# United States Patent

**Dickey et al.**

[15] **3,678,720**

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## [54] ROLLER LEVELER AND METHOD OF LEVELING


[72] Inventors: **Clyde W. Dickey**, State College; **Ray A. Bland**, Pittsburgh, both of Pa.

[73] Assignee: **Sutton Engineering Company**, Pittsburgh, Pa.



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[52] **U.S. Cl.** ..... **72/160**, 72/199

[51] **Int. Cl.** ..... **B21d 1/02**

[58] **Field of Search** ..... 72/160–165,



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*Primary Examiner*—Milton S. Mehr

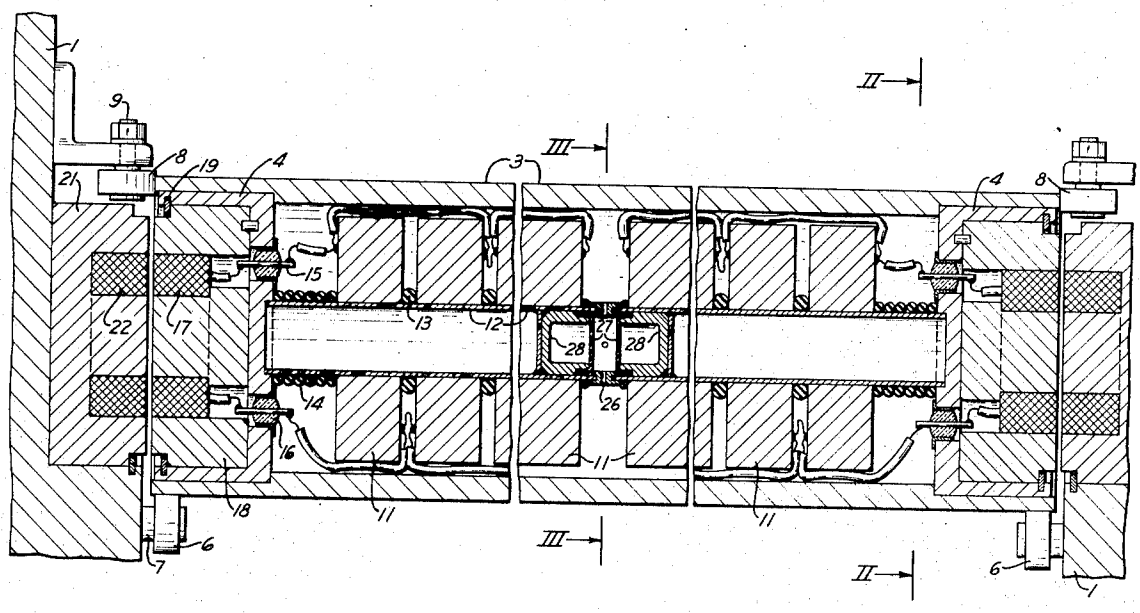
*Attorney*—Brown, Murray, Flick & Peckham



[57] **ABSTRACT**

In a roller leveler a roll is rotatably supported in a position to be engaged by an elongated workpiece traveling through the leveler. The roll has a hollow cylindrical body, inside of which there are ferroelectric transducers close to its inner surface. These transducers are driven electrically to vibrate the roll body radially in all directions at ultrasonic frequencies to relieve residual stresses in the workpiece passing across the roll.


**10 Claims, 8 Drawing Figures**



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4 Sheets-Sheet 1

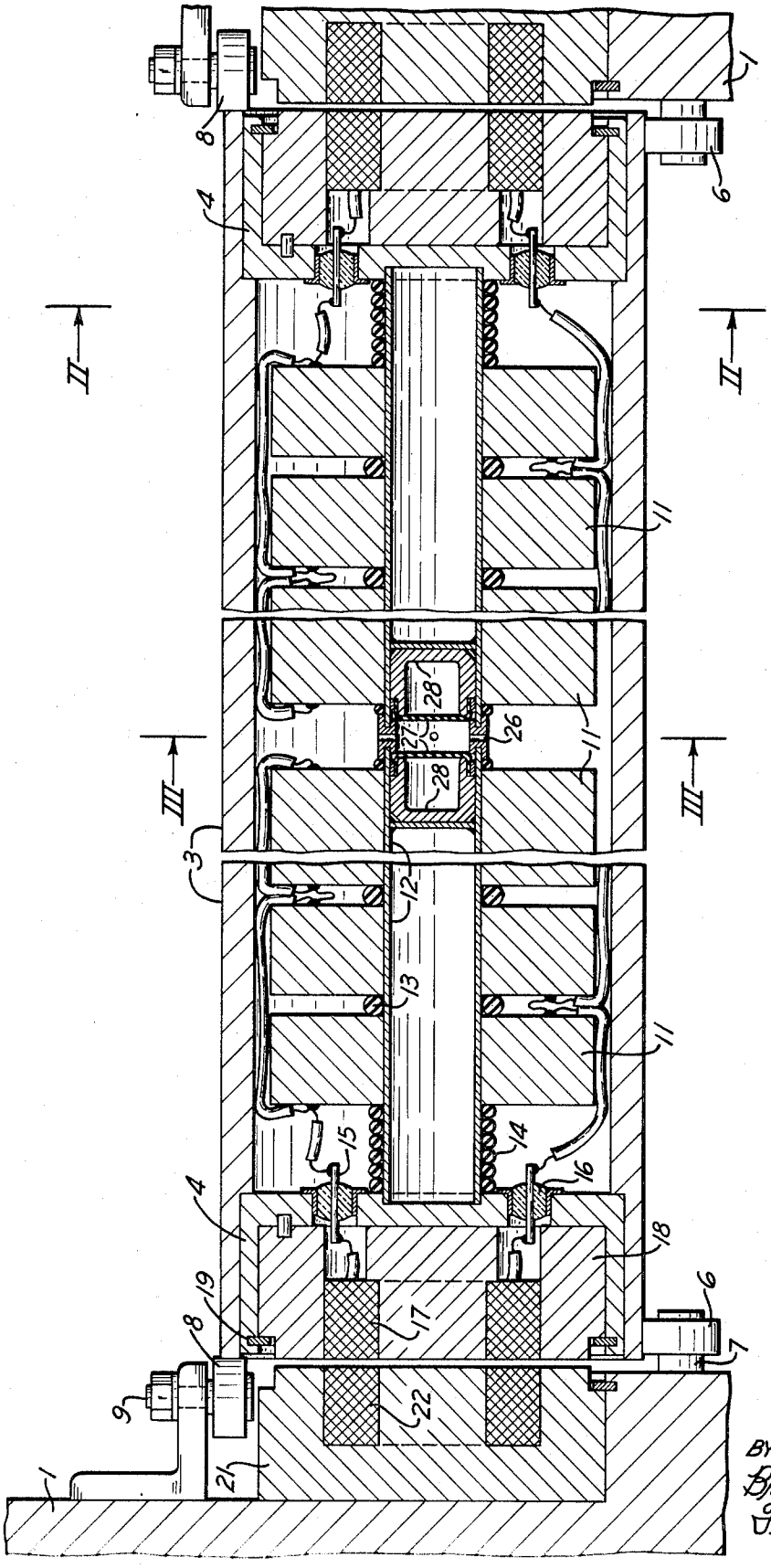



Fig. 1

INVENTORS.
CLYDE W. DICKEY
RAY A. BLAND
BY
Brown, Murray, Flick & Peckham
ATTORNEYS.

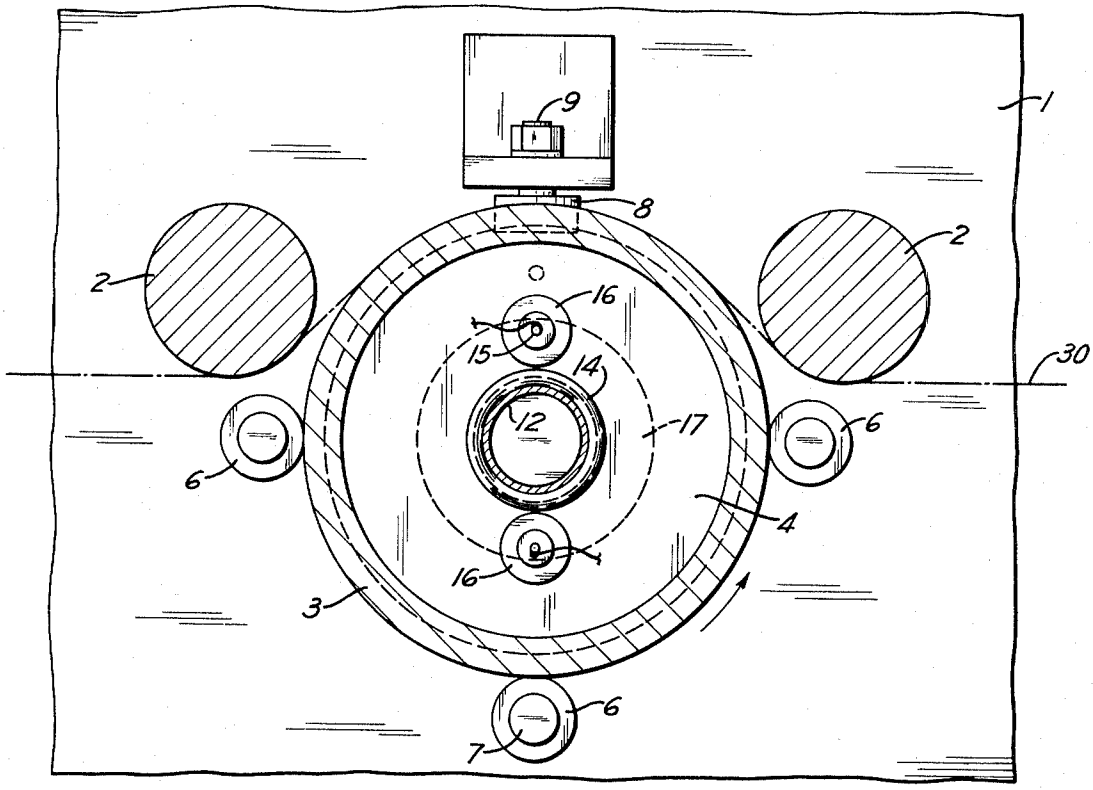



Fig. 2

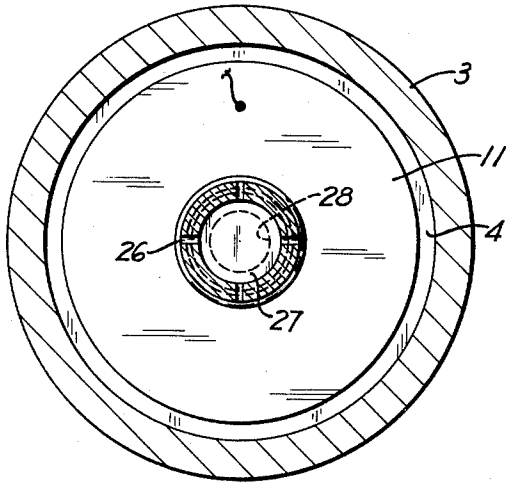



Fig. 3

INVENTORS.
CLYDE W. DICKEY
RAY A. BLAND

BY

Brown, Murray, Flick & Peckham
ATTORNEYS.

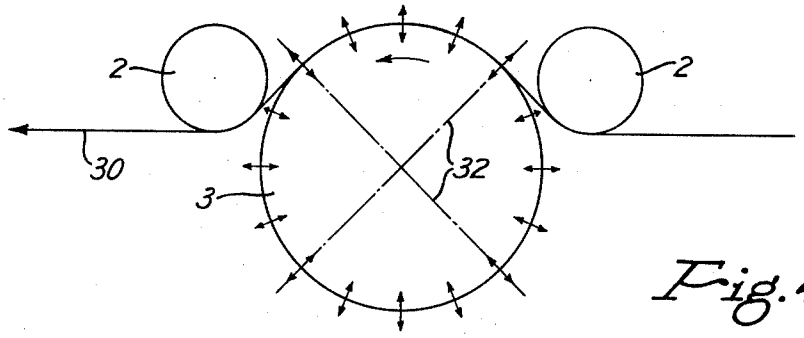



Fig. 4

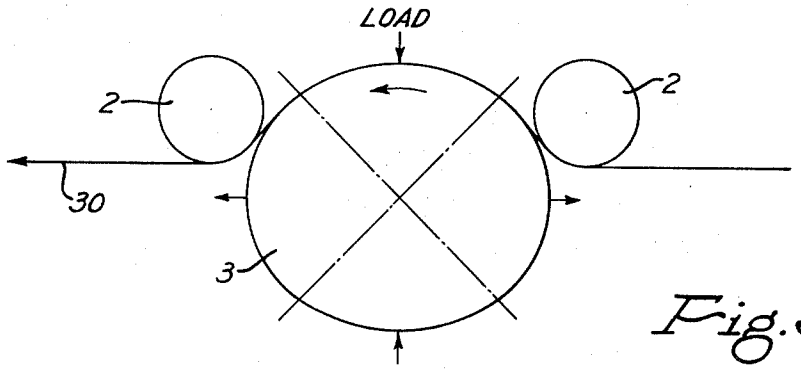



Fig. 5

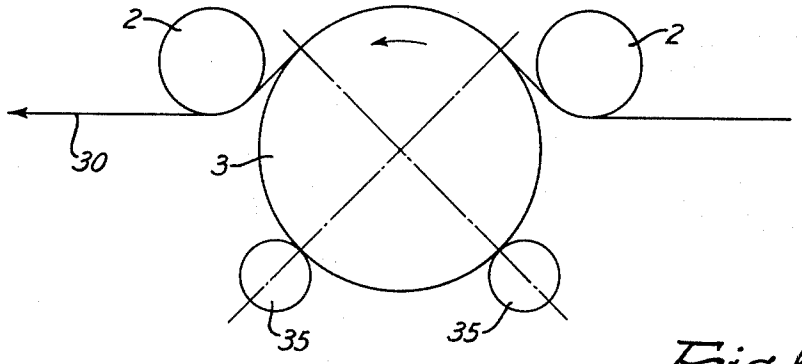



Fig. 6

INVENTORS.
CLYDE W. DICKEY
RAY A. BLAND

BY

Brown, Murray, Flick & Peckham
ATTORNEYS.

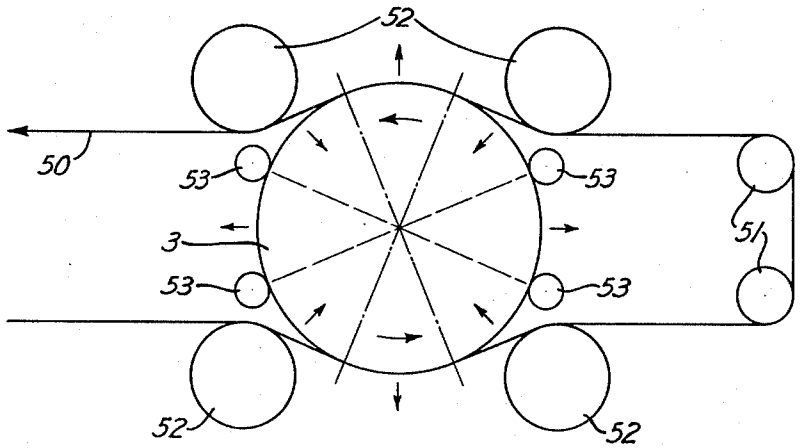



Fig. 8

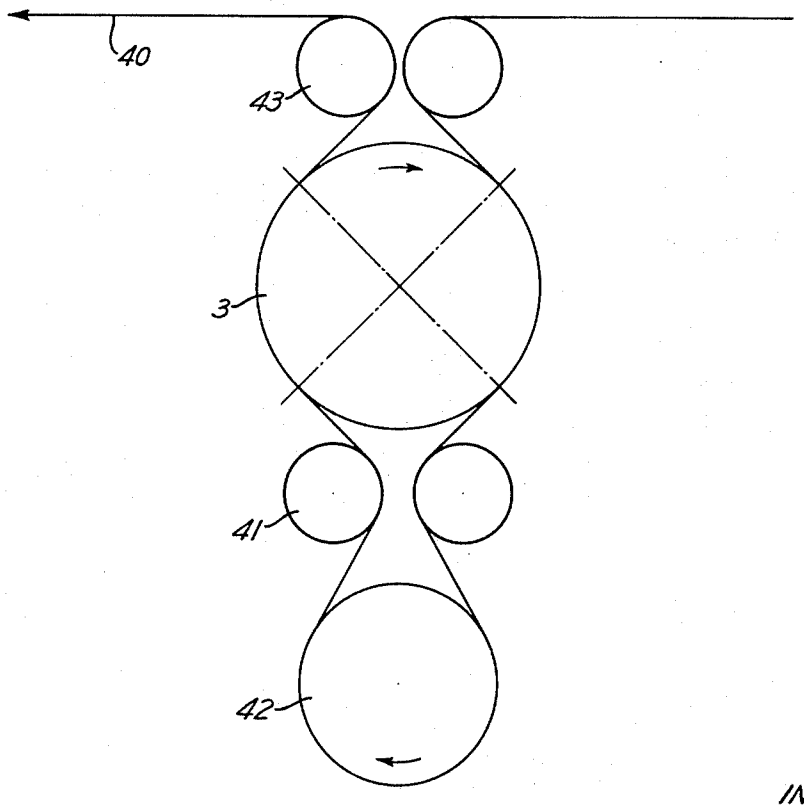



Fig. 7

INVENTORS.
CLYDE W. DICKEY
RAY A. BLAND
BY
Brown, Murray, Flick & Peckham
ATTORNEYS.

# ROLLER LEVELER AND METHOD OF LEVELING

The reforming of sheet, strip, or even shapes, which exhibit lack of flatness or the presence of waves, wrinkles, or bows is accomplished by a process known as leveling or straightening. In this process the work is placed under a large tensile or flexural stressing load of magnitude at or near the yield strength of the material. The resulting elongation or redistribution of internal stresses produces a product relatively free of geometrical irregularities; in other words, it is flat. This working of the material to straighten it imposes unusually large stresses on the material and on the machinery performing the leveling process.

It is conventional in leveling processes to feed the metal strip through a series of deflection rolls while applying a large tensile stress to it. This flexing of the material alternately applies tensile and compressive stresses to the strip as it passes through the series of rolls. It is apparent that the degree of leveling or flatness obtained for material of a given thickness is sensitive to roll diameter as well as to tension on the strip. Within a range of material thicknesses and roll diameters, certain adjustments may be made between tension and wave depth or flexural stresses to obtain essentially a flat or leveled workpiece. It becomes progressively more difficult, however, to process material that is very thin compared to roll diameter. This is usually attributed to the inability to apply sufficient flexural stresses to maintain the plastic state of the material. Decreasing the roll diameter and increasing the number of rolls to produce sufficient flexural stresses for leveling very thin strip material increases the machine design complexity, due to the necessity for maintaining stiffness in the small diameter work rolls to prevent excessive flexing or bending between discontinuities of backup rolls. It has been suggested that the material thickness should be no less than 2 percent of the roll diameter for efficient leveling. This means that for a material thickness less than 0.010 inches the roll diameter may become less than 0.500 inches, or even less for material thinner than 0.010.

To meet the demand for leveling thin strip material without the need for highly flexible small diameter rolls, a large variety of roll arrangements of somewhat orthodox design have been developed. However, the increased complexity of these machines has reduced the dynamic range of feeds or speeds with which the material may be processed if efficient leveling is to be preserved.

It is among the objects of this invention to provide for roller leveling which requires fewer rolls, which is not so dependent upon the ratio of roll diameter to material thickness as heretofore, which reduces bearing friction on the rolls, which imposes lower loads on the leveler, which can operate at higher speeds, which results in less long-time relaxation in stored material that has been leveled and which reduces the danger of breakage of strip material being leveled. Another object is to provide means for generating in a leveler roll specific modes of high frequency vibrations that are not readily stalled or rendered static by heavy loads.

This invention is predicted on the superimposing of two stresses; i.e., high frequency dynamic stresses on a continuous or static stress of tension and/or bending. Ultrasonic amplitudes sufficient to produce a significant strain in the material being leveled are assisted by the static tension developed between the material supply and take-up points. Likewise, the tension imposed on the material is made more effective by the superimposed dynamic stresses. High intensity ultrasonic energy gives significant redistribution of residual stresses in the material being leveled and thereby aids the leveling process.

The invention is illustrated in the accompanying drawings, in which

FIG. 1 is a longitudinal section through an improved roll in a roller leveler;

FIGS. 2 and 3 are cross sections taken on the lines II—II and III—III, respectively, of FIG. 1;

FIG. 4 is a diagram of strip traveling through the roller leveler;



FIG. 5 is a similar diagram illustrating vibration of the central roll; and

FIGS. 6, 7 and 8 are diagrams of three different modifications.

Referring to FIGS. 1 to 3 of the drawings, the superstructure or framework 1 of a roller leveler supports at least three parallel horizontal rolls. The two outer rolls 2 extend a short distance down the opposite sides of the intermediate roll 3 and are adjustable vertically in a well known manner. It is a feature of this invention that the body of the intermediate roll is a heavy walled hollow cylinder, the ends of which are sealed. It is made of low loss metal, such as Inconel or Monel. The sealing preferably is done by cup-like cases 4 tightly mounted in the ends of the roll body with their open ends facing outwardly. The roll is supported in the framework and held against movement sideways by means of rollers 6 that engage its periphery at its opposite ends. These rollers are rotatably mounted on studs 7 projecting inwardly from the framework. Axial movement of the roll is prevented by similar rollers 8 engaging the end faces of the roll body and rotatably mounted on studs 9 also supported by the framework.

In accordance with this invention, a series of ferroelectric transducers 11 is mounted inside the hollow roll body. They are close to its inner surface, but do not touch it to avoid being fractured by heavy mechanical loads on the outer surface of the roll body. These transducers are short hollow cylinders, through which a support extends. They vibrate radially and are resonant at or near the point at which roll 3 resonates. The support preferably is a tube 12 concentric with the roll body, with its ends fitting in central recesses in the end walls of cases 4. The transducers can be spaced apart and from the cases by means of O-rings 13 and 14 encircling the tube. The transducers are formed of ferroelectric ceramic material of the $ABO_3$ type and have terminals plated on their opposite sides. They are polarized electrically and the positive terminals are electrically connected to one another, while the negative terminals likewise are connected to one another.

In order to energize the transducers, two transformers are used unless the roll is so short that only one transformer is required. The terminal wires of the transducers are connected to the inner ends of metal conductors 15 sealed in glass plugs 16 that are sealed in holes in the cases. At each end of the roll the outer ends of these conductors are connected to the terminals of a load coil 17 or secondary winding in a transformer core section 18 of moderately high permeability ferrite material held in the case by a snap ring 19. The outer surfaces of this core section and the winding or coil are substantially flush with the end surface of the roll body. Opposing the core section is another core section 21 that is coaxial with it. This core section is rigidly mounted in the framework and contains a primary winding or drive coil 22 directly opposite the load coil and wound in a manner to match its impedance. The two core sections are spaced apart by a small air gap not exceeding 10 mils in width. An air gap of this magnitude is satisfactory for large magnetic coupling with cores of this type operating in a frequency range above 20 KHz. The transformers thus formed furnish electric current from the outside to the transducers, without mechanical connection, to cause them to vibrate radially at ultrasonic frequencies while rotating at high speed. The absence of bonding of the transducers to either support tube 12 or roll body 3 results in a more efficient and economical design with less tendency to oscillate in inefficient spurious modes of vibration.

In order to transmit the vibrations of the transducers efficiently to the encircling roll body, which is designed to be radially resonant at the driven frequency, all of the empty space between the central tube 12 and the inner surface of the roll body is filled with a suitable low loss oil, such as silicone fluid, that will not be affected adversely by high frequency vibrations. When the transformer is energized, the vibrations of the transducers are transmitted through the oil to cause the roll body to vibrate radially in all directions. It is necessary that all undissolved gases be purged from the oil, as gas bub-

bles would act as acoustic pressure release bodies due to their expansion and contraction in the sound field. That would materially reduce the ultrasonic power delivered to the workpiece.

Since it is necessary that the ultrasonic roll be filled with the oil and that there be no air pockets, provision is made for thermal expansion of the oil. This is done by providing an expansion chamber for the oil. This chamber, or a pair of chambers, are formed conveniently in the central tube that supports the transducers. Thus, the tube may be provided with a plurality of spaced small radial holes **26** that allow oil to enter the tube and fill the space between a pair of flexible diaphragms **27** spaced a short distance apart. The diaphragms close the open ends of a pair of capsules **28** that fit tightly in the tube and face each other. The capsules contain nothing but air. When the oil in the roll expands, more of it is forced in between the diaphragms and that forces them apart and causes them to compress the air in the two capsules. When the oil cools and contracts, the compressed air in the capsules expands and holds the diaphragms tightly against the body of oil between them as oil is forced out of the central tube to keep the space around it filled. The small size of holes **26** causes them to present a high dynamic impedance to the high frequency energy generated within the oil, whereby vibrational energy loss to the pressure release capsules **28** is held to a minimum.

As shown in FIG. **2**, a metal strip **30** drawn through the leveler under tension from a supply coil is held in engagement with the vibrating roll **3** by means of idler rolls **2**, which are so positioned that they will direct the strip part way around the roll between them, but not more than 90°. It will be seen that the strip is reversely bent or flexed as it leaves one idler roll, passes across the vibrating ultrasonic roll in engagement therewith and then under the other idler roll. If, for example, the ultrasonic roll is approximately three inches in diameter for resonance near 25 KHz, then the strip should extend approximately 2½ inches around that roll. Under full power at a moderate figure of merit for the roll, the peak-to-peak displacement of the vibrating roll surface may be as high as 400 microinches. The strain produced with each vibration of that portion of material between the idler rolls thus exceeds 0.0001 inch per inch. A percentage of the dynamic strain produced in the material is taken up by the longitudinal tension maintained in the strip as it travels through the leveler. One function of idler rolls **2** is the prevention of propagation of high energy ultrasonics along the strip, which in the case of very thin and ductile material under high tension could conceivably produce premature cold working in the material.

With the roll and arrangement of strip just described, all portions of the roll surface vibrate in phase; that is, they all move in and out together as indicated by the straight arrows in FIG. **4**. This radial vibration is one of the principal resonant modes of the hollow roll, but it is subject to deterioration in efficiency by the loading on the side wall of the roll caused by high tension in the strip. It can only be efficient when the tension in the strip is relatively light, such as when thin gauge material is processed. The radial resonance is determined by the diameter and circumference of the hollow roll and is independent of wall thickness so long as the wall is thin compared to the wave length. Consequently, the fixed resonant parameters of the radial mode allow little control variation at the power source for compensation.

In addition to the radial mode, an elliptic or bell mode of vibration also occurs at the same time as a result of the unbalanced load on the surface of the roll, due to its contact by strip material under tension. Thus, vibration of the portion of the roll in engagement with the strip is restrained, so axes of symmetry are established for the bell mode, which is characterized by parallel nodal lines extending lengthwise of the surface of the roll along the opposite ends of the arcuate surface engaged by the strip. The nodal lines intersect the upper ends of broken diametric lines **32** in FIG. **4**, while another pair of nodal lines intersect the lower ends of the broken lines. The bell mode of resonance is a highly variant mode. For a given diameter or roll, the resonant frequency depends on wall thickness. As the wall thickness is increased, the resonant frequency increases.

The instantaneous displacement of the bell mode is seen, greatly exaggerated, in FIG. **5**. That portion of the roll is contact with the strip at any instant is moving out of phase with the sectors of the roll at right angles to it. On the other hand, the diametrically opposite arcuate surface is in phase with the portion of the roll in contact with the strip. Consequently, as the roll is squeezed along one diameter it bulges along a diameter at right angles to the first diameter. The squeezing and bulging then reverse. The wall thickness at the nodal lines functions as a compliant spring, whereas the outward or inward moving portions, as shown by the arrows, function as a distributed mass. The frequency sensitive features of the bell mode are thus the wall thickness of the roll, the pressure normal to the wall caused by the tension in the strip, and the positions of backup rolls when used.

As the load shown in FIG. **5** is increased by increasing tension on the strip, the resonant frequency of the bell mode is lowered as though the distributed mass were increased. However, as the idler rolls **2** are lowered relative to roll **3** to increase the area of the latter engaged by the strip, the material is brought closer to the nodal lines, whereby the effective stiffness of the roll in contact with the strip is increased. The increased stiffness thus tends to compensate frequency shift due to tension. The superpositioning of the bell mode vibrations on the fundamental in-phase radial vibrations makes it extremely difficult to stall the vibrations, even when the roll is heavily loaded by the workpiece. This is a great advantage.

Another feature of the idler rolls **2** shown in FIG. **5**, is to maintain a fixed length of strip material between the points of tangency with the idler rolls, such that this segment of material is longitudinally resonant at the driving frequency. Most metals will resonate at approximately 20 KHz if the segment between the idler rolls is approximately 4 inches in length.

Bell mode vibrations can be enhanced by using a pair of backup rolls **35** in light contact with the ultrasonic roll, as shown in FIG. **6**. By placing them against the vibrating roll along the lower nodal lines, they will not interfere with vibrations because there are none in those locations, which are the neutral points. The backup rolls also determine the location of nodal lines, and it becomes apparent that this system made up of roll diameter and wall thickness, spacing of idler rolls, area of wrap by strip, location of backup rolls, and the magnitude of tension on the strip, forms a complete composite oscillator system. In this system, with some inherent compensation for frequency shift due to variation of one or more of the parameters mentioned above, a power generator for the transducers is used which can be tuned in frequency for maximum efficiency. In addition, the generator may be automatically controlled in its frequency so that maximum efficiency is always attained.

A further advantage of the efficiency of the bell mode in transmitting energy into thin strip material **40** can be realized by causing the strip to engage the ultrasonic roll **3** at diametrically opposite sides thereof as illustrated in FIG. **7**. With this arrangement two different lengths of the strip receive energy simultaneously from a single vibrating roll, and at the same time the bell mode of vibration is enhanced by the symmetrical loading of the roll surface. The material should not contact more than a 90° section of the roll surface at any one area of contact, and the two areas of contact should be diametrically opposite each other. The loop in the strip that makes this possible may be formed by a cluster of rolls, such as by a pair of idler rolls **41** mounted on fixed axes, and a floating roll **42** beneath them. There is another pair of idler rolls **43** above the vibrating roll to guide the strip around it. Those sectors of the roll not in contact with the strip are unrestrained, whereby a preferred bell mode resonance is obtained in which the desired maximum roll surface displacement is caused to occur in the centers of the unrestrained areas at top and bottom of the roll and in the centers of the areas in contact with the strip at the sides.

The preceding diagrams show the generation, stabilization and utilization of efficient fundamental mode of resonant vibration. Higher order bell modes may be generated where it is preferred to use a larger diameter roll as the ultrasonic roll, but a more convenient way of attaining higher order bell mode resonances is by using small backup rolls in specific locations as shown in FIG. 6 or, better yet, as shown in FIG. 8. In the latter diagram four diametrical nodal areas or a total of eight surface nodes are indicated. The nodal lines are separated at angles or 45°, with the bell mode vibration displacement at any instant indicated by the straight arrows. The strip **50** engages opposite sides of the ultrasonic roll **3** because it travels around a pair of idler rolls **57** at one side of the vibrating roll. It is held against the latter by idler rolls **52**. It engages only 45° of the roll surface at each side. The higher order bell mode is generated by positioning four smaller backup rolls **53** in contact with the ultrasonic roll. These small rolls are placed between the strip-engaging areas in positions where their lines of contact with the ultrasonic roll are intersected by the nodal lines. The small rolls assure the nodal lines remaining in exactly the desired positions so that precession will not occur, which would cause beat notes or rumbles to develop. The centers of the areas of the strip contacting the ultrasonic roll are located at antinodes of the roll surface, as is true in every case. High efficiency is due to the large number of unloaded antinodes. If desired, such as when leveling heavy gauge material, a large roll **3** may be used that is not a vibrating roll, and idler rolls **52** may all be ultrasonic rolls, thereby permitting the utilization of more energy.

In all arrangements utilizing the bell modes, the strip should not be allowed to span across a nodal line for a given segment of contact. When greater contact area is required, a plurality of spaced sectors of contact is used. Each sector should not exceed a single antinodal portion of the roll. A plurality of idler rolls or cluster of rolls could be used to bring the strip into contact with the ultrasonic roll at many different areas of contact. The use of this feature depends upon material stiffness or thickness limitations as well as on surface speeds or other processing requirements. However, better performance and stability of resonance modes are realized by adhering to diametrical symmetry in contacting the work surface with either the material being processed or the higher order idler rolls.

Ultrasonic leveling as described herein has many advantages over conventional leveling processes. The more important advantages are summarized as follows:

- Lower static tension can be used so that higher speeds are possible.
- Lower static tension causes less strain on the bearings and backup rolls.
- Lower static tension results in less structural failure and less danger of breaking thin strip material.
- Acoustic annealing during leveling yields greater elongation of strip with lower static tensions.
- There is greater diffusion of internal stresses in the work material.
- A controlled work hardened material is produced, due to the cold working caused by the ultrasonic vibrations.
- There is less long-time relaxation in stored material after ultrasonic leveling because the material has been stress stabilized.
- High frequency stresses are introduced in the presence of static stresses for the reduction or elimination of polarizing type of stresses that restrain further plastic deformation of polycrystalline materials.
- The application of ultrasonic vibrations aids considerably in the relief from residual stresses caused by application of large static stresses.

According to the provisions of the patent statutes, we have explained the principle of our invention and have illustrated and described what we now consider to represent its best embodiment. However, we desire to have it understood that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically illustrated and described.

We claim:

**1.** In a roller leveler, a framework, an ultrasonic roll, and means rotatably supporting the roll in the framework in a position to be engaged by an elongated workpiece passing through the leveler, said roll comprising a hollow cylindrical roll body, a support inside said hollow roll body and extending axially thereof, means rigidly holding said support and spacing it from the inner surface of the roll body, ferroelectric transducers inside said roll body supported by said support close to but spaced from said inner surface of the roll body, means sealing the opposite ends of the roll body, a liquid filling all of the empty space between said support and the encircling roll body, and electrical means for driving the transducers to vibrate said roll body radially at ultrasonic frequencies to cause the workpiece to become flat.

**2.** In a roller leveler according to claim **1**, thrust rollers in said framework engaging the opposite ends of said roll body to prevent axial movement of the roll, and said roll-supporting means being support rollers engaging the outer surface of the roll body at its ends for preventing radial displacement of the roll.

**3.** In a roller leveler according to claim **1**, said electrical means including a transformer core section mounted in an end of said hollow roll body, and a secondary winding carried by said core, the leveler also including a transformer core section mounted in said framework at said end of the roll, and a primary winding carried by said last-mentioned core section, the two core sections being axially aligned with a slight air gap between them.

**4.** In a roller leveler according to claim **3**, one of said core sections being rigidly mounted in said roll body, and the other core section being rigidly mounted in said framework.

**5.** In a roller leveler according to claim **1**, said support being hollow and provided with an air chamber having a flexible wall, and said support being provided with an opening outside said chamber communicating with said wall, said liquid engaging said flexible wall to compress air in said chamber when the liquid in said roll body expands with heat.

**6.** In a roller leveler according to claim **1**, idler rolls mounted in said framework at opposite sides of said ultrasonic roll for engaging the side of the workpiece opposite to the side engaging said roll and means for adjusting the spacing between said idler rolls to obtain longitudinal resonance in the workpiece.

**7.** In a roller leveler according to claim **6**, backup rolls engaging the ultrasonic roll at points diametrically opposite the ends of the arc of said roll engageable by the workpiece.

**8.** In the method of roller leveling or straightening a longitudinally moving elongated metal workpiece by reversely bending it, the steps comprising directing the workpiece part way around a hollow roll in engagement therewith throughout an arc of not more than 90°, simultaneously returning the strip in the opposite direction part way around the opposite side of said roll in engagement therewith, and subjecting the roll to radial vibrations in all directions at an ultrasonic frequency.

**9.** In the method of roller leveling or straightening a longitudinally moving elongated metal workpiece by reversely bending it, the steps comprising directing the workpiece part way around a hollow roll in engagement therewith throughout an arc of not more than 90°, supporting the roll at points diametrically opposite the ends of said arc, and subjecting the roll to radial vibrations in all directions at an ultrasonic frequency.

**10.** In the method of roller leveling or straightening a longitudinally moving elongated metal workpiece by reversely bending it, the steps comprising directing the workpiece part way around a hollow roll in engagement therewith through an arc of not more than 90°, and vibrating the roll radially at an ultrasonic frequency, the roll having a diameter and wall thickness that provides bell mode resonance when vibrated at said frequency.

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