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
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 Applicant: **Kennecott Corporation, Midland Building 101 Prospect Avenue, Cleveland Ohio 44115 (US)**


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 Inventor: **Shinopulos, George, 25 Eugene Road, Burlington Massachusetts 01803 (US)**
 Inventor: **Bower, Terry F., 6605 Elmcrest Drive, Hudson Ohio 44236 (US)**
 Inventor: **Randlett, Ronald M., 17140 Woodacre Terrace, Chagrin Falls Ohio 44022 (US)**

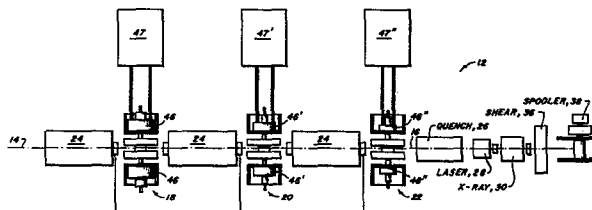
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 Representative: **Fisher, Bernard et al, Raworth, Moss & Cook 36 Sydenham Road, Croydon Surrey CR0 2EF (GB)**

 **Two high hot rolling mill process and narrow strip product.**

 A rolling mill capable of forming a hot, continuously cast metallic strand into a strip with a large bite and with one pass per mill stand uses only two small diameter rolls per stand, each mounted for rotation in a pair of chock blocks and each having a comparatively narrow, enlarged diameter working portion. The outer surface of the working portion is profiled to maintain the product centered on the rolls and to accommodate for thermal expansion. An hydraulic motor that produces a large torque at a low rotational speed with good control rotates each roll. The motors are coupled to their associated rolls directly. A pair of hydraulic cylinders mounted on upper frame beams are each connected to one of the chock blocks of the upper roll. The upper frame and the cylinders pivot together to provide a direct overhead access to the rolls and their chock blocks for a rapid replacement of the rolls. The mill includes rotary brushes that are adjustably loaded against the working portions of the rolls to remove adhered strand material and to prevent a release agent from accumulating on the rolls. An

entrance guide assembly provides a partial atmosphere control and edge rolls that to some extent steer the strand to the center of the rolls. A narrow strip with a recrystallised grain pattern and accurately controlled dimensions is produced by three such two high mills operating in tandem. The first mill produces the high reduction and sets the width of the strip. The second mill reduces the thickness further. The third mill is a finishing mill that produces a final thickness reduction.



Two high hot rolling mill process
and narrow strip product

5 This invention relates in general to a rolling mill
process for rolling a hot metallic strand into a strip of
well defined dimensions and good quality, and the strip
produced by this process. More specifically, it relates
to two high mill with a comparatively small frame and an
hydraulic drive system that provides a high torque at a
10 low speed that is capable of a large reduction without
slippage and allows a rapid roll replacement.

A wide variety of mill stands are known for hot and cold
rolling metals. Where there is a large separating force
15 between the working rolls, whether due to a large reduc-
tion and/or to the nature of the material being rolled,
there are a number of inherent design problems. One is
that the rolls work against a separation force that is
sufficiently large to bend or even to deform the rolls
20 depending on the diameter, length and material of the roll
as well as the nature of the material, its temperature,
and the reduction ratio. The diameter of the roll is also
important because for a given "bite" (thickness reduction
of the product entering the mill) the "bite ratio" (roll
25 diameter over bite) is an important factor in determining
when slippage will occur between the rolls and the
product. As low a ratio as possible is desired to
minimize roll size (and therefore roll cost) and/or
maximize bite. Typical bite ratios for mills currently in
30 use are in the range of 50:1 to 100:1. Another considera-
tion is that larger diameter rolls produce a greater

spread, however, the attendant separation force is also larger. Ideally, the roll design should produce the desired spread with the minimal separation force.

5 Heretofore, in order to deal with large separation forces
(e.g., in excess of 45,359 kg/stand (100,000 lbs/stand),
it has been necessary to use a four high mill, that is,
one with two working rolls and two "back up" rolls that
provide mechanical support for the working rolls. Such
10 mills are also characterised by a quite heavy, expensive
frame that can accommodate all four rolls and resist the
large forces generated by the rolling. U.S.-A-3,103,138;
U.S.-A-3,391,557; U.S.-A-3,550,413 and U.S.-A-3,568,484
are exemplary of such four high mill stands. While
15 certain mills produce a high reduction by passing the
product through the mill multiple times, this is not
possible in a continuous, on-line casting and rolling
operation. (For example, rolling operations with twenty
passes are not uncommon).

20
Frequently the gap of the mill is adjustable to produce an
output strip that has a uniform gauge even though the
gauge, temperature or metallurgical qualities of the input
product may vary. The aforementioned patents, for
25 example, describe arrangements for varying the gap. More
sophisticated systems produce a control signal that
adjusts the gap in response to a sensed deviation in the
gauge of the rolled product from a preset value. Many
systems use hydraulic cylinders that act either with or
30 against the separation force to provide this adjustment.
The hydraulic system, however, has heretofore been a
significant complicating factor when the rolls must be
replaced, whether due to ordinary wear, damage or to
accommodate a different product run. U.S.-A-3,864,955,
35 for example, discusses the importance of roll changes and
describes an arrangement which attempts to facilitate roll

replacement. U.S.-A-3,323,344 discloses another arrangement. However, known systems, for conventional four high mills require hours to replace rolls. This time represents a significant loss of productivity for the rolling
5 operation. Where the product being fed to the mill is continuously cast, the roll change will shut down the entire production line.

The torque and speed of rotation of the rolls are also
10 important in producing a high reduction without slippage. More specifically, in order to hot roll copper and brass strand with a large bite (e.g., in excess of 2.54 cms (1 inch) and a low bite ratio (e.g., 7:1), the drive system for the working rolls must have a comparatively high
15 torque (typically in excess of 1356 Nm (1,000 ft-lbs.) to achieve a large bite and a comparatively low speed (typically less than 400 rpm) to couple the rolling mill speed to that of the caster. In addition, it is necessary to vary these parameters depending on the particular
20 product being run and other factors such as the roll diameter. Heretofore mill stands requiring a variable high torque at a low speed have used electric motors with a reducing gear train. This arrangement provides the required operating characteristics, but it is a costly
25 system that takes up a large amount of space compared to the mill itself. Moreover, applicant is not aware of any commercially available direct drive trains for rolling mills that can produce thousands of Nm (ft-lbs) of torque. Further, known drive trains with many components are not
30 "stiff". As a result, the drive system is not closely responsive to servo changes in the drive input. Indeed no known rolling mill is designed to utilise a highly responsive direct drive. The drive train of the present system is a directly coupled hydrostatic drive commonly
35 used in large earth moving equipment.

Torque requirements are also interrelated with other design factors such as roll diameter and anticipated separation forces and thus, size and cost of the mill, the gauge of the rolled product and friction. Heretofore, the lower rolling force of small diameter rolls and their ability to roll thin gauge products has generally been balanced against offsetting considerations through the use of back-up rolls. If two rolls are used where substantial separation forces are produced, prior art mills have used costly, massive rolls with very large diameters, e.g., 61 to 91 cm (two to three feet). Heretofore, high reduction rolling using unsupported (two high) small diameter rolls (less than at least 30.5 cm (one foot) in diameter) has not been commercially practical. U.S.-A-4,218,907 describes a two high mill which provides operating characteristics only achievable previously with four high mills. However, this two high mill requires a special bearing assembly which supports the rolls over all or most of their length.

Other design problems arise from the fact that the material being rolled is hot. One well known problem is that the hot strip product will heat the working rolls and cause their contours to change due to thermal expansion. This in turn can cause changes in the gauge and profile of the rolled strip. U.S.-A-4,262,511 describes as a solution a system that distributes a coolant over the rolls in response to a signal indicative of the shape of the rolled product. Other systems simply adjust the mill gap to accommodate for temperature changes. In cold rolling, profiled rolls have been used. No known system, however, has produced a strip product having consistently uniform dimensions where the input to the mill is a very hot strand that is not already in a strip form. When hot rolling thin gauge materials with a high thermal conductivity, it is also important not to quench the

material with the rolls while at the same time not overheating the strip or the rolls from an input of mechanical energy.

5 Another problem inherent in hot rolling, particularly with a large reduction and non-ferrous metals, is the transfer of metal from the product to the rolls. This transfer is a problem because it alters the contour of the rolls, the gap, and the coefficient of friction between the rolls and
10 the product. One solution has been to apply a "release agent" to the rolls to deter the adhesion of the metal to the roll. While this helps, it is not totally effective. Another solution is to mechanically remove the adhered metal. Known arrangements use fixed scrapers and/or fixed
15 brushes to remove the metal. Where there is a substantial transfer of a comparatively soft metal, e.g., copper or brass, these systems are not acceptable because there is a rapid buildup of metal on the scraper (remover) which either reduces its effectiveness or, with a large enough
20 buildup, destroys the device. Removal of the adhered metal is also important to maintain a uniform friction which in turn produces a constant separation force. When coupled with a "stiff" mill, this constant separation force assists in maintaining a uniform gauge.

25 It is therefore a principal object of this invention to provide a rolling mill and process that produces a high quality narrow strip from a continuously cast hot metallic strand where the mill is only two high and uses small
30 diameter rolls yet is capable of producing a high reduction with precisely controlled dimensions and profile of the rolled strip product.

35 Another major object of this invention is to provide a hot rolling mill and process utilizing mill rolls designed to self-center the strand or strip on the working portion of the roll.

Another significant object of the invention is to provide a hot rolling mill and process with the foregoing capabilities and characterised by a variable high torque, low speed drive for the rolls that does not require an electric motor or reducing gears.

Another object of this invention is to provide a hot rolling mill and process that inhibits the transfer to an adhesion of metal on the rolls.

A further object of this invention is to provide a hot rolling mill and process that accommodate for the thermal expansion caused by working a hot material.

Still another object of the invention is to provide a hot rolling mill with a compact, lightweight frame which nevertheless withstands substantial separation forces and allows a fast roll change.

A rolling mill and process according to the present invention receives continuously cast, hot metallic strand, particularly strands of copper and copper alloys, and produces a high quality narrow strip with precisely controlled dimensions and profile and with a high reduction. The mill has only two working rolls with a comparatively small diameter, each mounted for rotation in chock blocks. One roll is fixed and the other roll and its chock blocks are movable vertically under the control of a pair of hydraulic cylinders to vary the gap between the rolls. The chock blocks are mounted in a generally rectangular frame assembly that includes vertical members that mount the chock blocks and upper members that span the vertical members. The upper members mount the hydraulic cylinders and are pivotally mounted to provide direct overhead access to the working rolls and their chock blocks. The frame is preferably constructed of steel I-beams which provide a frame that is strong enough

to withstand the large separation forces. Deformation of the frame is accommodated by feedback control systems and the ability to vary the gap between the rolls with a high degree of precision and responsiveness. For copper and
5 brass, this mill can produce a bite in excess of 2.54 cm (one inch) and approaching 5.1 cm (two inches) and bite ratios of as low as 5:1 without slippage.

Each roll is driven independently by an hydraulic motor
10 that can develop a large variable torque at a low rotational speed. There is a direct coupling between the motor and the roll. The motors are preferably of the radial piston type with a swashplate in the pump power supply to adjust the speed. In the preferred form, the
15 rolls also propel the strand or strip.

Each roll has a narrow, enlarged diameter rolling portion that contacts the hot metallic strand. The outer surface of this working portion has an inverse "crowning" or
20 concave contour along its working length, preferably with a generally V-shaped contour. After thermal stabilization, the outer surface of the roll produces a rolled product that either is uniform or has slightly more material at its center than its edges. This design has
25 been found to be effective in controlling the lateral position of the strand. An internal passage conducts a flow of a cooling liquid (water) through the roll. Roll thickness is adequate to maintain a hot roll surface temperature, thus preventing quenching of the rolled
30 strip.

To control the accumulation of adhered metal on the rolls, a rotary brush engages the outer working surface of each roll. In the preferred form, the brush is formed of steel
35 wire bristles, rotated at a high rpm, and mounted on a pivoted frame that is loaded against the roll by a

pneumatic cylinder and a counter spring. A release agent is also preferably sprayed onto the exterior of the rolls.

5 The mill stand preferably includes an entrance guide assembly with a generally tube-like, open ended enclosure that holds a reducing atmosphere of an adjacent reheater around the hot strand or strip as it travels from the reheater to the work rolls. The entrance guide may receive a reducing gas atmosphere from an adjacent
10 reheater or it may have a burner located within the assembly. The entrance guide includes a pair of mutually inclined guide plates to assist in guiding the strand or strip, especially during start-up. It may also include adjustable, horizontal rolls to align the strand with the
15 mill gap and side rolls or a pair of mutually inclined guide plates to guide the strand horizontally.

The hot rolling process of the present invention is preferably performed by a set of three tandem, two-high,
20 small roll diameter mills that include gauge and width, measuring devices to generate measurement and controls signals for the mills. In the preferred embodiment useful for the continuous hot rolling of copper or brass rod into a narrow strip, the first mill stand produces the greatest
25 reduction and spreads the strand to substantially its full width. Two successive mill stands of the same design, after reheating the strip, reduce its gauge with only a minor change in width. The first and second stands produce an output strip with slightly more material at the
30 center of the strip than its edges and the third mill produces a strip with a substantially uniform gauge. The present invention includes a narrow strip product formed by this process.

35 Embodiments of the invention will now be described by way of example, reference being made to the accompanying drawings, in which:-

Fig. 1 is a highly simplified top plan view of a tandem hot rolling mill operation according to the present invention;

5 Fig. 2 is a more detailed top plan view, with portion broken away, of the three mill stands shown in Fig. 1;

Fig. 3 is a view in side elevation of the mill stands shown in Fig. 2;

10

Fig. 4 is a top plan view of the first mill stand shown in Figs. 1-3 with frame portions, rotary brushes, entrance and exit guides, and gauges removed for clarity;

15 Fig. 5 is a view in front elevation of the mill stand shown in Fig. 4;

Fig. 6 is a detailed view in front elevation of the rolls and their associated chock blocks shown in Figs. 4 and 5
20 with the right lower chock block shown in vertical section;

Fig. 7 is a view in side elevation of the chock blocks shown in Fig. 6;

25

Fig. 8 is a detailed view in vertical section of the chock block shown in Figs. 6 and 7 and the roll portions supported in that chock;

30 Figs. 9A, 9B and 9C are views in front and side elevation and top plan, respectively, of the mill frame assembly of the first mill stand shown in Figs. 1-5 with the motors, rolls, and other equipment removed for clarity;

35 Fig. 9D is a fragmentary view of the upper portion of the mill stand shown in Fig. 9B but with the upper frame beams and the hydraulic cylinders mounted on those beams pivoted

partially toward an open position that allow a direct overhead replacement of the rolls;

5 Fig. 10 is a simplified view in side elevation of the mill stand shown in Figs. 1-5 and 9A-9C but also showing an entrance guide assembly, sprays for a release agent and a rotary brush system;

10 Fig. 10A is a simplified top plan view of the release agent spray system shown in Fig. 10;

Fig. 11 is a bottom plan view of the entrance guide assembly shown in Fig. 10;

15 Fig. 12 is a view in vertical section taken along the line 12-12 in Fig. 11 with three alternative vertical guide rolls shown for the three mill strands;

20 Fig. 13 is a view in vertical section and in partial side elevation of the horizontal rolls of the entrance assembly shown in Fig. 10;

Fig. 14 is a view in side elevation of the horizontal roll assembly shown in Fig. 13;

25

Fig. 15 is a view in front elevation of the entrance guide assembly shown in Fig. 10;

30 Fig. 16 is a view in vertical section taken along the line 16-16 in Fig. 13;

Fig. 17 is a detailed view of the working portion of the rolls shown in Figs. 2 and 4-6;

35 Fig. 17A is an enlarged view of the profile of the outer surface of the roll working portion shown in Fig. 17 that

accommodates thermal expansion and self-centers the strand or strip being rolled;

5 Fig. 17B is a view corresponding to Fig. 17A of an alternative profile;

Fig. 18 is a view in side elevation of the rotary brush assemblies shown in Figs. 2, 3 and 10;

10 Fig. 19 is a top plan view of the rotary brush assembly shown in Fig. 18;

Fig. 20 is a highly simplified view in side elevation showing the action of the rolls of the first mill stand to effect a very high reduction of an incoming cast rod into a narrow strip, and

Fig. 21 is a highly simplified view in side elevation of the tanks that hold and feed the release agent.

20 Fig. 1 shows a tandem hot rolling line 12 that receives a continuously cast metallic strand 14 and reduces it to a narrow strip 16 of accurately controlled width and gauge. While this line can hot roll a wide variety of metals and strands having a variety of cross-sectional shapes, it will be described herein with respect to its preferred use, the continuous hot rolling of copper and copper alloy rod having a circular cross section into a narrow strip. This rod is preferably supplied directly from a continuous casting operation of the type described in U.S.-A-4,211,270 and U.S.-A-4,301,857, the disclosures of which are incorporated herein by reference. This rod leaves the caster red hot and advancing at speeds that are usually in the range of 76.2 to 762 cm/min (cpm) (30 to 300 inches per minute (ipm)) depending on the diameter of the rod being cast and the desired production line speed.

The line 12 includes first, second and third hot rolling mill stands 18, 20 and 22, respectively. Each stand is preceded by a gas-fired reheating furnace 24 that raises the temperature of the strand 14 or strip 16 to the
5 desired rolling temperature, typically 760°C (1400°F). The separation between adjacent mill stands is sufficiently short that the strip will not cool substantially (or require excessively long reheating furnaces), but long enough that the speed and gap controls on each stand are
10 able to adjust without adversely affecting the strip, e.g., causing unstable plastic flow. After the strip leaves the third stand 22 it is cooled in a closely coupled quench tank 26 to control oxidation. A gauge area including a laser width gauge 28 and an X-ray thickness
15 gauge 30 follow the quench tank. Width gauges 28 are also mounted at the exit of the last mill stand to provide an immediate measure of the width of the strip 16 as it leaves the mill. Each of these instruments generates a measurement signal that is used to control the operation
20 of the line 12. Each mill also preferably has a two-colour infrared pyrometer (not shown) mounted to measure the temperature of the strip as it enters the mill. The line terminates with a shear 36 and a spooler 38. The shear is used primarily to remove portions of strip that
25 do not meet set tolerances, for example, the initial portion of a strip when the line starts up before the rolls have fully adjusted to a steady state operating condition. The spooler 38 collects the strip 16 in an even, level wound coil on a core.

30

With particular reference to Figs. 2-5, each rolling mill stand 18, 20 and 22 has substantially the same construction. (Like parts are identified with the same reference number, but common parts associated specifically with the
35 second mill are noted with a prime (')) and parts associated with the third mill are noted with a double prime (''). Unprimed numbers refer to parts of the first mill

stands which will be described in detail.) The mill stand 18 is organized around a frame assembly 40 formed primarily of steel I-beams in a generally rectangular array around the passline 16a of the strip 16. Two rolls 42,42 are each mounted in associated chock blocks 44,44 for rotation. The rolls are formed of the material sold under the trade designation Astrolly hipped on a tool steel base. Other suitable materials are the material sold under the trade designation Waspaloy and cemented tungsten carbide.

An hydraulic motor 46 that receives a supply of pressurized hydraulic fluid from an hydraulic power supply 47 drives each of the rolls 42,42. Hydraulic cylinders 48,48 acting through rods 48a,48a and the upper chock blocks 44,44 position the upper roll and apply the necessary downward force to offset the separation force generated by rolling the strip. The rods 48a,48a are each connected to the associated chock blocks through a shear pin 49 (Fig. 7). If unexpectedly large separation forces are generated, the pins 49,49 will shear thereby protecting the frame against possible damage and allowing the use of a structurally weaker (and less costly) frame than would otherwise be safe. The cylinders 48 are preferably 12.7 cm (five-inch) diameter with a 10.16 cm (four-inch) stroke and a 5.08 cm (two-inch) diameter rod capable of operating with applied fluid pressures of 246 kg/cm² (3,500 psi) to generate downward forces of 31752 kg (70,000 lbs) per cylinder or 63500 kg (140,000 lbs.) per stand. The cylinders also preferably include an internal ultrasonic distance measuring device which can measure vertical movement of the rods 48a with a resolution of 0.00254 mm (0.0001 inch). Of course, other standard, commercially available displacement measuring devices such as linear variable differential transformers can be used, but with some loss of accuracy. The cylinders 48,48 are each controlled independently to vary the profile of the strip 16.

The frame has a base member 40a formed of a pair of beams 40a(1) aligned generally parallel to the strip and a pair of cross beams 40a(2) aligned generally transverse to the strip. The beams 40a(1) are located generally under the hydraulic motors 46,46 and the beams 40a(2) support the overlying components of the mill, but are spaced to allow clearance for the rolls and their mountings. The cross beams 40a(2) support a movable motor mounting plate 50 and a fixed motor mounting plate 52. The movable plate 50 is supported on a pneumatic cylinder 54 that counterbalances the motor so that there are approximately equivalent loads in the cylinders 48,48. Upper and lower C-shaped mounting brackets 56 and 58 are secured to the inner face of the plate 50. Each of these brackets supports a vertically oriented slide shaft 60 journalled in an associated pillow block 62 which in turn is mounted on a vertical side frame member 40b. The slide shafts guide the vertical movement of the upper motor. Since the motor mounting plate 52 is fixed to the beams 40a(2),40a(2), the associated hydraulic motor 46 mounted on its outer face and the lower roll 42 driven by this motor do not move vertically during operation (except for a very small deflection due to the separation forces). A spline coupling between the motor 46 and its associated roll 42 is designed to accommodate this deflection.

With particular reference to Figs. 9A-9D, the frame 40 includes four of the side members 40b disposed in pairs to locate and support the chock blocks 44,44 laterally. However, all four chock blocks 44 can slide vertically within the members 40b. The vertical members preferably have cross bars 64 that connect adjacent members 40b on the same side of the rolls. The frame 40 is capped by two upper frame beams 40c,40c that extend in the direction of travel of the strip to bridge one member 40b to another member 40b on the opposite side of the rolls. One end of

each beam 40c is mounted by pivotal movement about a pivot pin 66. When the upper members are in a closed position for rolling, as shown in Figs. 2-4, the opposite end of each member 40c is secured to the adjacent member 40b by a set of bolts 41. The frame 40 is then a compact, comparatively lightweight, yet strong assembly that is capable of containing the separation forces of rolling. A maximum value for the separation forces encountered in hot rolling copper or brass with a high reduction (large bite) is 63500 kg (140,000 lbs). Stated in other terms, each frame should be able to withstand separation forces that produce stresses in the range of 140 to at least 246 kg/cm² (2,000 to at least 3,500 psi). It should be noted that the strength of the frame assembly 40 in combination with the ability to adjust the position of the movable roll accurately and quickly using the cylinders 48 avoids the need for a massive, stiff and quite expensive frame which is common in prior art rolling mills that are subjected to large separation forces.

A principal feature of this invention is that when the bolts 41 are removed, the beams 40c, 40c can be pivoted in unison about the pins 66,66 as shown in Fig. 9D. The cylinders 48,48 are each mounted on one of the beams 40c and pivot in unison with them, provided that a shear pin 55 connecting the lower end of the rod 48a to the associated upper chock blocks 44 has been removed. This "flip top" frame construction allows a direct, unobstructed overhead access to all of the chock blocks and the rolls 42,42 once the beams 40c, 40c are fully pivoted to an open position. Because the chock blocks are freely slidable within the side members 40b (once cooling and lubrication lines and couplings have been disconnected), the rolls and their associated blocks are readily and quickly replaced using an overhead crane (not shown) either individually or as a fully assembled unit of rolls, bearings and chocks.

Roll replacement with the mill stand of the present invention takes approximately fifteen minutes. Roll replacement in comparable conventional mills takes at least one and more typically several hours. This dramatic
5 reduction in roll replacement time is also due, in part, to the fact that the hot rolling mill of the present invention can produce a large reduction in copper and brass strands and strips without back-up rolls. It is also due in part to drive train for the rolls described
10 below and in part to the comparatively small dimensions of the roll and chock assemblies.

With reference principally to Figs. 6 and 17, the rolls 42 of the present invention are characterised by a relatively
15 narrow central working portion 42a having an enlarged diameter as compared to neck portions 42b, 42b journalled in bearing assemblies 70 mounted in each chock block 44. However, the diameter of even this "enlarged" working portion 42a is small, less than 30.5 cm (a foot) and
20 typically 12.7 to 17.8 cm (five to seven inches), as compared to conventional two high rolls used in "break down" mills where there is a substantial reduction in the thickness of the product being rolled and there are large separation forces. The enlarged diameter is particularly
25 important in the rolls of the first mill 18 because the degree to which the strand is spread into a strip configuration is a function of the diameter of the working portion of the roll that engages the strand, with larger rolls giving more spread; but the roll load that develops
30 is less for smaller rolls. Thus rolls must be large enough for bite and adequate spread, but small enough to prevent excess loading and excess roll cost.

Strip width leaving the first stand rolls 42, 42 depends on
35 rod alloy, rod size delivered to the stand, the extent of reduction of thickness within the rolls, roll diameter, and friction conditions in the rolls. A range of strip

width can be obtained from a single rod diameter; width can be varied by changing the extent of reduction. The increase in width is called spread. Spread increases most rapidly at high reductions, with a small incremental
5 reduction in thickness causing a large increase in width. Widths up to three times initial rod diameter can be obtained.

10 It is quite important that the outer working surface of each portion 42a is inverse "crowned", that is, it has a concave profile receding, when the roll is cold, to a point of maximum depression 43 ,43' that is centered on the passline of the strand or strip being rolled as shown in Figs. 17A and 17B, respectively. As shown in a heavy
15 solid line in Fig. 17A, the profile 45 for the rolls in the first mill 18 is preferably V-shaped along the longitudinal axis of the roll. In the second and third mills 20 and 22, the profile 45 is preferably a truncated V-shape as shown in a heavy solid line in Fig. 17B, that
20 is, with sloped sides that meet at a central portion with a constant diameter. The precise contour depends on the thermal response of the roll and the size, shape and temperature of the product being rolled. In any event, after thermal stabilisation, the outer surface of the
25 portion 42a is generally flat, but with a slight recess near the center point (light, solid line profiles in Figs. 17A and 17B) to produce a rolled product that has slightly more material near its centerline than its edges.

30 This roll design, which results in a rolled strip with a slightly "fat" middle portion, has been found to be surprisingly effective in holding the product centered laterally on the rolls despite the presence of sometimes substantial tendency for the strand or strip to "wander"
35 laterally otherwise. This control has been found to be so effective that centering guide rolls at the entrance side of the mill are preferably used only on the second and third mill stands 20 and 22 where this profiling must be

reduced in order to produce a final output product with a uniform gauge across its width. By way of illustration only, the rolls of the first mill stand have a central working portion with an edge diameter of 187.325 mm (7.375 inch) (cold) that recedes to a minimum diameter of 187.071 mm (7.365 inch) (cold) at the strand passline 16a which is normally coincident with the point 43. At the second mill stand, a typical roll has a working portion with a diameter of 149.225 mm (5.875 inch) (cold) that recedes to a central area, the point 43', with a constant minimum diameter of 149.022 mm (5.867 inch) (cold).

Another factor in the thermal response of the roll is the degree to which the roll is cooled. In the present invention, the roll has an internal, longitudinally extending passage 42c that conducts a flow of cooling water from a "quick disconnect" inlet 72 in one chock block to a "quick disconnect" outlet 74 in the opposite chock block. The passage 42c preferably has an enlarged central volume 42d within the roll portion 42a to increase the cooling at this portion. The diameter of the passage 42c and volume 42d are selected so that the roll thickness is adequate to maintain a hot roll surface temperature, thus preventing quenching of the rolled strip. The cooling water is directed from the inlet and outlet to the passage 42b via radial channels 42e in the neck portions of the roll, an annular passage 76 in the chock block, and a passage 78. A typical flow rate for the cooling water is 15 litres (four gallons) per minute for each roll. Preferably the flow in each of the rolls 42,42 is in opposite directions so that the strip will be exposed to similar cooling across its width. Those skilled in the art will thus appreciate that the chocks 44 provide a compact support for the rolls while at the same time providing continuous lubrication and a rotary union for the introduction of the cooling liquid into the roll.

It should be noted that the working area of the rolls 42,42 span a comparatively small distance between the chock blocks 44,44. Stated conversely, most of the roll length is taken up by the neck portions 42b,42b which are supported almost along their entire length by the chock blocks and the associated bearing assemblies. This geometry is a principal reason that a small diameter roll design works despite the substantial separation forces that are present. It should also be noted that a small side clearance is designed into each roll 42 to accommodate lengthwise thermal expansion of the roll, but to limit the lateral movement of the roll once it is at its usual operating temperature.

Each roll 42 is driven independently by one of the hydraulic motors 46. There is therefore no gearing or other power transmission coupling which is usually employed to transmit power from one driven roll to another slave roll or rolls. Another feature of the present invention is that the motors are coupled directly to the rolls through a spline coupling assembly 80 including a "roll half" 80a found integrally with one end of each roll and mating "motor half" 80b mounted on the drive shaft 46a of the motor. To connect the motor to the roll, the coupling halves 80a and 80b are simply mated and bolted to one another. This coupling allows rolls to be changed easily. Using this direct drive, the "stiffness" of the drive train is substantially increased. This makes both rolls 42,42 more responsive to servo changes in the drive. Also, the comparatively few components in the roll drive produces drives for the two rolls 42,42 that are more closely matched in stiffness than conventional prior art drives.

This simple coupling is possible due to the use of hydraulic motors that provide a high torque (in excess of 1356 Nm (1,000 ft-lbs)) at a low rpm (less than 400, and

often less than 100). The hydraulic motors 46,46 are preferably the radial piston type with adjustment in the speed output provided by a swashplate in the hydraulic power supply 47. With this arrangement, the pressure
5 across the motor can be varied to maintain the rolled strip at a constant speed. This drive system provides a precise and responsive control over the power supplied to the rolls 42,42. For the first mill stand 18, the motors 46,46 preferably operate at 251 kg/cm^2 (3,570 psi)
10 pressure (281 kg/cm^2 (4,000 psi, peak)) to produce a required total torque of 16,948 Nm (12,500 ft-lbs) (23524 Nm (17,350 ft-lbs,) peak) at a maximum speed of 34.5 rpm (2032 cpm with a 17.78 cm roll) (800 ipm with a seven-inch roll). The reduction and spreading at the
15 second and third stands are less and therefore they have lower requirements. Since the strip is moving faster after each reduction, speed requirement of the motors goes up in each stand. The second stand 20 preferably utilises motors 46',46' of the same type as the motors 46,46 but
20 ones which produce a required total output torque of 8813 Nm (6,500 ft-lbs) (11199 Nm (8,260 ft-lbs,) peak). The motors 46",46" of the third mill stand preferably have a required total output torque of 3390 Nm (2,500 ft-lbs) (3525 Nm (2,600 ft-lbs,) peak).

25
With reference to Figs. 10-16, the mill stands 18, 20 and 22 each include an entrance guide assembly 90 that can guide the strand 14 or strip 16 to the gap between the working portions of the rolls and also provides a partial
30 enclosure to control the atmosphere around the reheated product before it is rolled. The assembly 90 is organised around a tube-like enclosure 92 that is mounted to the frame 40. The enclosure 92 extends from a point immediately adjacent the associated reheater to a point immediately
35 before the rolls and is bolted to the frame assembly 40 so that it is readily removable. A reducing atmosphere that controls oxidation of the strand or strip is produced in the reheater. The enclosure receives this atmosphere

and holds it around the hot product. Alternately, the entrance guide can include its own burner that produces a reducing gas atmosphere. This arrangement is usually of value only for copper which reduces more readily at
5 working temperatures than copper alloys such as cartridge brass.

Some degree of vertical guidance, useful primarily on the third mill stand 22, is provided by a set of horizontal
10 rollers 94,94 located in the enclosure 92" and rotatably journalled in mounting blocks 96,96 that travel along a threaded shaft 98. Rotation of the shaft through a worm gear 100 adjusts the relative position of the rollers 94,94 to guide strand or strips of varying dimensions into
15 the nip of the rolls 42",42". A coarse degree of lateral guidance, useful primarily during start up, is provided by a pair of mutually inclined plates 102,102 that funnel the product to the center of the roll portions 42a",42a". Lateral guidance can also be provided by vertical guide
20 rollers 104,104 mounted for rotation in the enclosure 92. However, if they are spaced closely enough to the strand or strip to provide any reasonable degree of guidance, it has been found that the forces tending to displace the product are sufficiently strong that the rollers 104,104
25 produce only a highly localised guidance. If they are used, the product is guided in grooves 104a,104a having a square cross section. Other configurations have proven to be significantly less effective. Usually only the vertical rollers 104',104' and 104",104" at the second and
30 third mill stand 22 provide a significant degree of guidance of the strip once it is between the rolls.

Because the product being rolled is hot and the separation forces are significant, there is a substantial transfer of
35 metal from the product to the rolls where it can adhere and accumulate. This problem is especially troublesome with softer, non-ferrous metals such as copper, brass and

aluminium. The hot rolling mills of the present invention provide two systems to control this problem, first, a system 110 that sprays a release agent onto the exterior of the rolls to reduce adhesion, and second, a mechanical
5 brushing system 140.

As is best seen in Figs. 10, 10A and 21, the spray system includes primary and auxiliary nozzles 112, 112a that spray each roll portion 42a with a fan-like spray S of the
10 release agent that covers the outer surface of the roll portion 42a. The particular release agent chosen will depend on factors such as the type of metal being rolled, the degree of reduction and the temperatures of the product and the roll. Where the reduction in gauge is
15 more moderate, the release agent can be any of a wide variety of known ingredients which provide some degree of lubrication. Where the reduction is more substantial (the first mill stand 18), it is also necessary to use a "gritty" ingredient such as clay carried in a water
20 suspension. It also helps if the clay resists flocculation. In the production of copper strip, for example, a mixture of water, a water soluble lubricant, and clay are useful at the first mill stand 18, while water alone can be an effective release agent and lubricator at the second
25 and third mill stands 20 and 22 (although water and a water soluble lubricant are preferred).

The release agent is mixed in tanks A and B (Fig. 21) and at least tank B containing the "gritty" solution is
30 maintained in a constant agitation by an agitator 114 or the like to hold the particulate matter in suspension. Preferably a lubricating solution 116 is mixed in the tank A and a "gritty" solution 118 is mixed in the tank B. The solutions from both tanks are then fed to the nozzles
35 112, 112a. Because there is usually a particulate held in suspension, there is a substantial risk of clogging of the feed lines 120, 122. Therefore, the solution is pumped

intermittently from the tanks to the nozzles and the feed lines are purged with water after use.

With reference to Figs. 10, 18 and 19, the brush system
5 140 constantly removes metal, oxide, and release agent
which nevertheless adheres to the roll portions 42a,42a.
It includes a rotary brush 142 that rotates against the
outer surface of each roll portion 42a at a high rota-
tional speed, e.g., at least 2000 rpm and preferably 3,000
10 rpm. The brush also has a comparatively large diameter,
e.g., ten inches, which together with this high rotational
speed produces a large swept surface area per minute.
Also, because the brush is cylindrical and rotates
rapidly, its bristles impact the roll at a high velocity.
15 As a result of these features, the metal is removed
efficiently from the rolls and does not collect in a small
area (as with the scraper) where it could score the roll.
The bristles are preferably formed of high carbon steel.

20 The brush 142 is mounted rotatably at one end of a frame
144 in friction (sleeve) bearings 143,143. At the
opposite end, the frame is replaceably held in a pivot
mount secured to the mill frame 40 by a pivot shaft 146
and a pair of U-shaped mounting brackets 144a,144b. An
25 hydraulic motor 148 mounted on the frame drives a pair of
belts 150,150 that in turn rotate the brush. The loading
of the brush against the rolls is controlled by an air
cylinder 152 connected between a cross bar 145 linking the
mounting brackets 144a,144b and the pivot end of the frame
30 140. A spring 154 located on the opposite side of the
frame 140 from the air cylinder provides a counterbalanc-
ing force. The friction bearings together with the spring
154 also damp vibrations induced in the brushing system
during use. In one extreme position, the cylinder pivots
35 the frame so that the brush is spaced from the rolls.
Intermediate positions, in combination with the spring
154, provide varying loading forces. An optimal loading

force removes all of the accumulated metal from the rolls without significantly increasing bristle wear or loss. A typical value for the loading force is 11.34 kg (25 lbs). The precise value will vary with factors such as the
5 nature of the metal, the size of the rolls and the brushes, the rate of bristle wear, the rate of loss of bristles from the brush, the diameter and rotational speed of the brush, and wear or possible damage to the roll.

10 In operation the line 12 continuously hot rolls a metallic strand 14 into a strip 16 (Fig. 20) having a highly uniform configuration and a recrystallised grain pattern. The line preferably operates to roll copper or copper alloy rod into narrow strips. In addition to rolling the
15 strand or strip, each mill, and in particular the first mill 18, act as drives for the strand or strip. The speed at which the strand and strip is driven by the mills is controlled to maintain a tension in the strand and strip without unstable plastic flow due to excessive tension.

20

Relatively simple controls are required to operate these tandem mills. The first stand (regardless of the reduction) controls the casting rate of the caster. The second stand gap and speed is controlled by means of a
25 manual "reduction ratio" setting. At zero reduction, the speed and gap of the second stand matches the speed and gap of the first stand. As the reduction in the second stand is increased (manually), the speed increases automatically in the proper ratio (speed in X thickness in
30 = speed out X thickness out) to maintain tension in the strip. By leaving sufficient distance between roll mill stands, the strip has room to stretch slightly without unstable plastic flow. We have found that a simple control system without feedback controls is sufficient to
35 control mill speed adequately. Similar considerations apply for control of third stand mill speed, and resulting inter-stand strip tension between the second and third mill stands.

The first mill 18 acts principally as a rough "break down" mill which transforms red hot rod into a relatively thick gauge narrow strip with a width substantially equal to the final width of the finished strip. There is a large bite and a substantial spreading of the strand at the first mill. The second mill 20 is another "break down" mill. It reduces the gauge of the strip while substantially maintaining the width set by the first mill. (As a rough rule of thumb, reductions are accompanied by small increases in the width of approximately the same magnitude as the reduction itself.) The line speed is maintained automatically by having the second mill run at a higher rotational rate than the first mill set mainly by the reduction in thickness. The third mill 22 is principally a hot finishing mill that sets the final gauge and width and produces an output strip with a substantially uniform gauge across its width that is also comparatively free of camber. Again, the third mill operates automatically at a higher rotational rate than the second mill to maintain the line speed with the reduction introduced by this mill, but also to maintain the interstand tension in the strip without unstable plastic flow in the strip. Thus the mill controls automatically vary mill speeds in the second and third stands depending on reductions in those stands.

By way of example, but not of limitation, the first mill stand has "17.78 cm" ("seven inch") rolls and the second and third having "13.97 cm" ("five and one-half inch") rolls. Each mill stand is capable of withstanding a maximum separating force of 63,500 kg (140,000 lbs). The maximum rpm's of the stands 18, 20 and 22 are 37, 202 and 500, respectively. The corresponding maximum surface speed of the strip 16 at these stands is 2065, 8854.6 and 21844 cpm (813; 3,490 and 8,600 ipm), respectively. In a typical run beginning with 28.6 mm (1-1/8 inch) diameter brass strand cast at 254 cpm (100 ipm), the first mill

stand produces a strip approximately 3.81 mm (0.150 inch) thick, and 66.55 mm (2.62 inch) wide at 642.6 cpm (253 ipm). The second and third mill stands generally maintain this width while reducing the section to 1.9 mm (0.075
5 inch) by 68.33 mm (2.69 inch) and 0.99 mm (0.039 inch) by 69.34 mm (2.73 inch), respectively. The surface speed at the second and third mills is 1250 and 2360 cpm (492 and 929 ipm), respectively.

10 As another example, the hot roll mill of this invention, when used in tandem three mill operation, can transform 5.08 cm (two inch) diameter copper strand cast at 165.1 cpm (65 ipm) into a strip 0.305 mm (0.012 inch) thick by 81.3 mm (3.2 inch) wide at 13970 cpm (5,500 ipm).
15 The thickness at the first mill is 6.1 mm (0.24 inch) and at the second mill 0.965 mm (0.038 inch). The separating forces at each mill are approximately 39916 kg, 62142 kg and 27669 kg (88,000 lbs, 137,000 lbs, and 61,000 lbs), respectively. The torque applied to the rolls at the
20 stands are 13151 Nm, 6101 Nm and 1022 Nm (9,700 ft-lbs, 4,500 ft-lbs, and 754 ft-lbs), respectively.

There has been described a novel, two high hot rolling mill with small diameter rolls and a process utilising
25 this mill that are capable of producing a narrow strip of copper or copper alloys from a continuously cast strand. The rolling is characterised by a large bite with only one pass in each millstand. The strip material has a recrystallised grain pattern and the final product has
30 precisely controlled dimensions with a uniform gauge. Preferably the process uses three tandem two-high mills that produce this reduction and spreading without slippage. The rolls of at least the first and second mills are self-centering to control the lateral position
35 of the strand or strip. They also accommodate for thermal expansion. These objectives are achieved using a mill that is markedly more compact, lightweight and less costly than comparable conventional mill stands. Further the

mill stands of the present invention allow a change of rolls with an overhead crane in a markedly reduced time as compared to conventional mills of comparable operating characteristics. The mill stand of the present invention
5 also has systems for controlling the transfer and accumulation of metal on the working rolls and systems for continuously and automatically monitoring the operation of the mills and providing feedback control signals to produce a preselected end product.

10

While the invention has been described with reference to its preferred embodiment, it will be understood that various variations and modifications will occur to those skilled in the art from the foregoing detailed description
15 and the accompanying drawings. Such variations and modifications are intended to fall within the scope of the appended claims.

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Claims:

1. A mill for continuously rolling hot metallic strand into a strip with a large bite and a low bite ratio
5 comprising,
a frame,
a pair of rolls, oriented generally parallel to one another, said rolls each having a comparatively small diameter,
10 means for mounting said rolls in said frame, said mounting means being movable to allow a variation in the gap between said rolls,
means for driving said mounting means for at least one of said rolls to produce said high reduction and to
15 set said gap, and
means for rotating each of said rolls at a relatively low speed and at a relatively high torque.
2. A hot rolling mill according to claim 1 characterised
20 in that said rolls each have a comparatively narrow working portion located between the associated ones of said mounting means, said working portion having a diameter that is greater than that of adjacent portions of said roll.
- 25
3. A hot rolling mill according to claim 2 characterised in that the outer surface of said working portion is crowned to accommodate for thermal expansion and produce a rolled strip with slightly more metal at its center than
30 at its edges.
4. A hot rolling mill according to claim 2 or 3 characterised in that each of said rolls has an interior passage that carries a circulating cooling liquid.
- 35
5. A hot rolling mill according to any one of the preceding claims characterised in that said drive means

includes a pair of drive members that each act on a separate one of said mounting means for one of said pair of rolls, said drive members being independently adjustable to vary the profile of said strip.

5

6. A hot rolling mill according to claim 5 characterised in that the other of said pair of rolls and its associated mounting means and rotating means are fixed.

10

7. A hot rolling mill according to any one of the preceding claims characterised in that said rotating means comprises an hydraulic motor associated with each of said rolls.

15

8. A hot rolling mill according to claim 7 further characterised by means for directly coupling said hydraulic motors to their associated rolls.

20

9. A hot rolling mill according to claim 8 characterised in that said hydraulic motor is a radial piston motor with an adjustable swashplate pumping system to control said rotation.

25

10. A hot rolling mill according to any one of the preceding claims characterised by the provision of means for preventing the accumulation of strand material on said rolls during said reduction.

30

11. A hot rolling mill according to claim 10 characterised in that said accumulation preventing means includes rotary brush means that engage the outer surfaces of said rolls.

35

12. A hot rolling mill according to claim 11 characterised in that said rotary brush means includes a mounting frame, a rotary brush mounted at one end of said frame, a

motor mounted at the other end of said frame, and means for adjustably loading said brush against an associated one of said rolls.

5 13. A hot rolling mill according to claim 12 characterised in that said adjustable loading means includes a pivoted mounted means for said frame and means for driving said frame about said pivot means in a direction that produces said loading.

10

14. A hot rolling mill according to claim 10 characterised in that said accumulation preventing means includes a system for spraying a release agent onto said rolls.

15 15. A hot rolling means according to any one of the preceding claims characterised by means for guiding said strand into said gap between said pair of rolls.

20 16. A hot rolling mill according to claim 15 characterised in that said guide means includes an enclosure that provides a protected atmosphere for the strand prior to said reduction.

25 17. A process for continuously rolling hot metallic rod into a high quality narrow strip of accurately controlled dimensions using only one pass per mill stand to nevertheless produce a large total reduction, comprising the steps of

30 providing a pair of rolls that engage the rod at a working portion of said rolls characterised by having a diameter that is comparatively small yet large enough to produce said large bite without any significant slippage between said working portions and the rod,

35 mounting said rolls for a relative vertical movement to vary the gauge and control the wedge of the strip, urging said rolls toward one another, and

rotating each of said rolls at a high torque and a controlled speed of rotation,

whereby said rolling not only produces said large bite reduction in thickness but also sets the width of said strip at substantially its maximum value in a first rolling pass.

18. A process according to claim 17 characterised by the step of continuously removing metal that adheres to said rolls.

19. A process according to claims 17 or 18 further characterised by the step of continuously inhibiting the adhesion of said metal on said rolls.

20. A process according to claim 18 characterised in that said continuous removing includes the steps of rotary brushing each of said working portions at a high speed.

21. A process according to claim 19 characterised in that said continuous inhibiting comprises spraying a release agent onto said rolls.

22. A process according to any one of claims 17 to 21 further characterised by providing a second such rolling process in tandem with said large bite rolling which substantially reduces the gauge of the strip without substantially changing its width, the roll rotating speed of said second rolling process being at a higher rate than that of said low speed of rotation, but at a value that does not produce unstable plastic flow in the strip due to excessive tension.

23. A process according to claim 22 further characterised by a third such rolling process in tandem with said large bite rolling and said second rolling process that reduces

the gauge of the strip to a final preselected value without substantially changing its width, the roll rotating speed of said third rolling process being at a higher rate than that of said second rolling process, but at a value that does not cause unstable plastic flow in the strip due to excessive tension.

24. A process according to any one of claims 17 to 23 characterised in that said urging and said rotating also propel the rod and the strip through said rolling process.

25. A process according to any one of claims 17 to 24 further characterised by the step of providing a longitudinal profile on the outer surface of said roll working portions that produces a rolled strip, after thermal stabilisation, that has a slight excess of metal near its center as compared to its edges, said excess acting to self-center the rod and strip on said working portions.

26. A process according to any one of claims 17 to 25 further characterised by the step of continuously cooling said pair of rolls.

27. A process according to claim 26 characterised in that said cooling comprises the steps of forming a central, longitudinally extending passage in each of said rolls and directing a flow of liquid through said passage.

28. A process according to any one of claims 17 to 27 characterised in that said rotating comprises the steps of providing a variable output hydraulic motor for each of said rolls and coupling said motor to an associated one of said rolls directly.

29. A narrow metal strip product having accurately controlled dimensions and a recrystallised grain pattern formed by the process of any one of claims 17 to 28.

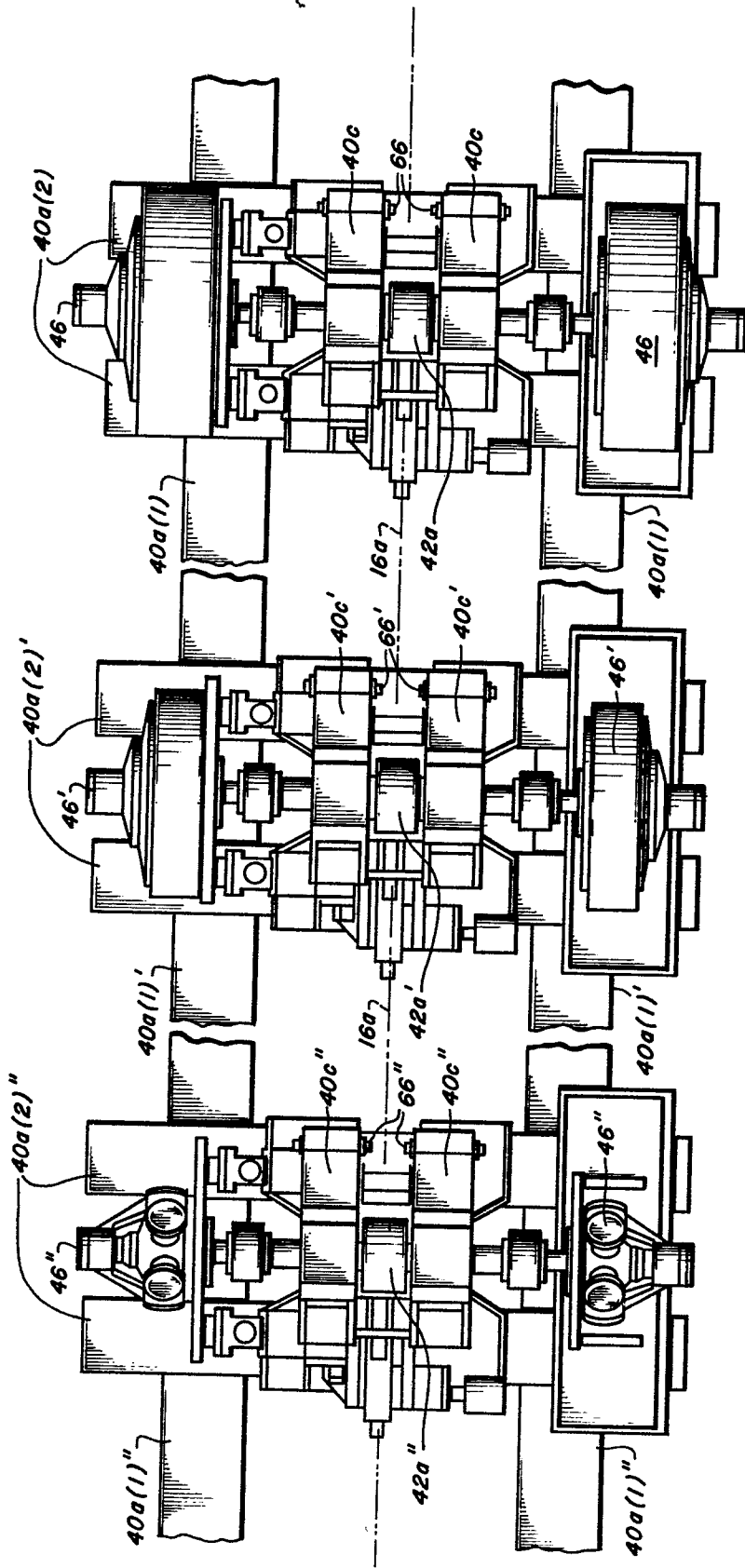
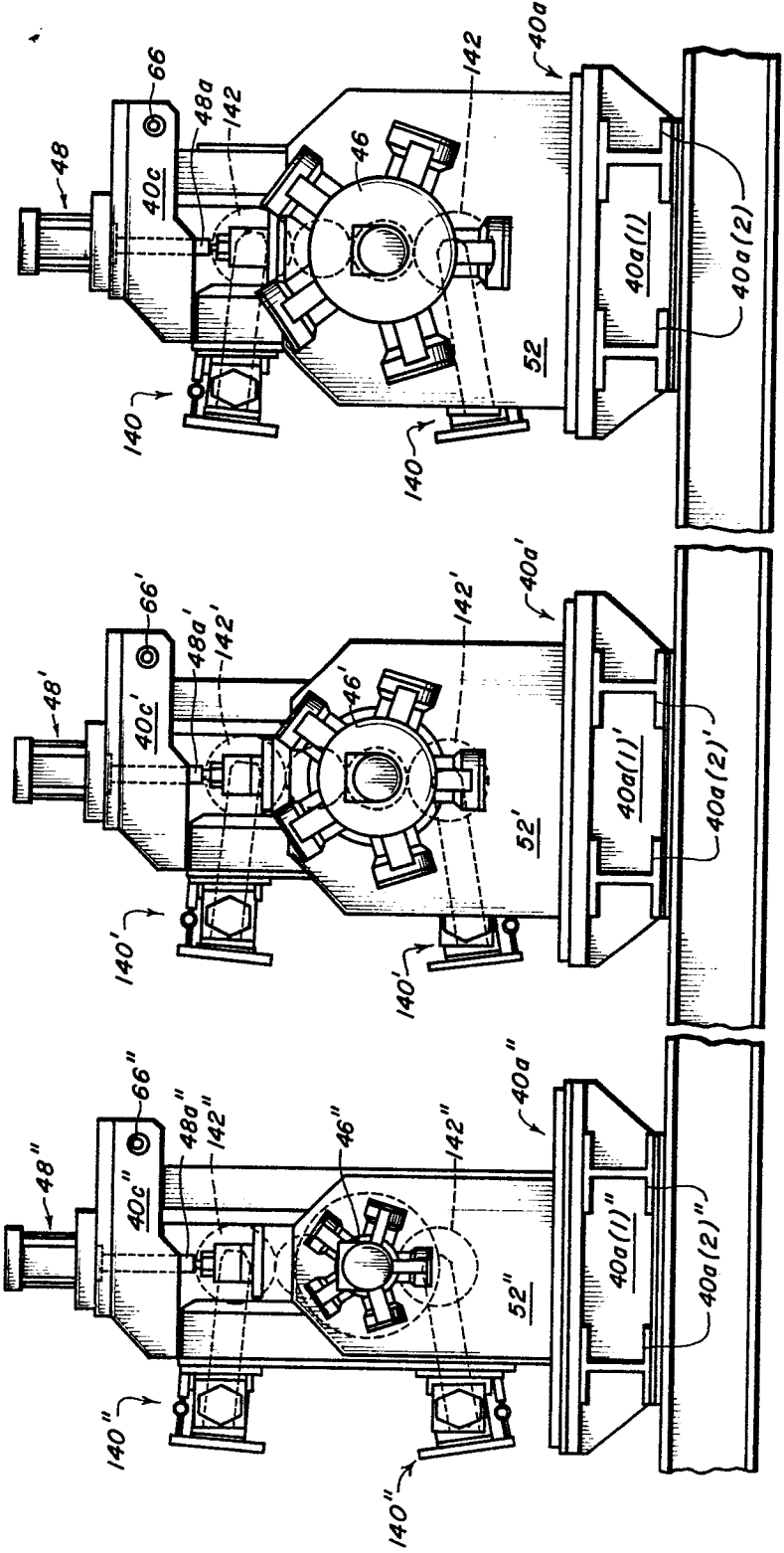


FIG. 2



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FIG. 3

FIG. 4

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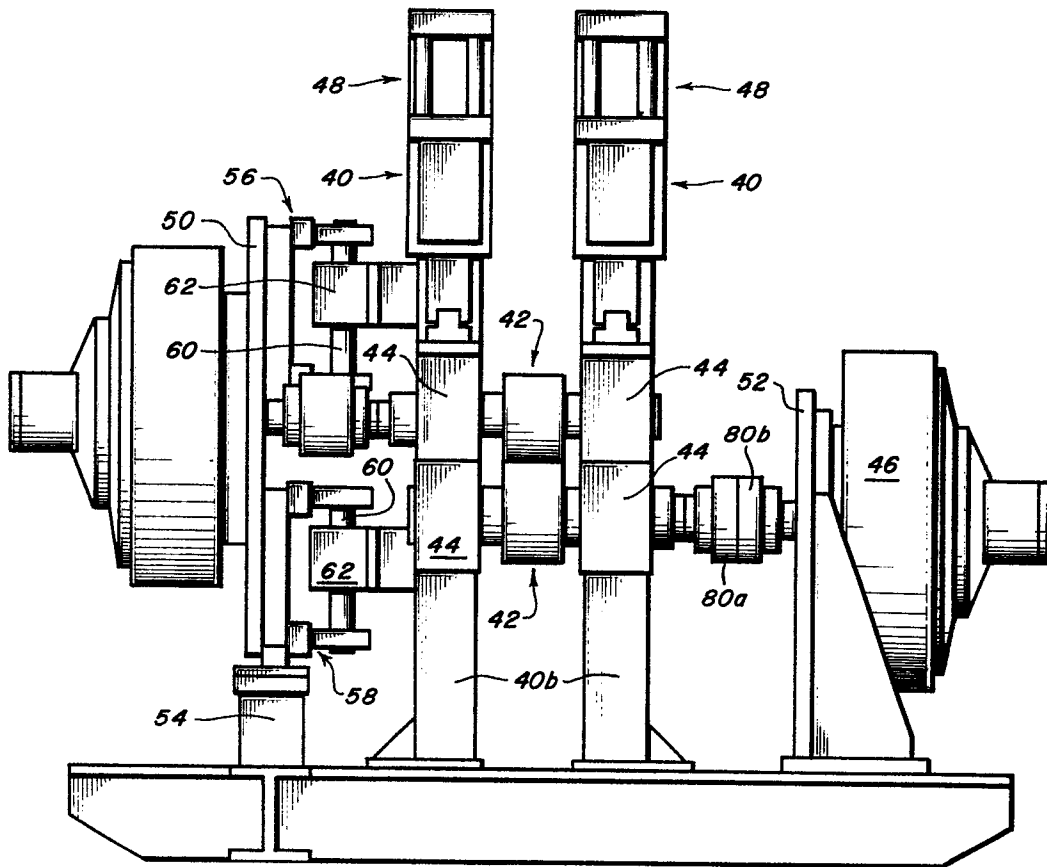
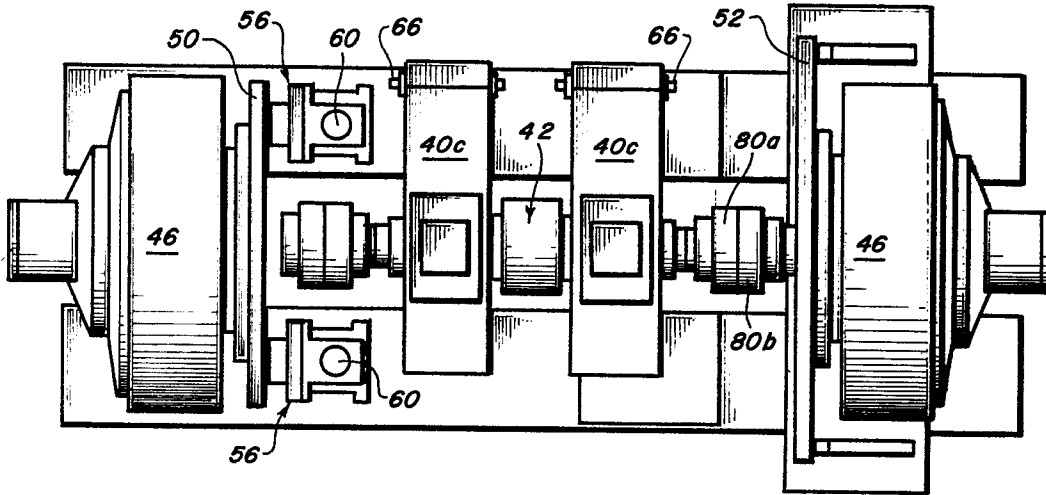


FIG. 5

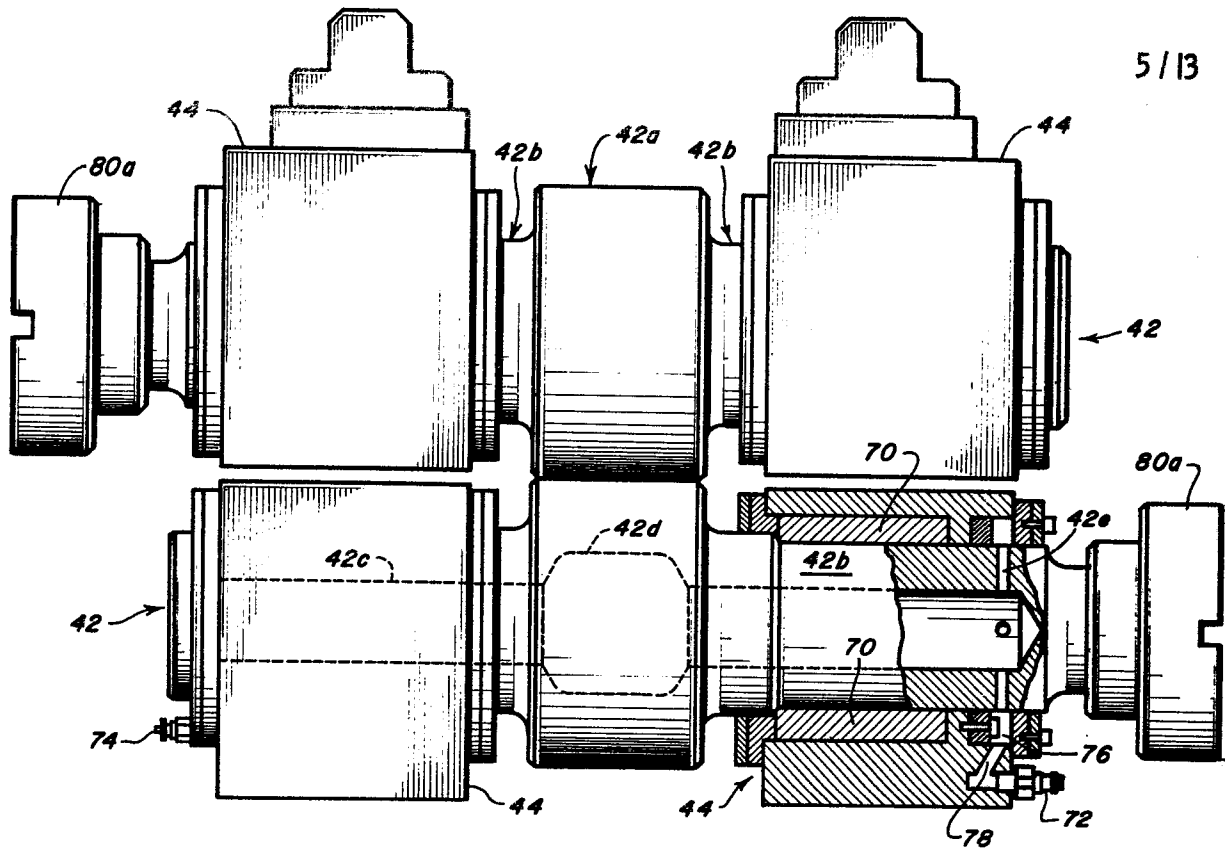


FIG. 6

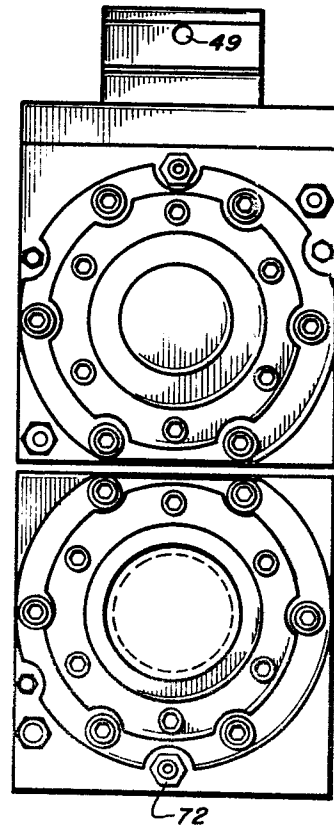
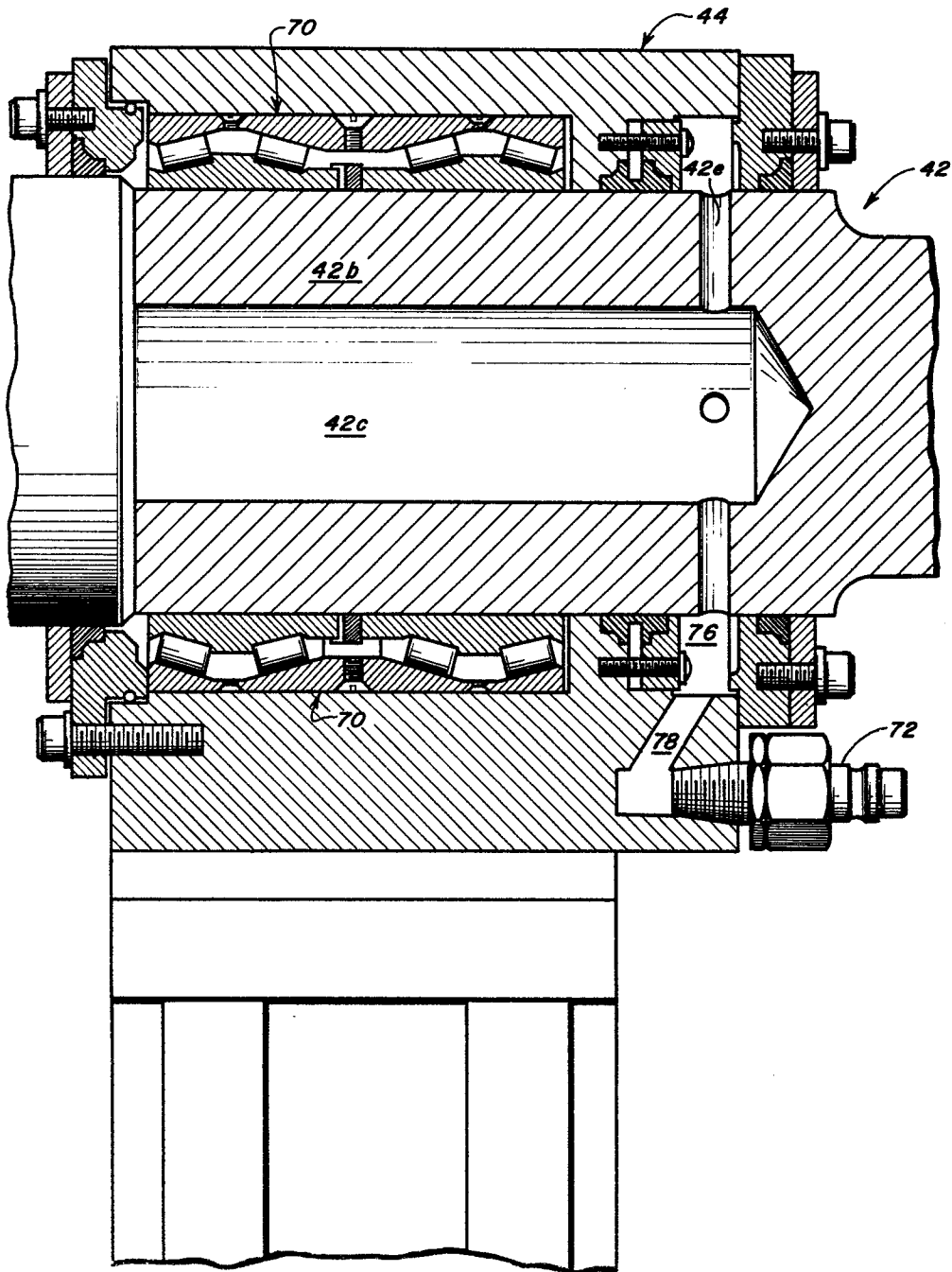


FIG. 7

FIG. 8

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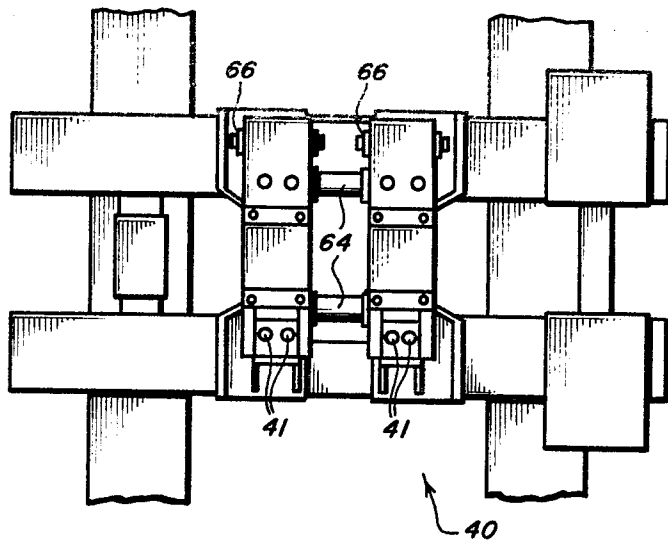


FIG. 9C

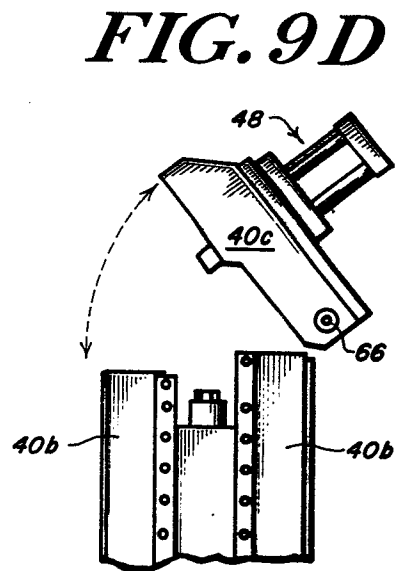


FIG. 9D

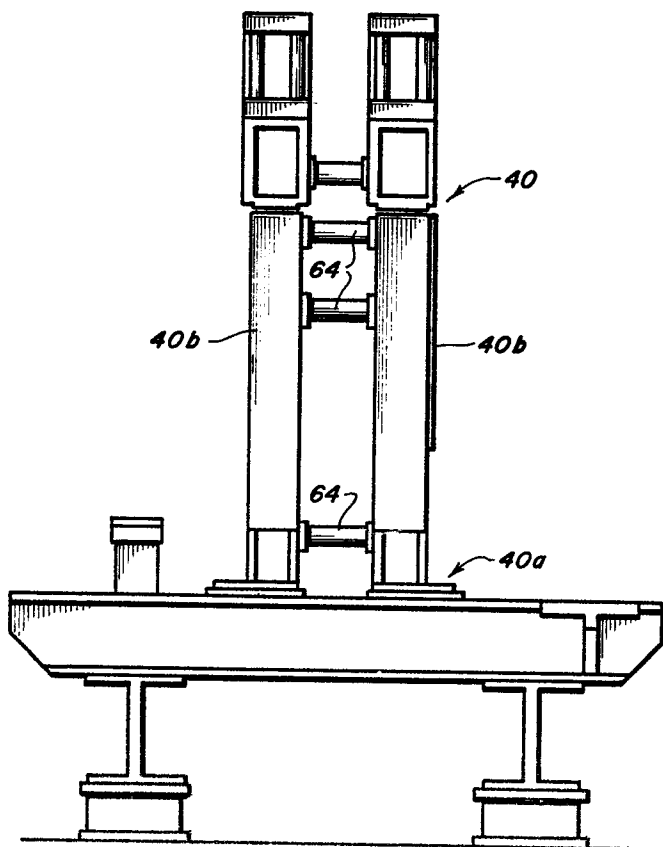


FIG. 9A

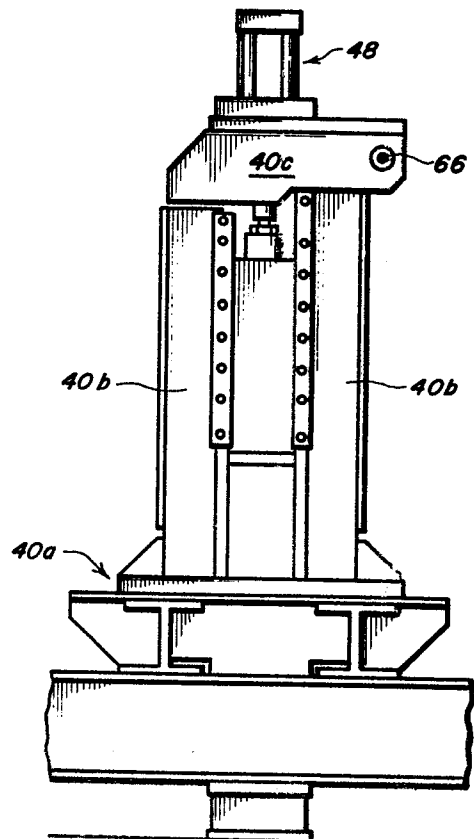


FIG. 9B

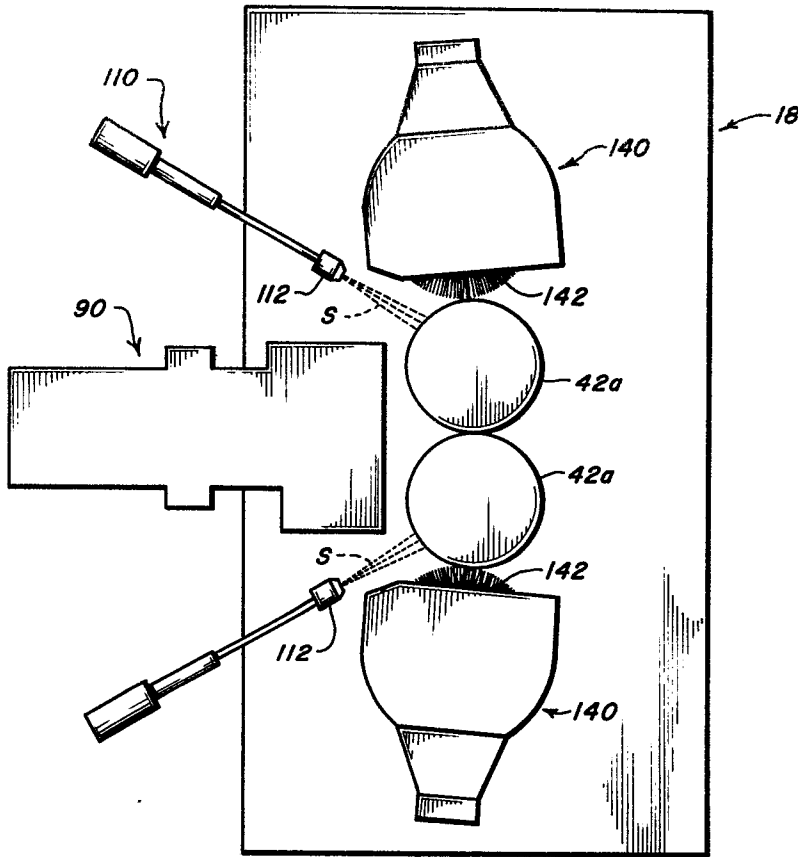


FIG. 10

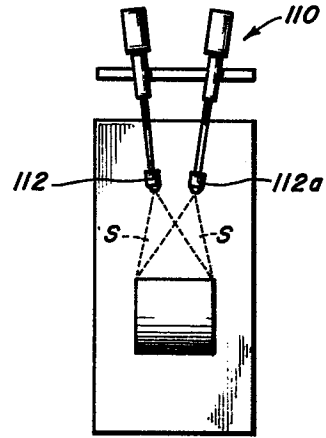


FIG. 10A

FIG. 17A



FIG. 17B

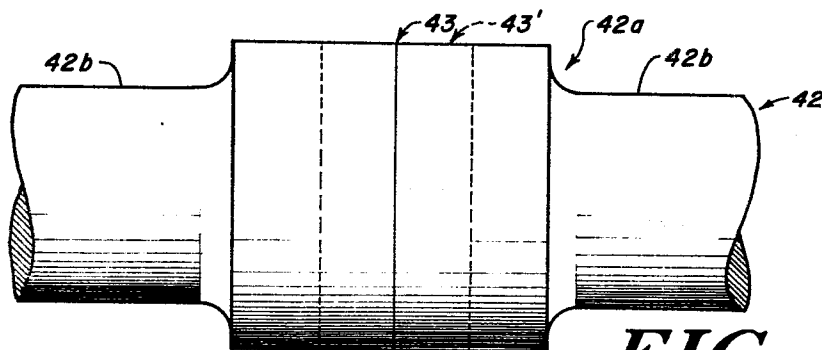
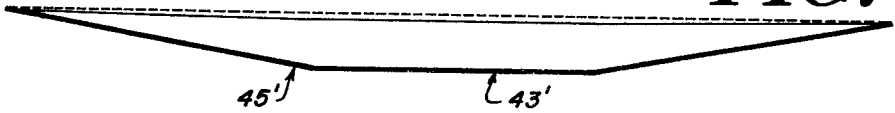


FIG. 17

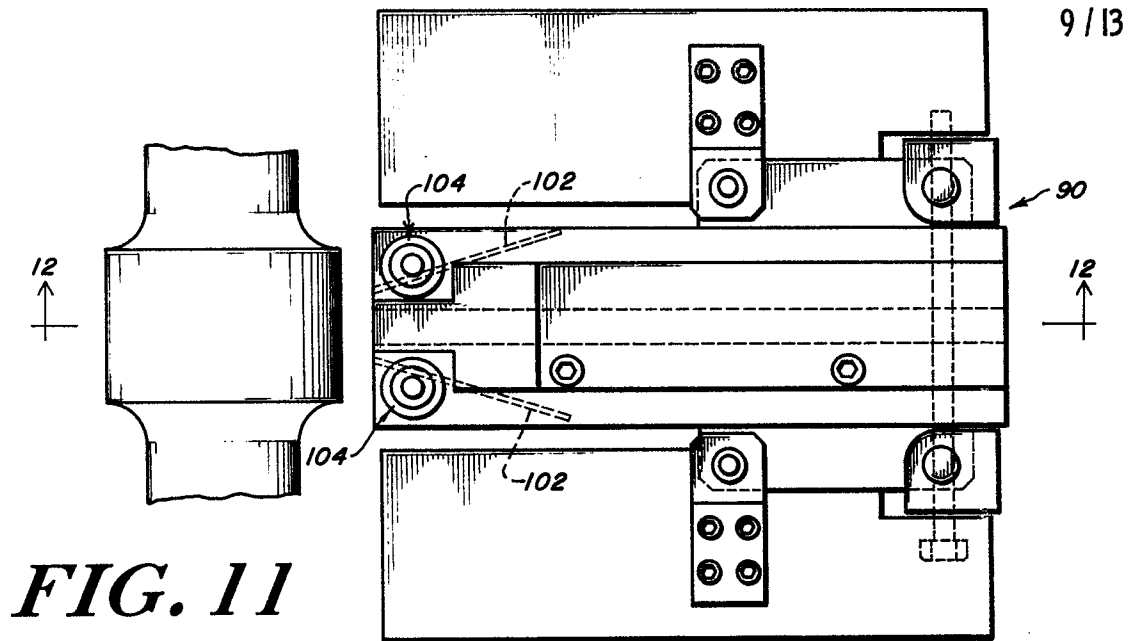


FIG. 11

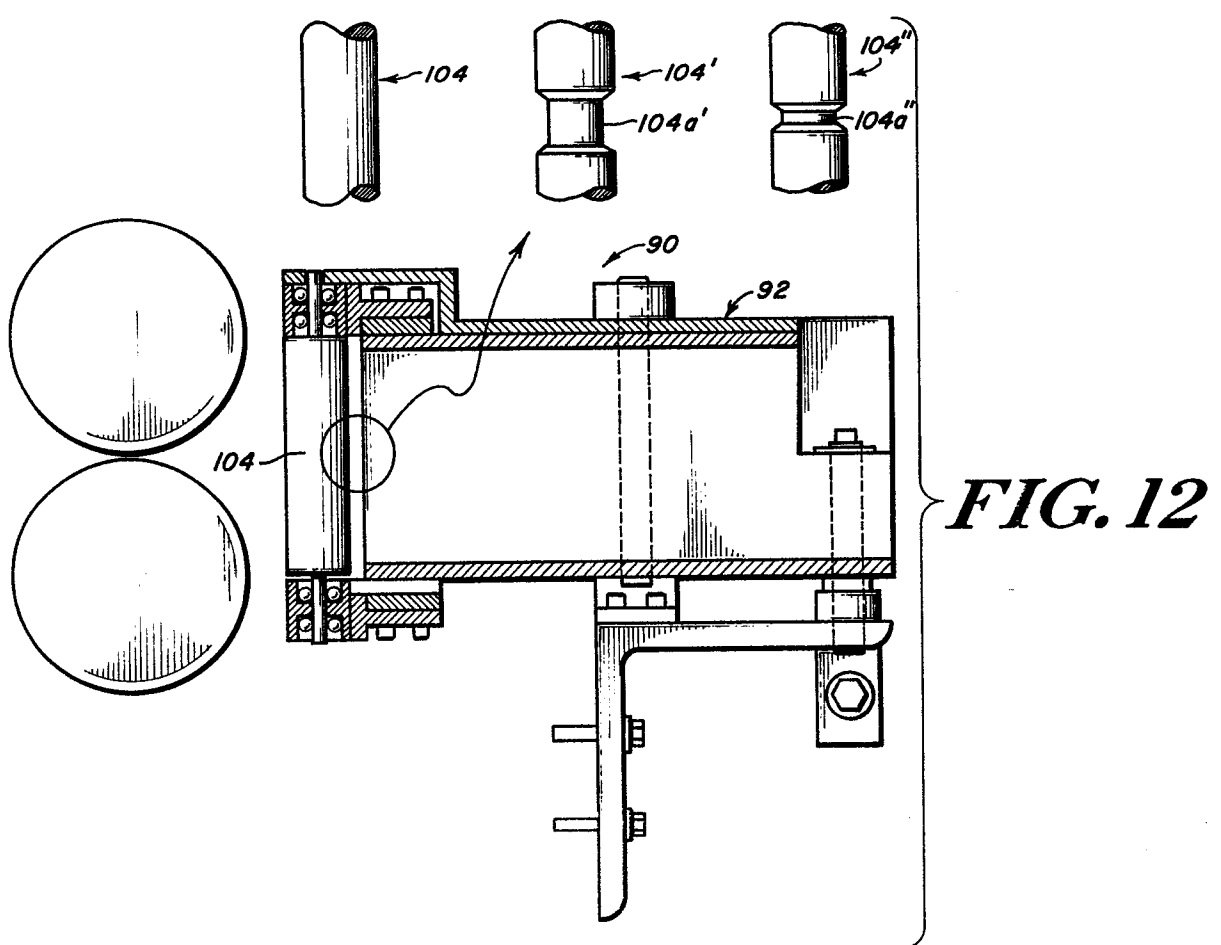
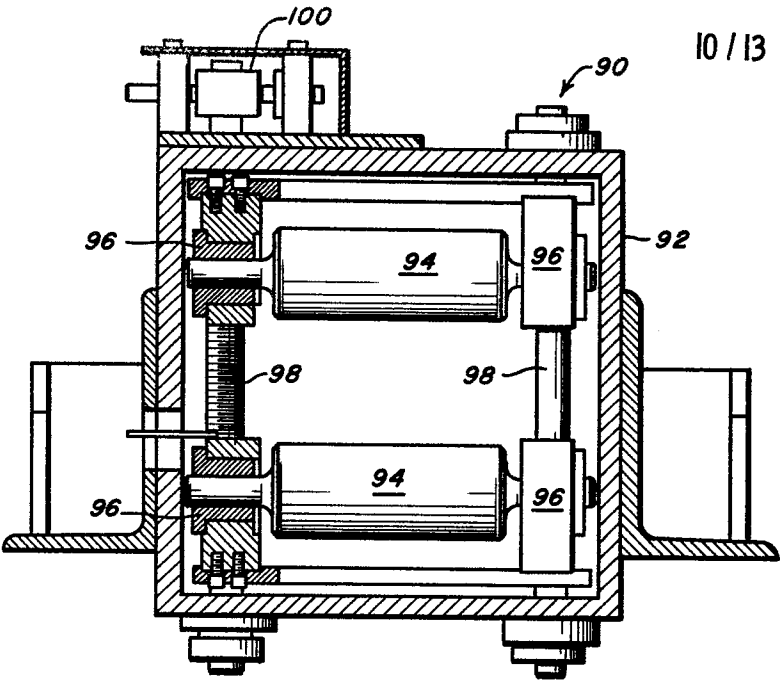


FIG. 12



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FIG. 13

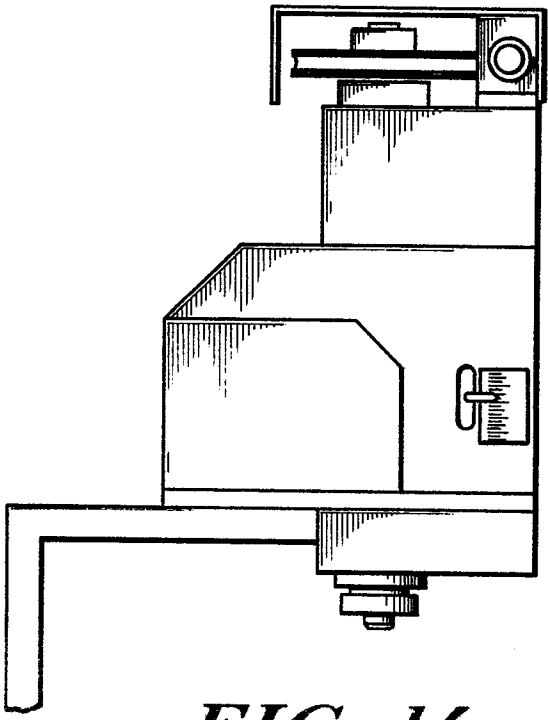


FIG. 14

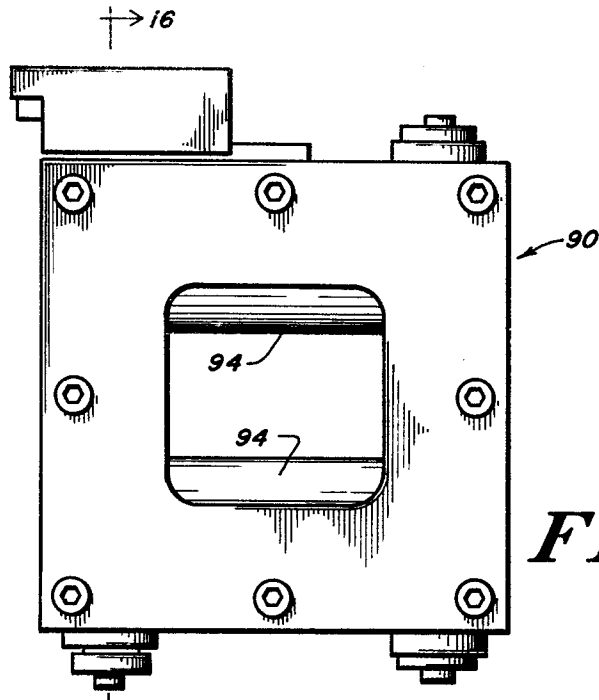


FIG. 15

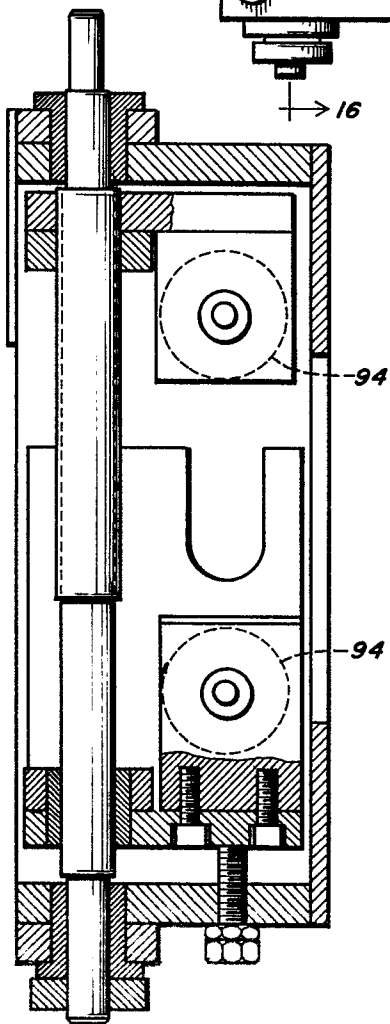


FIG. 16

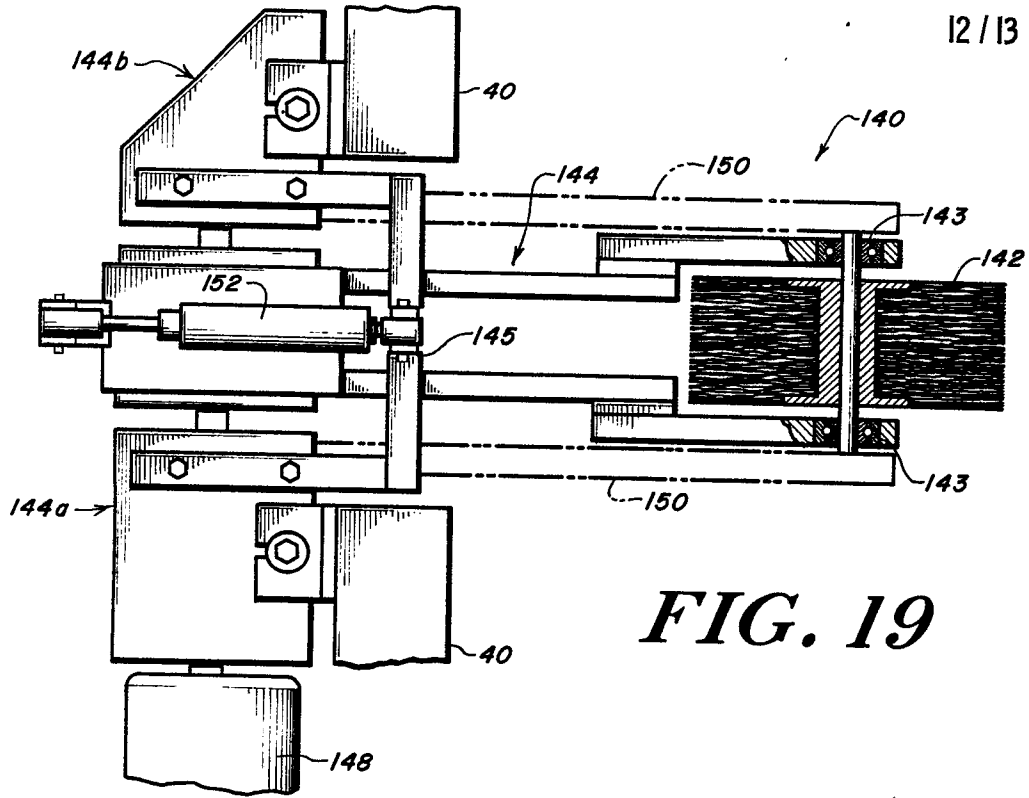


FIG. 19

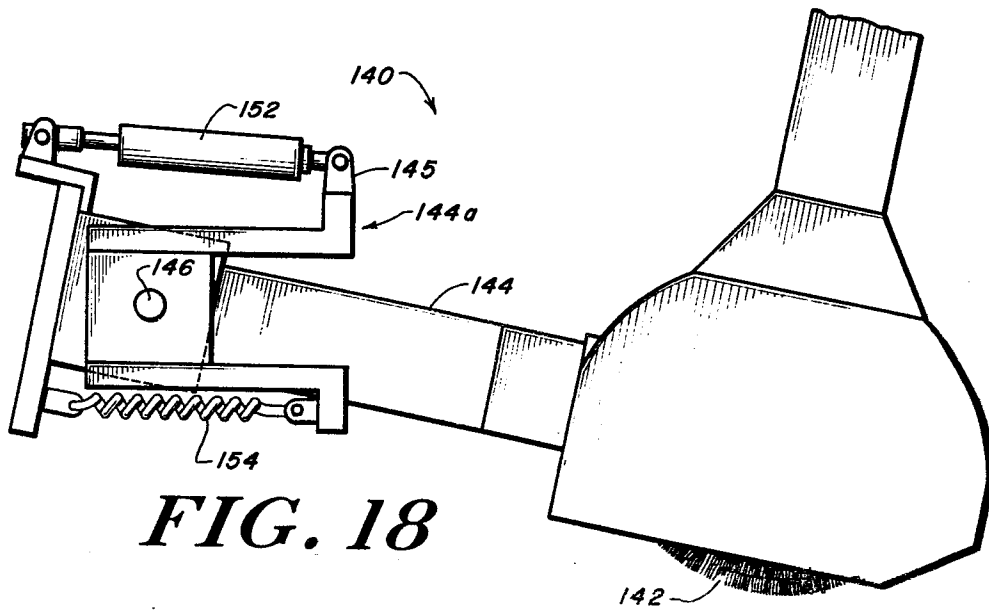


FIG. 18

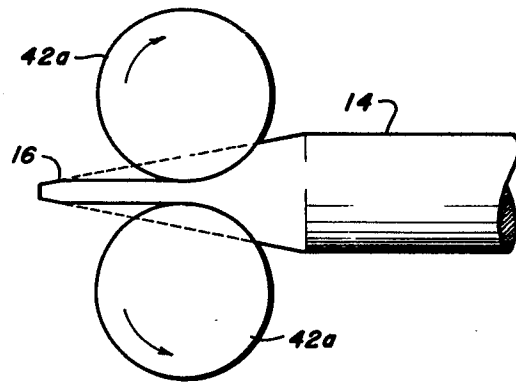


FIG. 20

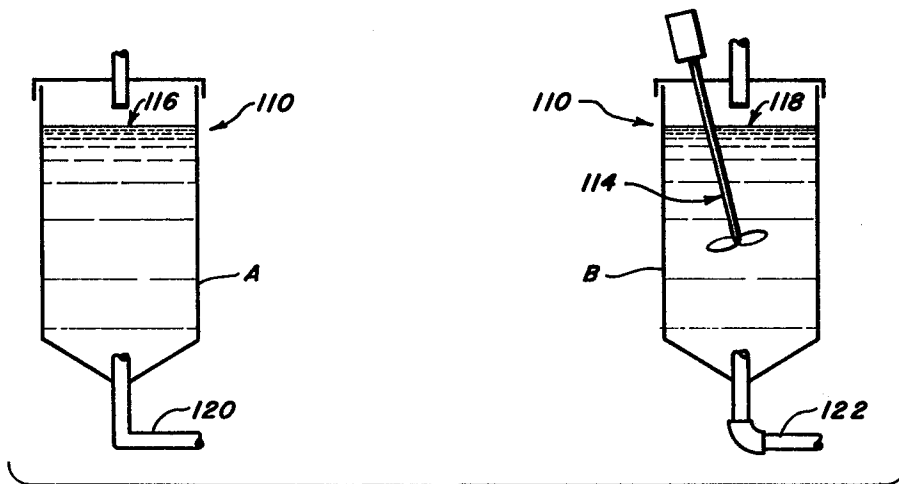


FIG. 21