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APPARATUS AND METHOD APPLYING VIBRATORY ENERGY

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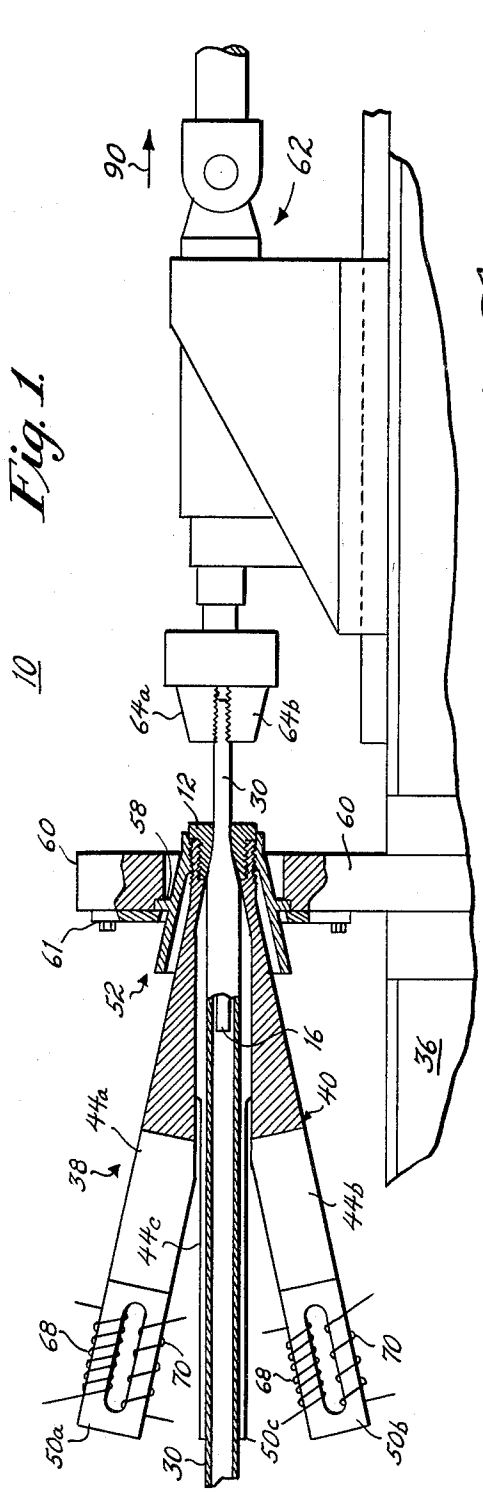


Fig. 1.

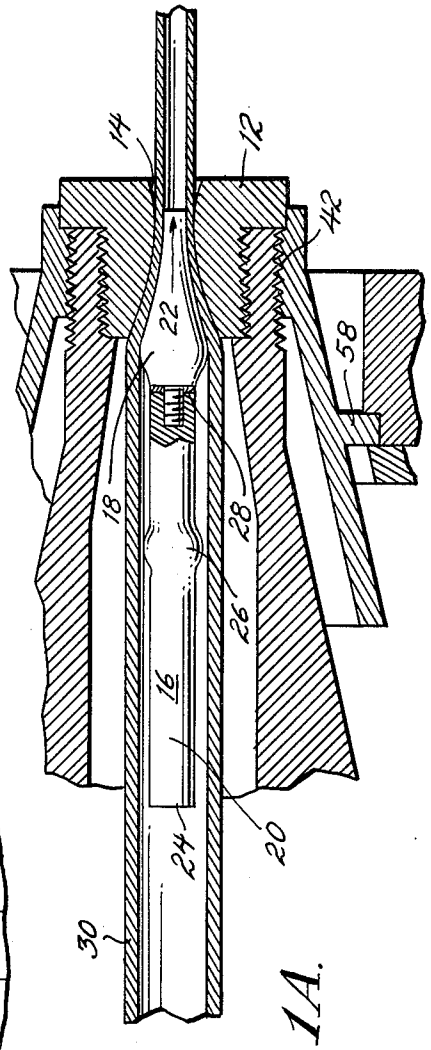


Fig. 1A.

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APPARATUS AND METHOD APPLYING VIBRATORY ENERGY

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The present invention relates to a method and apparatus applying vibratory energy, and more particularly to a method and apparatus for applying vibratory energy in floating plug drawing of articles including tubing.

The apparatus and methods by which tubing may be drawn can be classified under several headings:

(1) *Sinking.*—This is the drawing of tubing through an appropriate die which results in a decrease in the outside diameter of the tubing. Since no constricting force is applied to the inside surface of the tubing, the wall thickness of the tubing does not change much.

(2) *Mandrel drawing.*—This is the drawing of tubing through an appropriate die which results in a decrease in the outside diameter of the tubing. However, the tubing is also drawn over a mandrel having an outside diameter equal to the final inside diameter desired for the drawn tubing. The mandrel moves with the drawn tubing and is removed in a subsequent step of the operation. Mandrel drawing results in a decrease of both outside diameter and wall thickness of the tubing.

(3) *Plug drawing.*—This is the drawing of tubing through an appropriate die with a plug on the inside of the tubing which fixes the inner diameter of the drawn tubing. This plug is maintained at a fixed position relative to the die in two general ways: (*a*) *back supported plug.* The plug is held in position by a supporting rod which is threaded through the undrawn portion of the tubing and fastened to a rigid member of the draw bench; (*b*) *floating plug.* The plug is of such configuration that at the appropriate position relative to the die, the frictional force tending to draw the plug deeper into the die is counterbalanced by the force of deformation of the tubing. This results in the plug's being maintained in an equilibrium position.

It can be seen that the floating plug drawing and the sinking process can be used on long lengths or coils of tubing, whereas the other methods can be used only on discrete straight lengths.

It has been proposed heretofore to employ vibratory energy when drawing material, as in United States Patents 2,393,131; 2,568,303; and 2,638,207 which are not known to have been commercialized, apparently because of significant deficiencies with respect to the application and utilization of the vibratory energy there described.

Various improvements in employing vibratory energy when drawing material have been proposed, as in United States patent application Serial No. 289,559 entitled "Vibratory Energy Method and Apparatus," filed June 21, 1963, in the names of Charles A. Boyd et al.; United States patent application Serial No. 289,694 entitled "Method and Apparatus Employing Vibratory Energy," filed June 21, 1963, in the names of Charles A. Boyd et al.; United States patent application Serial. No. 289,558 entitled "Method and Apparatus Utilizing Vibratory Energy," filed June 21, 1963, in the name of Charles A. Boyd et al.; and United States patent application Serial No. 303,022 entitled "Method and Apparatus Using Vibratory Energy," filed August 19, 1963 in the name of Charles A. Boyd et al. However, neither the method nor the apparatus of the present invention has been described therein.

Accordingly, it is an object of this invention to provide an improved method and apparatus for drawing of tubing.

Another object of the invention is to provide an improved floating plug system for drawing of tubing under vibratory energy application.

It is also an object of this invention to provide an improved floating plug system for drawing of tubing under vibratory energy application without the necessity for joining the plug securely to a source of vibratory energy.

A further object of this invention is to provide an improved method and apparatus for continuous drawing of tubing.

These and other objects of the invention are accomplished by providing a plug having a controlled acoustical geometry and by drawing with said plug under the influence of a vibratorily activated die.

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

FIGURE 1 is an elevational view of apparatus embodying the present invention, partly in section and partly in diagrammatic form.

FIGURE 1A is an enlarged sectional view of a fragment of the apparatus illustrated in FIGURE 1.

Referring to the drawings in detail, wherein like numerals indicate like elements, there is shown in FIGURE 1 a vibratory tube drawing apparatus designated generally as **10**.

The apparatus **10** is in the nature of a draw bench and includes a die **12** having an orifice **14**. A floating plug **16** (see FIGURE 1A) extends into or through the orifice **14** and defines with the die **12** a restricted passageway through which the tube material **30** is drawn.

Die **12** is an element of a transducer-coupling system (designated generally as **38**), other elements of which are acoustical coupler **40** (which includes a plurality of horns **44***a*, **44***b*, **44***c*—and **44***d* not shown) and a plurality of transducers designated **50***a*, **50***b*, **50***c*, and **50***d* (the last not shown).

System **38** is designed to operate at a given frequency, which is preferably a resonant frequency. System **38** is preferably dimensioned to have an over-all physical length equivalent to an acoustical length of a whole even number multiple of a one-half wavelength in the material of which it is made at the said frequency, so as to have, for efficient operation, an antinode (loop) area of the vibration at the tube-contacting portion of the die.

Each of the transducers **50***a*, **50***b*, **50***c*, and **50***d* may be of the magnetostrictive type as shown and of conventional construction comprising a half-wavelength-long laminated core of nickel, nickel-iron alloy, or other magnetostrictive material, properly dimensioned to insure axial resonance with the frequency of alternating current applied thereto by coil **68** so as to cause it to increase or decrease in length according to its coefficient of magnetostriction. The detailed construction of a suitable magnetostrictive transducer is well known to those skilled in the art and does not form a part of the present invention and, accordingly, no description of its construction will be made herein. It will be appreciated by those skilled in the art that in place of the magnetostrictive transducers **50***a*, **50***b*, **50***c*, and **50***d*, other known types of transducers may be substituted; for example, electrostrictive or piezoelectric transducers made of barium titanate, quartz crystals, lead zirconate titanate, etc., may be utilized.

Each of transducers, **50***a*, **50***b* and **50***c*, and **50***d* is provided with an excitation coil **68** and a polarizing coil **70**. Excitation coils **68** of transducers **50***a*, **50***b*, **50***c* and **50***d* are connected to a power supply (incorporating an amplifier, not shown, and oscillator, not shown) suitable for powering the transducers **50***a*, **50***b*, **50***c*, and **50***d*; such

equipment well known to the art. The desirability of magnetically polarizing the magnetostrictive transducers **50***a*, **50***b*, **50***c*, and **50***d* by means of polarizing coils **70**, in order for the metal laminations in said transducers to efficiently convert the applied energy from excitation coils **68** into elastic vibratory energy, is also readily understood by those skilled in the art. Low voltage direct current can be supplied to coils **70** by battery, rectifier, or other means well known to the art.

The aforesaid power supply system, in a typical example, is capable of producing electrical signals in the range of between about 60 cycles per second and about 300,000 cycles per second. This frequency range is suitable for purposes of the present invention, including as it does frequencies in both the audible range (such as up to about 15,000 cycles per second) and the ultrasonic range (generally above about 15,000 cycles per second). A preferred frequency would be in the range of from about 3,000 to about 50,000 cycles per second with the optimum being between about 14,000 to about 35,000 cycles per second. Normally, a frequency is chosen which will provide a suitable size of apparatus for a given application or set of applications, with the ultrasonic range having the further advantage of inaudibility for operator comfort.

Thus, transducer-coupling system **38** may be constructed to operate at 15,000 cycles per second, for example.

As is well known to the art, the electrical frequency of the alternating current power supply (such as 60 cycles per second) is changed to match the mechanical or elastic vibratory frequency of the transducers (15,000 cycles per second in this example, as aforesaid).

It is to be noted that the source of high frequency alternating current may be a motor alternator having suitable frequency control, and that such a motor alternator source is particularly appropriate for drawing applications requiring relatively large amounts of power.

The die **12** has, for purposes of ease of attachment to acoustical coupler **40**, an axially extending portion **42** (see FIGURE 1A) to whose outer surface one end of coupler **40** is secured by means of cooperating threads. The other end of coupler **40** which is remote from the die, namely, each of the horn ends **44***a*, **44***b*, **44***c*, and **44***d*, is fixedly secured to a transducer. That is, horn end **44***a* is joined to transducer **50***a*, horn end **44***b* is joined to transducer **50***b*, **44***c* is joined to **50***c*, and **44***d* is joined to **50***d*, preferably by brazing or some other type of metallurgical joint.

Acoustical coupler **40** is essentially a mechanical transformer and is of contoured construction for purposes including the increasing of the amplitude of vibration. Reference is made to United States patent application Serial No. 114,932 filed June 5, 1961, in the names of James Byron Jones et al., entitled "Three Limb Vibratory Device," which is co-pending, for details concerning construction of a coupler such as coupler **40** and its associated plurality of transducers such as transducers **50**.

The horn-type construction of system **38** is particularly suitable for application of relatively high levels of vibratory energy at a given frequency, and for avoiding undesirable modes of vibration in connection with both the powering and the operation of a relatively large single coupler, as well as for appropriate access and attachment to a member such as the die in order to vibrate it axially of the direction of draw.

Preferably, for support purposes and to minimize frequency shift of the vibratory apparatus and loss of vibratory energy to the associated supporting members, the die **12** is supported by a force-insensitive mount **52**.

Such force-insensitive mount **52** may comprise a sleeve, one-half wavelength long at the operating frequency and made from steel or other low hysteresis material such as nickel, aluminum-bronze, beryllium-copper, or Monel. One end of the sleeve **52** is metallurgically joined to the coupler **40**, preferably at an antinode or loop region of the vibration on the cylindrical portions of the latter, and the other end of the sleeve **52** is free from attachment. Sleeve **52** is provided with a radially outwardly extending flange **58** located one-quarter wavelength from its attached end, and a true node will develop at flange **58**. Reference is made to United States Patents Nos. 2,891,178; 2,891,179; and 2,891,180 each of which issued in the name of William C. Elmore and is entitled "Support for Vibratory Devices."

Flange **58** is removably secured to a support **60**, as by a clamping ring **61** and suitable bolts. Support **60** is rigidly secured to the draw bench **36**.

The mount **52** in the drawing comprises a conical tubular member (a form which is not necessarily preferred). It will be appreciated that, instead of being formed and positioned as shown, mount **52** may comprise a plurality of more or less rodlike members, all having flanges and some being attached to each of the straight portions of horns **44***a*, **44***b* **44***c*, and **44***d*. This may be desirable, as, for example, in associating mount **52** with coupler **40** in the section not representing an increase in amplitude of vibration, thereby minimizing the subjection of mount **52** to the increased stresses associated with the maximum amplitude implicit to the contoured portion. If this latter configuration is used, the position of the support members relative to the draw bench will also be adjusted accordingly.

Acoustical coupler **40** and die **12**, like support mount **52**, are preferably made from K-Monel or other material having low hysteresis, good electrical and thermal conductivity, and high acoustical transmission efficiency even when strained as much as 0.001-inch per inch, for example, including such materials as nickel-aluminum-bronze or beryllium-copper. The materials named are non-magnetic and are known to the art for their relatively good acoustical power handling qualities. However, for drawing purposes the die **12** may be made of other materials, such as those chosen principally for suitability for the drawing operation per se rather than for their acoustical properties, provided that such change is material for the die is taken into consideration in connection with design of the system for operation at a resonant frequency, as has been indicated to be preferable for purposes of the present invention.

In accordance with the present invention, there is provided a free-floating plug **16** having a forming end **18** and a free-floating end **20**. Plug **16** may comprise a single member, or forming end **18** and free-floating end **20** may be manufactured as separate members which may be fixedly connected (as by a metallurgical joint such as a brazed joint) or removably connected (as by cooperating threads). As shown in FIGURE 1A, a washer **28** of a soft material such as aluminum may be disposed between the juxtaposed end faces of the forming end **18** and the free-floating end **20**, which washer **28** is compressed or deformed when the forming end **18** is threaded to the floating end **20** to assure a good acoustic coupling if a screw connection is employed. Plug **16** (like coupler **40**, die **12**, and mount **52**) is preferably made from the above mentioned materials. However, as with die **12**, the forming end **18** may be made of a material (such as tungsten carbide, for example) chosen principally for suitability for the drawing operation per se, provided that such material change is taken into consideration in connection with the design of plug **16**, as will be explained hereinbelow.

In operation, as shown in FIGURES 1 and 1A, the forming end **18** of plug **16** extends into and through the orifice **14** and defines with the die **12** a restricted passageway through which the tube material **30** is drawn.

Plug **16** (like transducer-coupling system **38**) is designed to operate at a given frequency, which as aforesaid is preferably a resonant frequency, namely, the design frequency of system **38** (such as the 15,000 cycles per second above mentioned, for example). Thus, plug

16 is preferably dimensioned to have a resonant length, namely, an over-all physical length equivalent to an acoustical length of a single one-half wavelength or a whole number multiple of one-half wavelength in the material of which it is made at the said frequency. This is so that it will vibrate in the direction of the vibration of system 38, and so as to have for efficient operation an antinode or loop area of the vibration at the tube-contacting portion of the forming end 18 of the plug 16, namely, juxtaposed to the die orifice 14. Hereinafter, the tube-contacting portion of the forming end 18 at which is provided an antinode or loop area may be referred to as location 22. Preferably, plug 16 has a length of a whole even number multiple of one-half wavelength so as to have each of its two ends 18 and 20 operating in phase.

Thus, as indicated in FIGURE 1A, assuming for simplicity of explanation that the plug 16 is a single one-half wavelength long, there will be an antinode of vibration at the locations designated generally as 22 and 24 respectively and a node of vibration at the protrusion designated generally as 26.

It is to be noted that the relatively minor protrusion in length of forming end 18 beyond the smallest diameter of the die orifice 14 and therefore beyond the above-indicated antinodal region 22 may involve a slight adjustmnt in the aforesaid acoustical length of plug 16, such adjustment being well within the skill of one skilled in the art.

As is well known, the velocity of compressional waves in a medium varies according to the medium, and the appropriate length of plug 16 may be found by use of the well known equation (wavelength=velocity/frequency) showing the relation among frequency, velocity, and wavelength of sound. Thus, if the plug 16 is to be made of K-Monel, the velocity of sound in K-Monel is reportedly 4,480 meters per second, so that at a frequency of 15,000 cycles per second a single one-half wavelength in K-Monel would be 5.88 inches.

If all of plug 16 is to be made of K-Monel except for the forming end 18, and if the forming end 18 is to be made of tungsten carbide as is common in the drawing art, the velocity of sound in the tungsten carbide used is ascertained (reportedly approximately 4200 meters per second, although various tungsten carbides may have various values for Young's modulus and density which will result in various velocities of sound), and the one-half wavelength dimension is calculated (5.51 inches, using the above indicated 4200 meters per second and 15,000 cycles per second). Then, dependent on the length needed for drawing reasons for the tungsten carbide forming end 18 (with due consideration of its configuration, such consideration being within the skill of the art), the K-Monel length and the tungsten carbide length of plug 16 can be adjusted so as to conform with the wavelength dimensioning requirements above indicated for plug 16.

The free-floating end 20 of plug 16 may have a straight outline form (such as being in the form of a rod) so as to be entirely free-floating, or it may have a rod-like form except for radially outwardly directed protrusions at the nodal area (or one or more of the nodal areas, if the plug 16 has a length longer than a single one-half wavelength) such as are shown more clearly in FIGURE 1A. These protrusions serve to assist in the centering of the plug 16 with respect to both the tubing 30 and the die orifice 14, and their location along plug 16 is such as to minimize the effect of their presence on the vibratory characteristics and operation of plug 16. Allowance for such protrusions in connection with the wavelength dimensioning of plug 16 is entirely within the skill of the art. The outward extent of such protrusions or protrusion should be sufficient for aid in centering, but should not be so great as to contact the interior of the wall of the tubing even under vibratory activation conditions, though this outer limit for the extent should be approached as nearly as possible for centering reasons.

In operation, tubing 30 is telescoped over the plug 16 (usually after tubing pre-treatment such as pickling, cleaning, and lubrication, although tubing pre-treatment may be minimized or eliminated in some instances and with some materials when the present invention is used). The plug 16 is so arranged that the plug forming end 18 "floats" in the proper position in the die orifice 14. The tubing 30, in accordance with standard practice, is pointed, i.e., provided with a reduced outside diameter end portion such as end portion 32, which may be accomplished in a variety of ways including swaging. Such reduced end portion 32 is fed in the direction of arrow 90 through the die orifice 14. The jaws 64*a* and 64*b* of a pulling device 62 are clamped to the reduced end portion 32 of the tubing 30. Pulling device 62 is movably mounted on drawbench 36 for pulling the tubing 30 through the passageway defined by die 12 and forming end 18 of plug 16. The pulling device 62 is first actuated in the direction of arrow 90 to seat the forming end 18. That is, the tubing 30 is pulled in the direction of arrow 90 until the tubing 30 is locked between the die orifice 14 and the outer peripheral surface of the forming end 18 of plug 16. As shown more clearly in FIGURE 1A, the forming end 18 of the plug 16 has an enlarged diameter portion which is greater in transverse dimensions than the corresponding dimensions of the smallest diameter of the orifice 14 so that the plug 16 cannot be pulled through the orifice 14.

The tubing 30 can be translated by the pulling means for a short distance, so that the plug will seat properly and drawing can be readily accomplished. However, the invention is not limited to any particular sequence of steps in pointing the tubing and/or seating the plug, although certain sequences may be far more favorable. As is readily evident, various lengths of tubing may be accommodated in accordance with the present invention, including very long lengths as, for example, in continuous drawing.

After the forming end 18 of plug 16 is properly seated and positioned, and vibratory energy is applied to the system 38 including die 12 (and by reason of its acoustical geometry to the plug 16), the pulling device 62 will move the jaws 64*a* and 64*b* in the direction of arrow 90. A wide variety of devices may, of course, be utilized to pull the jaws 64*a* and 64*b*, such as a hydraulic cylinder, a cable windup device, etc. It will be appreciated that the jaws 64*a* and 64*b* will be provided with means for selectively opening and closing the same, so that the reduced end portion of the tubing 30 may be inserted and gripped therebetween.

It will be appreciated that the power input to the transducers may be varied according to the operating conditions utilized, including the material being drawn and the conditions of draw (such as the reduction to be achieved, the drawing speed, and the drawing tension), and also according to the transducer-coupling system and plug employed.

The position of the forming end 18 of plug 16 relative to the die 12 and die orifice 14 is a determinant of the depth of draw, and a free-floating plug such as plug 16 is more susceptible to dislodgement (under conventional drawing conditions as well as under vibratory activation conditions) then is a back-supported plug, for example.

The amount of power supplied and transmitted to the die area should not be sufficient to dislodge the forming end 18 of plug 16 from its location specified for drawing purposes. On the other hand, the power should be sufficient to accomplish the given reduction under a given set of operating conditions for a given material.

As is well known to those skilled in the art, power output (to the work) of acoustical vibration devices is not readily ascertainable directly, and indirect determi-

nation thereof often involves the use of liquids and other aspects not suitable for ready adjustment to differing industrial applications. Moreover, permissible power input is variable according to the transducer utilized and the acoustical coupler geometries and materials used, as well as such factors as the efficiencies of joints between the various members of the transducer-coupling system. For example, a magnetostrictive transducer is far more rugged and trouble-free than the ceramic transducers which have been in commercial use, but it has a lesser efficiency in converting electrical power into mechanical vibration, and steel is a more readily machinable and joinable coupler material than Monel or beryllium-copper, but it has a lesser acoustical transmission efficiency. The implications are obvious for differing amounts of acoustic power (expressed in electrical watts output from the power supply or input to the transducer) used with various equipment, even without taking a given drawing operation into consideration.

For those desiring to insure continued transmission efficiency for a given system (in order to obtain warning of malfunction, for example), or for those desiring to compare the relative transmission efficiencies of a plurality of systems, means may be used such as are described in co-pending patent application Serial No. 66,642 filed November 1, 1960, for "Method and Apparatus for Measurement of Acoustic Power Transmission and Impedance" by Dennison Bancroft et al.

For purposes of insuring a sufficient level of acoustical energy for purposes of the present invention, it is to be noted that provision has been made, in addition to a sufficient level of electrical power input to the transducer, for acoustical amplitude transformation. Also, this acoustical amplitude transformation should preferably involve, when a magnetostrictive transducer is used, a total transformer ratio (from the driving face of the transducer to the point of energy utilization) in the range of from about 3.0 to about 7.5. When an electrostrictive transducer (such as one of lead zirconate titanate) is used, such transformer ratio should preferably be in the range of from about 1.5 to about 5. This ratio depends in part upon the material or materials of which the coupling system member or members is made. The transformer ratio is of particular importance for purposes of most efficient (and most economical) utilization of the vibratory energy for drawing.

A lubricant may be applied to the inner and/or outer surfaces of the tubing **30** by means well known in the art. Such lubricants and lubrication are well known to the art and do not form a part of the present invention, except to the extent that the present invention (with some materials and under some conditions of draw) enables elimination or minmization of lubircation, including a lessening of criticality concerning the use of a special lubricant for a given material.

A principal advantage of the present invention is the provision of a free-floating plug, such as is known to the drawing art, with vibratory activation such as is desirable for reasons indicated below, but without the necessity for making said plug a component element of a transducer-coupling system. This is contrary to previous theory and practice, in view of the plurality of interfaces involved which would ordinarily be expected to cause considerable loss of acoustical energy. Also, plug **16** cannot be made a component element of a transducer-coupling system if practical continuous or long-tube drawing is to be employed; there are insurmountable access problems.

The preferred resonant length dimensioning of plug **16**, above indicated, apparently causes said plug to vibrate in phase with the vibration of the die **12**, thereby providing optimum material plasticity with resultant optimum drawing tension reduction, decreased chattering tendencies, increased drawing speed, and greater material reductions per pass than are obtainable in conventional free-floating plug drawing.

In view of the free-floating end **20** of plug **16** being acoustically free at its outer end (i.e., delivering no vibratory energy in view of the acoustical impedance mismatch with air), the nodal regions at odd whole number multiples of one-quarter-wavelength from said end **20**'s outer end are true nodes, which is a condition non-achievable as a practical matter, so far as is known, in a transducer-coupling system under power delivery conditions.

As aforesaid, this invention is not limited to any particular sequence of steps in pointing the tubing **30** and seating the forming end **18** of plug **16**, and the order of pointing and seating in the operation is not critical to the present invention. For example, and as may be particularly desirable in applications contemplating relatively higher area reductions per pass for a given material, the system **38** may first be energized, the reduced cross section end of the tubing may be threaded through the die orifice (with or without assistance of the pulling device, which device may aid in a desirable amount of "sinking" of the reduced cross section end of the tubing), and the forming end **18** of plug **16** may then be advanced into the tubing **30** and seated as desired. Advance activation of the system **38** before seating may serve to simplify production operations. It may also minimize likelihood of undesirable tubing metal pickup by the unenergized plug **16**'s forming end **18** during seating, such as may be encountered with certain materials or with relatively high area reductions for a given material.

For efficient operation, the pulling device **62** (including the jaws **64***a* and **64***b*) should be acoustically non-compliant. That is, the pulling device should not resonate in any mode at the frequency but should be essentially acoustically non-responsive, a condition attainable by various known means including appropriate adjustment of mass.

Although the invention is shown and described in connection with the drawing of tubes, it is to be understood that the invention is applicable generally to the drawing of elongated articles having wall structure formed at least partly about a longitudinal axis thereof.

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 description as indicating the scope of the invention.

I claim:

1. Vibratory tube drawing apparatus comprising a die having an orifice therein, a vibratory generator coupled to said die, means on one side of said die for pulling tubing in an axial direction through said orifice, a free-floating plug partially disposed in said orifice, said plug having a length equal to an integral number of one-half wavelengths in the material of which it is made at the frequency of said vibratory generator, said plug having one end thereof in said orifice and a second end thereof on the side of said die opposite from said pulling means.

2. Apparatus in accordance with claim **1** wherein said plug has a length of a whole even number of multiple of one-half wavelength in the material of which it is made at the frequency of said vibratory generator whereby each of its ends operates in phase.

3. Apparatus in accordance with claim **1** wherein said plug includes an enlarged centering portion, said enlarged centering portion being located at a node of vibration and having an outer diameter slightly less than the inner diameter of a tube to be drawn.

4. The apparatus of claim **1** wherein said plug one end being manufactured of a harder material than said second end, said second end and one end being acoustically coupled to one another.

5. The apparatus of claim **4** wherein said second end is rod-shaped, said one end having a portion thereof of a greater diameter than said rod-shaped second end, said second end having an expanded portion at a nodal point therealong in the material of which the plug is made at the frequency of said vibratory generator.

6. Apparatus for drawing elongated articles wherein

said articles have wall structure formed at least partly about a longitudinal axis thereof, said apparatus comprising a die having an orifice therein, a free-floating plug extending at least paritally into said orifice from one side of said die and defining with said die a restricted passageway for an article to be drawn, means associated with said die on the side thereof opposite said plug for pulling an article through said passageway, a vibratory generator including a transducer and a coupler coupled to said die, said plug having a length equal to an integral multiple of one-half wavelength in the material of which it is made at the frequency of said vibratory generator, said transducer and coupler being arranged so as to vibrate in an axial direction so that a vibratory loop occurs in said die.

7. A method of drawing tubes comprising the steps of providing a free-floating plug, telescoping a tube around the plug, feeding a reduced diameter portion of said tube to a die, seating said plug against the portion of said tube juxtaposed to the orifice of said die, coupling vibratory energy to said die, inducing vibrations in said plug in phase with vibrations of said die, and pulling said reduced diameter portion of said tube in an axial direction away from said die to reduce the cross sectional area of said tube as it passes through said die.

8. The method of claim **7** wherein the step of providing a plug includes providing a plug having a length equal to an integral number of one-half wavelengths in the material of which is made at the frequency of the vibratory energy applied to said die.

9. The method of claim **7** wherein the step of pulling said reduced diameter portion of said tube and the step of seating said plug against a portion of said tube juxtaposed to an orifice of said die are accomplished prior to said step of coupling vibratory energy to said die.

10. Vibratory tube drawing apparatus comprising a die having an orifice therein, a free-floating plug adapted to have one end extending at least partially into said orifice from one side of said die and defining with said orifice a restricted passageway for articles to be drawn, means associated with said die on the side thereof opposite from said plug for pulling an article through said passageway, a vibratory generator coupled to said die to vibrate said die in an axial direction with respect to said orifice, said plug having a length equal to an integral multiple of one-half wavelength in the material of which it is made at the frequency of said vibratory generator with a vibratory loop in the portion of said plug entering said orifice, an enlarged centering portion on said plug located at a node of vibration and having an outer diameter slightly less than the inner diameter of a tube to be drawn, and an enlarged diameter portion on said plug between said centering portion and the smallest cross-sectional area of said orifice, said enlarged diameter portion having a cross-sectional configuration which is larger in transverse dimensions than the transverse dimensions of the smallest cross-sectional area of said orifice.

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CHARLES W. LANHAM, *Primary Examiner.*

MICHAEL V. BRINDISI, *Examiner.*