

July 9, 1963

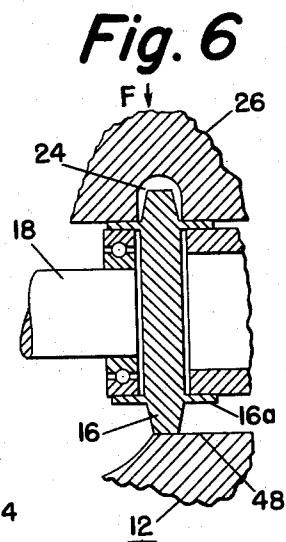
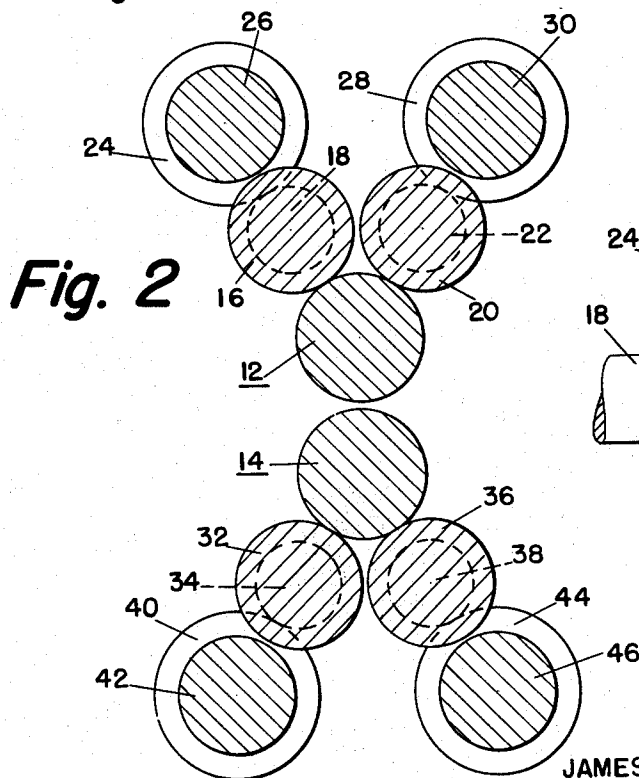
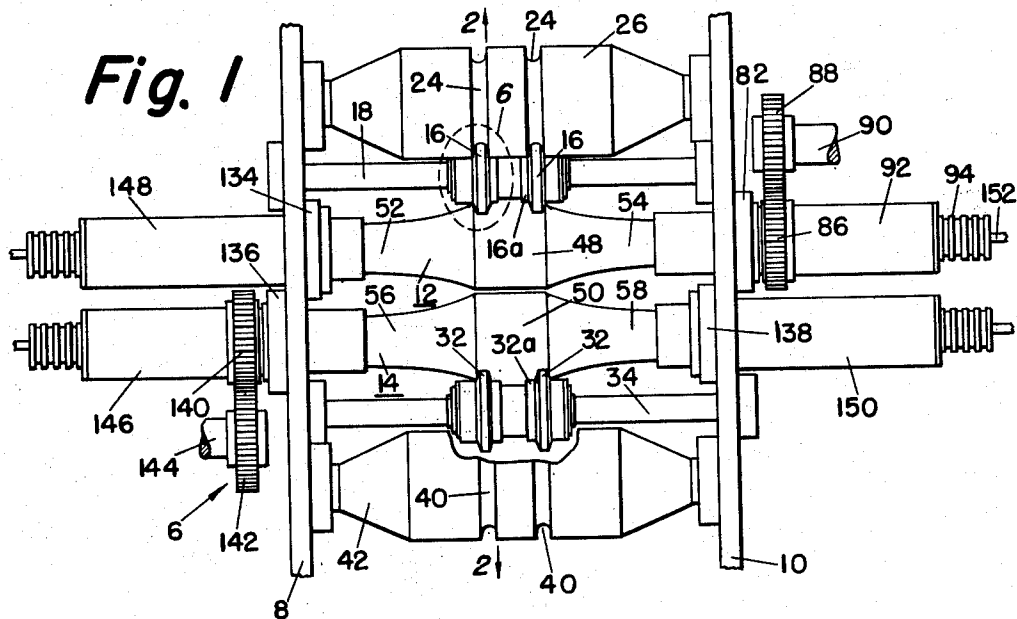
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3,096,672

VIBRATING ROLL AND METHOD

Original Filed July 28, 1960

3 Sheets-Sheet 1



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FIG. 3

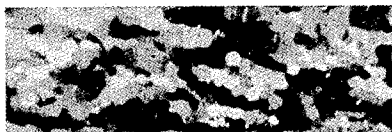
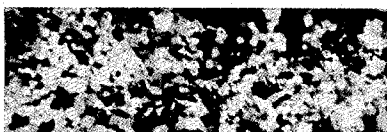


FIG. 4



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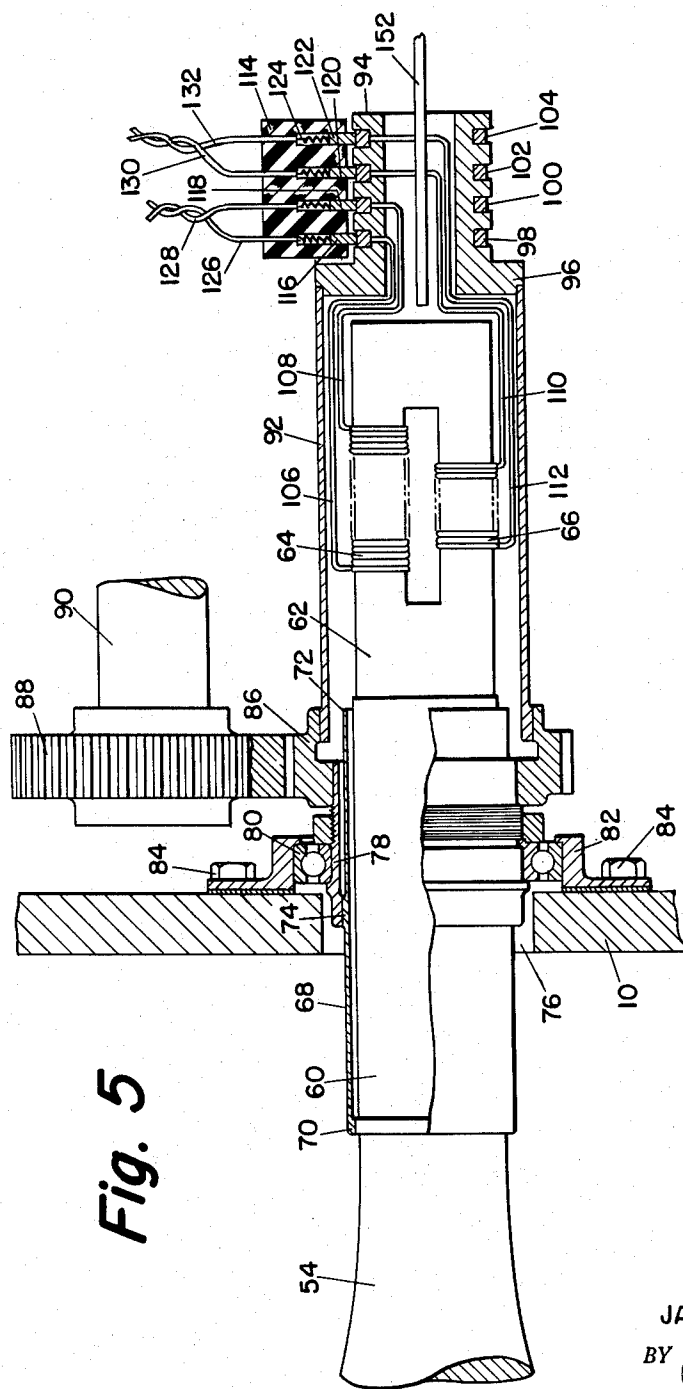


Fig. 5

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3,096,672

VIBRATING ROLL AND METHOD

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Continuation of application Ser. No. 45,926, July 28, 1960. This application Jan. 9, 1962, Ser. No. 169,700
17 Claims. (Cl. 80-60)

This invention relates to a rolling mill, and more particularly to a rolling mill for reducing the cross-section of metals in which vibratory energy is delivered to the surfaces of the metal being rolled.

This application is a continuation of my co-pending application Serial No. 45,926 filed on July 28, 1960, now abandoned, and entitled Rolling Mill.

Rolling is a very common and useful metal working process and includes both the rolling of flat strip or sheet and of round rod, smooth cylindrical rolls generally being used for rolling sheet and grooved rolls for rolling rod. As a rule, at least two rolls are used which rotate in opposite directions at the same peripheral speed, the distance between such rolls being slightly less than the height of the material, so that the rolls grip the metal, drawing it in, reducing the section, and increasing its length in proportion to such reduction. Sometimes tension reels are used to pull the strip through the work rolls. Often a two-roll or two-high rolling mill is inadequate for a given rolling situation, and various roll combinations are used, such as three-high, four-high, nine-high, etc.; also cluster mills may be used. The additional rolls act as stiffeners and supporters for the rolls in contact with the work, the working rolls usually being smaller than the backing rolls in view of the known roll-diameter to stock-thickness ratio which permits rolling to thinner sized with smaller rolls than with larger rolls.

Moreover, in roll-forming thin sheet, very high roll pressures are necessary to force the metal to flow, and surface friction becomes very important, so that the high pressures are practicable only by the use of small-diameter working rolls where the area of contact between roll and sheet is small. In the variation of rolling known as cross-rolling, sometimes used in the making of seamless tubing and the straightening of rounds, the rolls are rotated in the same direction with the metal being rotated as it passes between the rolls. Another variation is pack rolling, in which sheets are sandwiched in layers and the entire sandwich is rolled.

Rolling, be it hot-rolling (wherein the metal billet is heated prior to rolling) or cold-rolling, involves the working of the metal being rolled. Notwithstanding the working achieved by rolling, many metals possess large grain sizes even after rolling, although a smaller grain size would be preferred for various reasons. In particular, reduced grain size of beryllium is desirable, since the cast metal exhibits anisotropic large-size crystals which fracture readily on the basal plane under tensile stress, resulting in poor room-temperature ductility, machining difficulties such as chipping and cracking, etc. The use of vibratory energy to reduce grain size of metals has been suggested previously, but such application has involved the treatment of molten, rather than solid, metal or the use of a fluid coupling medium to deliver the energy from the source of vibration to the solid metal being treated. Moreover, the type of vibration used has been of the "hammering" type; i.e., vibration essentially perpendicular to the surface being treated.

In connection with the present invention, it has been found that reduced grain size of metals may be obtained without the necessity for vibrating the metal while the metal is in a molten or "mushy" state and without the

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use of a fluid coupling medium (the latter being possible notwithstanding the gap or discontinuity necessarily present between vibration source and solid metal to be treated, such gaps or discontinuities even though seemingly slight being known to the art to ordinarily occasion energy losses, formation of standing waves, etc.), provided the type of vibration described hereinbelow is utilized and provided sufficient force is applied to the metal and provided the energy level of the vibration delivered to the metal is adequate. It is to be noted that force is generally not utilized in connection with vibratory energy applied to or through fluids, and that the energy level of the vibratory energy applied to or through fluids is generally considerably less than the energy level suitable for use in relation to the present invention.

Furthermore, it has been found that, not only can grain size be reduced by means of rolling in accordance with the present invention, but also the static working forces requisite for rolling can be reduced by means of the present invention compared with the forces required in a conventional rolling mill. In certain situations, it is more important to reduce the static working forces requisite for rolling than to achieve a reduction in grain size. It appears that, whereas metal crystals usually undergo work-hardening during plastic deformation, this type of vibratory energy can induce a plasticity or softening effect in solid metals, an effect which is not associated with temperature and which acts to alter metal properties transiently and yet sufficiently so that lesser rolling and/or tensioning forces are required to produce the desired end result. However, the aforesaid conditions apply in connection with the present invention, namely, the conditions as to type of vibration, force level, and energy level of vibration.

This invention has as an object the provision of a novel rolling mill.

This invention has as another object the provision of a rolling process in which reduced rolling forces may be utilized to achieve the rolling of metals.

This invention has as yet another object the provision of a rolling process which will enable small grain size metals to be achieved.

This invention has as a further object the provision of a rolling process in which improved properties and characteristics are imparted to the metals being rolled.

Other objects will appear hereinafter.

For the purpose of illustrating the invention there is shown in the drawings a form which is presently preferred; it being understood, however, that this invention is not limited to the precise arrangements and instrumentalities shown.

Referring to the drawings wherein like reference characters refer to like parts:

FIGURE 1 is a front elevational view of an embodiment of the ultrasonic rolling mill of the present invention, with parts being shown in section and broken away for the sake of clarity.

FIGURE 2 is a vertical section taken on line 2-2 of FIGURE 1.

FIGURE 3 is a photomicrograph of 0.020 inch thick QMV cross-rolled beryllium revealing the relatively large grain size of beryllium which has been subjected to conventional rolling.

FIGURE 4 is a photomicrograph of 0.020 inch thick QMV beryllium which has been exposed to high-intensity shear-type vibration while the material was being reduced in thickness, and reveals the reduction in grain size of such beryllium.

FIGURE 5 is a sectional view through the vibratory device and support for one end of a working roll of the rolling mill of the present invention.

FIGURE 6 is an enlarged cross-sectional view through an axial plane within the encircled portion in FIGURE 1.

Thus, rolling according to the present invention comprises the formation of metallic materials of desired thickness and/or shape by translating the metal billet or partially-formed elongated metal between vibrating work rolls which apply vibration to the surfaces of the metal or metals contacting said rolls in the region so contacted, said vibration being essentially parallel to (in the plane of) said contacted surfaces (i.e., vibration essentially perpendicular to the static force which is also applied through said rolls). The invention contemplates applying such vibration to the top surface and to the bottom surface of the billet if a single sheet is being rolled, and to the top surface of the top billet and to the bottom surface of the bottom billet if two or more layers of stock are being rolled simultaneously.

Inasmuch as vibratory tools, and in particular ultrasonic tools, are resonant vibrating systems, i.e., systems for which, because the efficiency of conversion of the driving energy (usually electrical energy) into acoustical or vibratory energy is highest at the resonant frequency, design of the vibrating parts of these tools is in accordance with well known equations which relate resonant frequency to physical properties and especially to the physical dimensions of the materials of construction, the frequency of vibration employed in connection with the present invention is primarily related to the size of the vibrating parts of the apparatus and the materials of which these vibrating parts are made. Thus, large tools usually have a comparatively low resonant frequency (60 cycles per second or even much less) and small tools usually have a comparatively high resonant frequency (10 kilocycles per second and even much more), with a tool having a resonant frequency between these extremes being generally of intermediate size.

It is to be noted that, for the purposes of this invention, ultrasonic vibration is defined as high-intensity and/or high-frequency vibration, it being known to the art that the distinction between audible and inaudible frequencies per se is arbitrary.

Because the maximum permissible power input to these devices is also related to their physical dimensions, large low-frequency tools are generally able to handle more power than small high-frequency tools, other things being equal. It will be appreciated, therefore, that apparatus according to the present invention whose vibrating parts are of the comparatively-large, comparatively-low-resonant-frequency, and comparatively-high-power-input type may have more utility with larger or multiple billet rolling than may apparatus of the intermediate and smaller types. However, economical use of the intermediate and smaller types of apparatus, in preference to the large type, may be possible, in connection, for example, with the rolling of fine ribbon or wire from comparatively small billets.

It is clear, therefore, that the frequency of vibration of the vibrating parts of the apparatus of this invention is not related to the physical properties of the metal billet, viz., to any resonant properties the billets may have, and especially is this so since, under the influence of the rolling deformation, any such resonant properties may be expected to change as the dimensions of the material being rolled change during the rolling process. Power-handling capacity of the vibrating parts of the apparatus, rather than frequency of vibration, is an important factor in its construction and operation, since in any case sufficient vibratory energy of the appropriate type must be delivered to the surface or surfaces of the metal being rolled to obtain the transient effects hereinabove noted.

The applied static force, of course, must be sufficient to take advantage of the briefly altered properties of the metal occasioned by the vibration, which vibration as has been indicated is not primarily of the hammering type but is largely parallel to the plane of the vibratory-

contacted surfaces of the metal being rolled, and cause reduction of the metal's cross-section.

Altered properties, as used herein, does not imply any melting of the metal being rolled, since the subject invention does not involve bringing of the metal to its melting point temperature; it indicates that the metal is distortable under the influence of the vibration but is less easily distorted when the vibration is discontinued, which is a phenomenon observed when the type of vibration mentioned above is employed during the rolling process. The introduction of the vibratory energy will induce some temperature rise in addition to the rise associated with reducing the cross-section, but melting of the metal is unnecessary and, in fact, undesirable in connection with the subject invention and has not been known to occur (as determined by the use of thermocouples or approximated from a metallographic examination of a cross-section of the rolled product in the ordinary magnification range up to about 500 diameters) even under excessively high powers, for under such conditions the metal tends to be destroyed by the vibration rather than melted by it.

Hot-rolling, i.e., initiation and/or conducting of the rolling process at elevated temperatures below the fusion temperature (melting point or solidus temperature) of any of the pieces being rolled is within the scope of the present invention. A wide variety of metals may be rolled in accordance with this invention, and, while the rolling of most metals can be effected in the ambient atmosphere, such rolling may also be accomplished under vacuum conditions or in inert gaseous atmospheres.

It will be appreciated that, since metals are known to differ as to their properties and alloys of metals are also known to possess different properties, their reaction to the type of vibration employed herein may also be expected to differ so that differing amounts of force and vibratory energy level may be necessary in each case. However, the testing and adjustment of these rolling conditions are well within the skill of one skilled in the art.

The rolling mill 6 of the present invention comprises a pair of upright rolling mill frame members 8 and 10 spaced apart, between which the working rolls 12 and 14 are carried. The working roll 12 may be adjusted vertically in respect to the working roll 14 which is spaced therebeneath, and which is fixedly positioned.

The working roll 12 is engaged with the backup discs 16 of the backing roll 18 and the backup discs 20 of the backing roll 22. The backing rolls 18 and 22 are identical, and accordingly the description set forth below will be confined to the backing roll 18.

The backup discs 16 of backing roll 18 are engaged in mating grooves 24 of pressure roll 26. Similarly, the backup discs 20 of backing roll 22 are matingly engaged in the grooves 28 of pressure roll 30.

The working roll 14 is engaged by the backup discs 32 of backing roll 34, and the backup discs 36 of the backing roll 38. The backup discs 32 of backing roll 34 are received within the grooves 40 of pressure roll 42, and the backup discs 36 of backing roll 38 are received within the grooves 44 of pressure roll 46.

The bearings for the working roll 12, the backing rolls 18 and 22, and the pressure rolls 26 and 30 are such as to permit such rolls to be adjusted in respect to the frames 8 and 10 so as to accommodate for different gap distances between the working rolls 12 and 14. The bearings for the aforesaid rolls permit rotation of the rolls notwithstanding the application of very high pressures. The working roll 14, the backing rolls 34 and 38, and the pressure rolls 42 and 46 are fixedly positioned in respect to the frame members 8 and 10, so that while such rolls may be rotated under high pressure, they are not adjustable vertically, since the same is unnecessary due to the adjustability of the working roll 12, the backing rolls 18 and 22, and the pressure rolls 26 and 30 as aforesaid.

The metal sheet or strip to be rolled is introduced, as for example between front and back power reels inter-

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mediate the working rolls 12 and 14. The working rolls 12 and 14 are, except for their bearings, substantially identical. Thus, the working roll 12 comprises a central cylindrical portion 48 of maximum diameter, which is spaced from a similar central cylindrical portion 50 of maximum diameter of working roll 14. A pair of exponential horns 52 and 54 are disposed on either side of the central cylindrical portion 48 of working roll 12, with their portions of maximum diameter being contiguous to the juxtaposed end of the central cylindrical portion 48. Similarly, exponential horns 56 and 58 are secured to the central cylindrical portion 50 of working roll 14, with the maximum diameter portions of each such horn joining the juxtaposed end face of the central cylindrical portion 50.

Referring to FIGURE 5, a cylindrical coupler 60 is integral with or metallurgically attached to the minimum diameter end of the exponential horn 54. A magnetostrictive transducer 62 is metallurgically bonded in end-to-end contact with the other end of the cylindrical coupler 60. The magnetostrictive transducer 62 is of conventional construction and comprises a laminated core of nickel, nickel-iron alloy, Permendur (an iron-cobalt alloy), Alfenol (an aluminum-iron-alloy), or other magnetostrictive material, properly dimensioned to insure axial resonance with the frequency of the alternating current applied thereto so as to cause it to change in length according to its coefficient of magnetostriction. The detailed construction of a simple magnetostrictive transducer which, in the illustrated embodiment, comprises a nickel stack, is well known to those skilled in this art and does not form a part of the present invention, and accordingly no detailed description of its construction will be made herein.

The magnetostrictive transducer 62 includes the polarizing coil 64 and the excitation coil 66. The desirability of magnetically polarizing the magnetostrictive transducer 62 by means of polarizing coil 64 in order for the metal laminations in the magnetostrictive transducer 62 to efficiently convert the applied R.F. energy from excitation coil 66 into elastic vibratory energy will be readily understood by one skilled in the art.

It will be appreciated by those skilled in the art that in place of the magnetostrictive transducer 62 shown in the drawings, other known types of transducers may be substituted. For example, electrostrictive or piezoelectric transducers, made of barium titanate, quartz crystals, lead titanate, lead zirconate, etc., may be utilized. Magnetostrictive transducers conventionally operate in the frequency range from about 8,000 cycles per second to about 60,000 cycle per second, while electrostrictive or piezoelectric transducers have a frequency range extending to about 150,000 cycles per second. Various other types of devices may be used to excite the appropriate components of the subject invention, such as mechanical vibratory devices, electromagnetic devices, hydraulic devices which convert fluid pressure to mechanical vibration, etc.

The cylindrical coupler 60 is supported by a support mount 68. The support mount is a force-insensitive mount, namely a mount which enables vibratory energy to be applied to a work area with force and under a load without an appreciable shift in frequency of the device resulting from the load, and is described in U.S. Patents 2,891,180; 2,891,179; and 2,891,178. The disclosures of such patents are incorporated herein by reference. The support mount 68 in the illustrated embodiment comprises a cylindrical metal shell, such as a cylindrical steel shell or a shell of other suitable resonant material. Such shell 68 has a length equal to a single one-half wavelength. The shell 68 surrounds the cylindrical coupler 60, being concentric therewith and spaced therefrom. At the end of the shell 68 which is furthest from the magnetostrictive transducer 62 there is a radially inwardly disposed flange 70 which is metallurgically bonded to the cylindrical coupler 60. The end 72 of the support mount

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68 opposite from the flange 70 is free from any attachment, and accordingly when the vibratory device is vibrating a true node will develop in the support mount 68 at flange 74, which is one-quarter wavelength distant from the free end 72 of the support mount 68.

The cylindrical coupler 60 and the Elmore support mount 68 extend through an opening 76 in the rolling mill frame member 10. The flange 74 of the support mount 68 is supported by a cylindrical sleeve 78 which is concentric to and spaced from the support mount 68. The sleeve 78 is rotatably supported by a ballbearing 80 in a bracket 82. The bracket 82 is secured to the outer side of the rolling mill frame member 10 by bolts 84. Thus, one end of the working roll 12 is rotatably supported on the frame member 10.

A gear 86 is secured around the end of the sleeve 78 away from the frame member 10. A driver gear 88 meshes with the gear 86. The drive gear 88 is mounted on a drive shaft 90 which is connected to a source of power for rotating the working roll 12.

A cylindrical housing 92 (preferably of nonmetallic material, such as plastic) is secured to the gear 86, and extends around the magnetostrictive transducer 62. A cylindrical hub 94 of an electrical insulating material is secured to the end of the housing 92 by an annular flange 96. Four annular slip rings 98, 100, 102, and 104 of an electrically conductive metal are secured around the hub 94 in longitudinally spaced relation. Wires 106 and 108 electrically connect the ends of the polarizing coil 64 of the magnetostrictive transducer 62 to the slip rings 98 and 100 respectively. Wires 110 and 112 electrically connect the ends of the excitation coil 66 to the slip rings 102 and 104 respectively. The wires 106, 108, 110, and 112 extend longitudinally through the housing 92 and the hub 94, and then through radial holes in the hub 94 to their respective slip rings.

A brush holder 114 of an electrically insulating material is provided adjacent the outer surface of the hub 94, and is supported from the frame member 10. The brush holder 114 carries four brushes 116, 118, 120, and 122 which are insulated from each other, and slidably engage the slip rings 98, 100, 102, and 104 respectively. A separate spring 124 holds each of the brushes against its respective slip ring. Wires 126, 128, 130, and 132 extend through the brush holder 114 and are electrically connected to the brushes 116, 118, 120, and 122 respectively. The wires 126, 128, 130, and 132 are electrically connected to the power supply for the magnetostrictive transducer 62.

In the illustrated embodiment, the magnetostrictive transducer 62, the cylindrical coupler 60, and the exponential horn 54 are designed to be resonant at the applied operating frequency so as to deliver the optimum amount of power, and to have the joints, such as the joints between the magnetostrictive transducer 62 and the cylindrical coupler 60 and between the cylindrical coupler 60 and the exponential horn 54 and between the flange 70 and the cylindrical coupler 60 positioned at a loop of the wave motion whereby the joints will not be appreciably stressed.

The exponential horns 52, 56, and 58 are each also provided with a cylindrical coupler and a magnetostrictive transducer similar to the cylindrical coupler 60 and the magnetostrictive transducer 62 on the exponential horn 54. The exponential horns 52 and 56 are rotatably supported in bearing brackets 134 and 136 respectively mounted on the rolling mill frame member 8. The exponential horn 58 is rotatably supported in a bearing bracket 138 mounted on the rolling mill frame member 10. Each of the exponential horns 52, 56, and 58 is supported in its respective bearing block by an Elmore support mount, similar to the support mount 68, and a sleeve, similar to the sleeve 78.

The supporting sleeve for the exponential horn 56, like the supporting sleeve 78 for the exponential horn 54, has

a gear 140 secured thereto. A driver gear 142 meshes with the gear 140. Driver gear 142 is mounted on a drive shaft 144 which is connected to a source of power for rotating the working roll 14. A cylindrical housing 146 similar to the housing 92, is secured to the gear 140 and extends over the magnetostrictive transducer of the exponential horn 56. Similar cylindrical housings 148 and 150 are secured to the mounting sleeves for the exponential horns 52 and 58 respectively, and extend across the magnetostrictive transducers for the exponential horns 52 and 58. Each of the housings 146, 148, and 150 has a hub, similar to the hub 94, which has slip rings through which the polarizing coil and excitation coil of each of the magnetostrictive transducers are electrically connected to the power source. A tube 152 extends longitudinally through the hub 94 of the housing 92 into the housing 92. Similar tubes 152 extend longitudinally through the hub of each of the housings 146, 148, and 150. The tubes 152 are all connected to a source of air under pressure. The tubes 152 convey the air into the housings 92, 146, 148 and 150, and around the magnetostrictive transducers therein to cool the magnetostrictive transducers. It will be clear that this is only one method of cooling and that other cooling means may be incorporated, such as liquid cooling.

In order to permit the relatively free vibratory excursions of the surface of the cylindrical portions 48 and 50, the discs 16 and 32 are resonant members designed as flexural discs with nodal support flanges 16a and 32a. The flanges 16a and 32a flex under the influence of vibration without interfering with the ability of the discs to transmit strong forces on the surface of the cylindrical portions 48 and 50.

Rolls 18 and 34 support the resonant discs 16 and 32 only at their nodal flanges. The faces of the discs 16 and 32 do not contact the surfaces of the grooves 24 and 40. Forces applied as shown at F in FIGURE 6 are transmitted from roll 26 to the flanges 16a and 32a. In turn, the discs 16 and 32 will transmit the forces from their outer peripheral surfaces to the cylindrical portions 48 and 50.

In the operation of the rolling mill 6 of the present invention, the working rolls 12 and 14 are rotated through the drive shafts 90 and 144 and the driver gears 88 and 142. The working rolls 12 and 14 may be rotated in opposite directions or in the same direction according to the type of rolling to be accomplished. The power source for the magnetostrictive transducers secured to the exponential horns 52, 54, 56, and 58 is turned on to vibrate the working rolls 12 and 14 longitudinally of the axis of rotation of the working rolls. For this purpose, the magnetostrictive transducer secured to the exponential horn 52 of the working roll 12 is vibrated 180 degrees out of phase with the magnetostrictive transducer secured to the exponential horn 54 of the working roll 12. Thus, the magnetostrictive transducers secured to the exponential horns 52 and 54 are operating like a two-man saw to vibrate the working roll 12 longitudinally of its axis of rotation. Likewise, the magnetostrictive transducer secured to the exponential horn 56 of the working roll 14 is vibrated 180 degrees out of phase with the magnetostrictive transducer secured to the exponential horn 58 of the working roll 12. However, the magnetostrictive transducer secured to the exponential horn 52 of the working roll 12 is vibrated 180 degrees out of phase with the magnetostrictive transducer secured to the exponential horn 56 of the working roll 14. Thus, the working rolls 12 and 14 are vibrated in opposite directions with respect to each other so that when the working roll 12 is vibratorily moving (excursioning) in one direction, the working roll 14 is vibratorily moving (excursioning) in the opposite direction. The magnetostrictive transducers may be constructed to vibrate and may be vibrated at frequencies lower than the so-called ultrasonic frequencies, although the ultrasonic frequencies

of above about 15,000 cycles per second are preferred.

With the working rolls 12 and 14 rotating and vibrating longitudinally of their axis of rotation, the metal to be rolled is passed between the working rolls 12 and 14. By properly spacing the working rolls 12 and 14, they will apply sufficient force to the metal to reduce the thickness of the metal and proportionately increase the surface area of the metal. At the same time the vibrating working rolls 12 and 14 introduce primarily shear-type vibration into the surfaces of the metal passing between the working rolls 12 and 14; it will be understood that, due to Poisson's ratio, these rolls also introduce a component normal to the surfaces of the metal.

High-intensity shear-type elastic vibration applied to the surfaces of metals, such as beryllium, as the metal passes between the working rolls 12 and 14 results in a substantial reduction in grain size of the metal. For example, FIGURE 3 is a photomicrograph of a 0.020-inch thick QMV beryllium which has been subjected to conventional rolling. FIGURE 4 is a photomicrograph of a 0.020-inch thick QMV beryllium which has been exposed to high-intensity shear-type ultrasonic vibration while the material was being reduced in thickness. As can be seen by a comparison of FIGURES 3 and 4, the beryllium which has been ultrasonically treated has a reduced grain size as compared with the grain size of the beryllium which has been subjected to conventional rolling. It was found that, not only was grain size reduced but also that a reduction in the rolling and tensioning forces associated with rolling the metal was obtained as compared with the forces required in a conventional rolling mill.

The present invention may be embodied in other specific forms without departing from the spirit or essential attributes thereof and, accordingly, reference should be made to the appended claims, rather than to the foregoing specification as indicating the scope of the invention.

I claim:

1. A rolling mill for reducing the cross-section of a metal member comprising a pair of rolls supported in spaced relation for rotation about their longitudinal axes, means for maintaining the space between said rolls less than the thickness of a metal member, means for rotating said rolls about their longitudinal axes, said rolls being adapted to receive therebetween and reduce the thickness of the metal member, and vibratory energy generating means being coupled to at least one of said rolls so as to vibrate said one roll in a direction parallel to its axis of rotation.

2. A rolling mill in accordance with claim 1 in which said one roll is supported by a force insensitive mount.

3. A rolling mill in accordance with claim 1 in which the means for generating vibratory energy generates vibratory energy within the frequency range of 20 cycles per second to 250,000 cycles per second.

4. A rolling mill for reducing the cross-section of a metal member comprising a pair of rolls supported in spaced relation for rotation about their longitudinal axes, means for maintaining the space between said rolls less than the thickness of the metal member, means for rotating said rolls about their longitudinal axes, said rolls being adapted to receive therebetween and reduce the thickness of the metal member, and means for generating vibratory energy of a predetermined frequency and energy level so as to reduce the grain size of the metal in said metal member as the thickness of said metal member is being reduced by translation between said rolls, said generating vibratory energy means being coupled to one end of each of said rolls so as to vibrate each of said rolls in a direction parallel to their axes of rotation.

5. A rolling mill in accordance with claim 4 in which the means for vibrating the rolls vibrates one of the rolls

in the opposite direction to the direction of vibration of the other roll.

6. A rolling mill in accordance with claim 5 in which the means for generating vibratory energy for each of the rolls comprises separate means which are 180 degrees out of phase with each other.

7. A rolling mill for reducing the cross-section of a metal member comprising a pair of rolls supported in spaced relation for rotation about their longitudinal axes, means for maintaining the space between said rolls less than the thickness of a metal member, means for rotating said rolls about their longitudinal axes, said rolls being adapted to receive therebetween and reduce the thickness of the metal member, a resonant back up disc engaged with at least one of said rolls, a pressure roll engaging said disc, and means for generating vibratory energy of a predetermined frequency and energy level so as to reduce the grain size of the metal in said metal member as the thickness of said metal member is being reduced by translation between said rolls, said means for generating vibratory energy being coupled to at least one of said rolls so as to vibrate said one roll in a direction parallel to its axis of rotation.

8. A rolling mill in accordance with claim 7 wherein said pressure roll engages said resonant disc only at a nodal flange on said disc.

9. A method of rolling a metal comprising passing a metal member between a pair of rotating rolls, reducing the thickness of the metal member by applying sufficient force through said rolls while said rolls are engaged with said metal member, and simultaneously vibrating at least one of said rolls in a direction parallel to the surface of the metal member being contacted as the thickness of said metal member is being reduced by being passed between said rolls.

10. A method of rolling a metal comprising passing a metal member between a pair of rotating rolls, reducing the thickness of the metal member by applying sufficient force through said rolls while said rolls are engaged with the metal member, and simultaneously vibrating each of said rolls in a direction parallel to the surface of the metal member being contacted by said rolls at a sufficient frequency and energy level so as to reduce the grain size of the metal in said metal member as the thickness of said metal member is being reduced by being passed between said rolls.

11. A method in accordance with claim 10 in which the rolls are vibrated 180 degrees out of phase in respect to each other.

12. A method of rolling a metal comprising passing a

metal member between a pair of rotating rolls, reducing the thickness of the metal member by applying sufficient force through said rolls while said rolls are engaged with the metal member, and simultaneously introducing vibratory energy in a direction substantially perpendicular to the applied force through at least one of said rolls to the surface of the metal member, said vibratory energy being of a sufficient frequency and energy level so as to reduce the grain size of the metal in said metal member as the thickness of said metal is being reduced by passage between said rolls.

13. A method of rolling a metal sheet comprising moving a metal sheet between a pair of rotating rolls, reducing the thickness of said moving metal sheet by engaging the surfaces of said moving metal sheet with said rolls under conditions of sufficient force, and simultaneously applying vibratory energy to the surface of the metal sheet engaging one of said rolls, said vibratory energy being applied in a direction parallel to the plane of the metal sheet disposed between said rolls, said vibratory energy being at a sufficient frequency and energy level so as to reduce the grain size of the metal in said metal sheet as the thickness of said metal sheet is being reduced by its movement between said rolls.

14. A method of rolling a metal sheet in accordance with claim 13 wherein the applied vibratory energy is within the frequency range of 20 cycles per second to 250,000 cycles per second.

15. A method of rolling a metal comprising passing a metal member between a pair of rotating rolls, reducing the thickness of the member by applying sufficient force through said rolls while said rolls are engaged with the member, and reducing the amount of said force necessary to achieve a predetermined amount of reduction in the thickness of said member by introducing vibratory energy to at least one of said rolls in a direction substantially perpendicular to the direction of application of said force.

16. A method in accordance with claim 15 wherein said vibratory energy is continuous ultrasonic vibratory energy.

17. A method in accordance with claim 15 wherein said vibratory energy is introduced in a direction parallel to the surface of the metal member being contacted by said rolls.

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