire reduction thereof.

8. The process of claim 5 wherein the speed of the said succession of rolling operations and the feeding speed are so controlled as to cause the continuous formation of a back fin on the metal slab.

9. The process of claim 5 in which the speed of the said succession of rolling operations is made so great in proportion to the speed of movement of the reduced strip as to avoid the formation of visually apparent scallops.

10. The process claimed in claim 5 in which a preformed strip of metal at a temperature lower than the temperature of the slab is fed into said zone with said slab to produce a clad structure.

11. The process claimed in claim 5 in which the speed

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of the said succession of rolling operations and the feeding speed are so controlled as to cause the continuous formation of a back fin on the metal slab, and in which a preformed strip of metal is led into said zone with said slab to form a clad structure, the formation of said back fin serving to scarf said slab prior to the joining of the strip therewith.

12. The process claimed in claim 5 including the step of relieving lateral corner portions of said slab to minimize the formation of side fins.

13. The process of claim 5 wherein the thickness of the slab and the extent of reduction in said zone is so chosen as to exert on said slab forces which have strong rearward components, the feeding force being sufficient to overcome said components, whereby to subject said slab during at least an initial portion of the rolling to strong two-directional compression so as to minimize the tendency to produce internal cracks in the rolled product.

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