

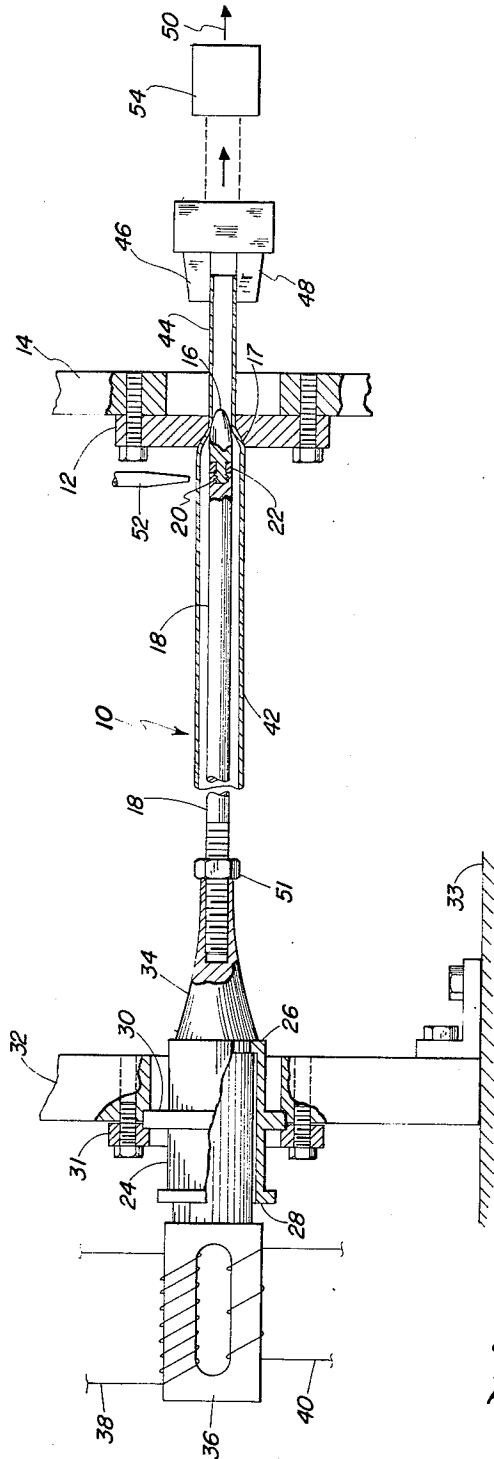
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TUBE DRAWING APPARATUS EMPLOYING VIBRATORY ENERGY

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## TUBE DRAWING APPARATUS EMPLOYING VIBRATORY ENERGY

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This invention relates to an apparatus employing vibratory energy, and more particularly to apparatus for drawing articles including tubes through a die.

Drawing is a well-known manufacturing process for forming materials, and it can be performed wet or dry, single stage or multi-stage, and with or without applying heat to the material before it is drawn through a die. In some materials, hardness may be increased by the drawing operation so that annealing is required before further drawing. In drawing of tubes, a plug (such as a back-supported plug) may be disposed within the tube so that the tube is drawn between the plug and the die. Drawing stresses the material above its elastic limit to permit plastic flow.

It has been proposed heretofore to apply vibratory energy when drawing material, as in United States Patents 2,393,131, 2,568,303, and 2,638,207 which apparently have not been commercialized.

According to the present invention, a method and an apparatus has been provided wherein the plug is coupled to a source of vibratory energy, preferably by a resonant member. With the present invention, there is obtainable greater reduction in cross-sectional area per pass, increased drawing speeds, and/or less drawing force than has been possible previously, as well as better surface finish and the ability to draw materials and/or articles heretofore difficult or impossible to draw with known apparatus and methods. Additional advantages of the present invention are that parts are relatively easy to change, that the electrical equipment can be located remote from the die and the lubricant applicator, and that maintenance and setup of the equipment is simplified.

It is to be noted that commercial tube drawing is presently performed with or without a plug, the plug being generally utilized in situations wherein it is desired to reduce wall thickness of the tube in addition to the "sinking" of the tube diameter which is provided by passage through the die without a plug. As indicated above, it has been proposed heretofore to vibrate the die. However, the present invention provides in many instances a comparable effect at less power with less complication in construction and utilization. Inasmuch as acoustical vibration equipment is generally priced according to both complexity and dollars per watt, the potential economic advantages of the present invention are considerable.

It is an object of the present invention to provide a novel apparatus for drawing tubes and other articles having wall structure formed about an axis.

It is another object of the present invention to reduce the tension force necessary to draw materials.

It is another object of the present invention to facilitate the drawing of articles made from metals or other materials which are difficult or impossible to draw by conventional equipment and methods.

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It is another object of the present invention to facilitate drawing articles with a greater reduction in wall thickness than can be accomplished on conventional equipment.

It is another object of the present invention to provide apparatus for drawing tubes and other articles in a manner which prevents breakage.

It is a further object of this invention to provide a novel apparatus for producing a tube of superior surface finish.

Other objects will appear hereinafter.

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

Referring to the drawing in detail, wherein like numerals indicate like elements, there is shown 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 removably supported by a frame member 14. The die 12 is provided with an orifice 17. A tapered plug 16 extends into or through the orifice 17 and defines with the die 12 a restricted passageway through which the article is drawn.

The rear end of the plug 16 is removably connected to one end of an acoustical transmission or coupler element 18 by means of a threaded stud 20; where it is not necessary to provide a readily removable connection, the plug 16 and the element 18 may be metallurgically connected as by brazing. A washer 22 of a soft material such as aluminum may be disposed between the juxtaposed end faces of the plug 16 and element 18. The washer 22 is compressed or deformed when the plug 16 is threaded to the element 18 to assure a good acoustic coupling.

The transmission element 18 is preferably a resonant length of metal, such as steel, aluminum-bronze, or Monel. By this is meant that element 18 will preferably have a length equal to a whole number multiple of one-half wavelength, or an even number of one-quarter wavelengths, in the material of which the rod is made at the frequency of operation. The combined length of plug 16 and element 18 preferably is dimensioned so that a loop or antinode area of the vibratory energy is juxtaposed to the die orifice 17.

The end of the acoustical element 18 remote from the plug 16 is joined, as by a threaded connection and lock nut, to one end of another acoustical coupler 34; the other end of coupler 34 is fixedly joined to a transducer 36, preferably by brazing or some other type of metallurgical joint. Elements 16, 18, 34, and 36 comprise a transducer-coupling system. The purpose of the threaded connection and lock nut 51 between members 18 and 34 is to permit minor adjustments in the free length of coupler 18 to insure resonance at the frequency of operation. This is desirable because changes in the plug 16 to accommodate different diameters and wall thicknesses of tubing will affect the resonance of member 18. By shortening or lengthening element 18 via the threaded connection into element 34 and locking it in position with the lock nut 51, the effect of modestly differing masses and lengths of elements 16 can be accommodated.

The transducer 36 may be of the magnetostrictive type and of conventional construction comprising 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 in-

sure axial resonance with the frequency of alternating current applied thereto by coil 38 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 transducer 36 shown in the drawing, 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. Coil 38 is connected to a power supply (not shown) incorporating an oscillator and amplifier suitable for powering the transducer 36; such equipment is well known to the art. Other types of power sources, such as a motor alternator with frequency control provision, can also be used for driving or powering coil 38 and transducer 36. The transducer 36 is also provided with a polarizing coil 40, the desirability of magnetically polarizing the transducer 36 by means of polarizing coil 40, in order for the metal laminations in transducer 36 to efficiently convert the applied energy from excitation coil 38 into elastic vibratory energy being readily understood by those skilled in the art.

Acoustical coupler 34 is essentially a mechanical transformer and is of conventional contoured construction for purposes of increasing amplitude of vibration. It may comprise a single member or for purposes of manufacturing convenience, it may comprise a cylindrical portion metallurgically bonded or screw-connected in end-to-end contact with a tapered portion, the tapered portion by means of its increasingly smaller cross section affording the increased amplitude. The tapered portion may be shaped so as to have a taper that is an exponential function of its length and satisfies the following equation:

$$S=S_0e^{-2Tl}$$

where S is the reduced area at any section of the tapered portion,  $S_0$  is the area of the cylindrical portion, T is a constant for the taper, and l is the length of the tapered coupler. This equation and the boundary conditions for resonance of a coupler such as coupler 34 are set forth at page 163 of *Piezoelectric Crystals and Ultrasonics* by Warren P. Mason, published in 1950 by D. Van Nostrand Company.

Preferably, for support purposes and to minimize frequency shift of the vibratory apparatus and loss of vibratory energy to the associated supporting members 31 and 32, a force-insensitive mount is attached to coupler 34. Such force-insensitive mount may comprise a sleeve 24, 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 26 of the sleeve 24 is metallurgically bonded to the coupler 34 preferably at an antinode or loop region on the latter, and the other end 28 of the sleeve 24 is free from attachment. Sleeve 24 is provided with a radially outwardly extending flange 30 located one-quarter wavelength from the fixed end 26 and a true node will develop at flange 30. 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."

The flange 30 is removably secured to a frame member 32. Frame member 32 is removably and adjustably supported from a support surface 33. It will be appreciated that, instead of the arrangement shown, frame member 32 may be adjustably connected to the draw bench 33 via adjusting means such as hydraulic cylinder means or a way slide adjustable fore and aft in the direction of the action of the draw bench as indicated by arrow 50 for longitudinal positioning of the transducer-coupling system 16-18-34-36.

In operation, a tube 42 is telescoped over the plug 16 and element 18. The tube 42, in accordance with standard practice, is provided with a reduced outside diameter portion 44, which may be accomplished in a variety of ways including swaging. Such portion 44 is fed through the die orifice 17. The jaws 46 and 48 of a pulling device are clamped to the free end of the portion 44. A lubricant may be applied to the inner and outer surface of the tube 42. For purposes of illustration, there is disclosed in the drawing a lubricating nozzle 52 adapted to discharge lubricant on the outer peripheral surface of the tube 42. The pulling device is first actuated in the direction of arrow 50 to seat the plug 16. That is, the tube 42 is pulled in the direction of arrow 50 until the tube 42 is locked between the die orifice 17 and the outer peripheral surface of the plug 16. Thereafter, vibratory energy is transmitted from the transducer 36 by way of coupler 34 and element 18, to the plug 16 and the plug 16 is vibratorily actuated in an axial direction.

The plug 16 may be vibrated at a frequency in the audible range (such as between about 59 to about 15,000 cycles per second) or in the ultrasonic range (generally about 15,000 cycles per second to about 300,000 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.

The tube 42 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 seating the plug, although certain sequences are far more favorable. As is readily evident, various lengths of tubing may be accommodated in accordance with the present invention.

After the plug 16 is properly seated and positioned, and vibratory energy is applied to the plug, the pulling device will move the jaws 46 and 48 in the direction of arrow 50. A wide variety of devices may be utilized to pull the jaws 46 and 48, such as a hydraulic cylinder, a cable windup device, a rack and pinion trolley device, a Digitork motor device, etc., and accordingly the pulling device is diagrammatically illustrated in the drawing as 54. It will be appreciated that the jaws 46 and 48 will be provided with means for selectively opening and closing the same, so that the portion 44 may be inserted and gripped therebetween.

Examples of the results achieved by the present invention include the following:

#### Example 1

Using a transducer-coupling system operating at 20,000 cycles per second and a power input to the transducer of 600 electrical watts, copper tubing having initial dimensions of 0.250-inch O.D. and 0.025-inch wall thickness was reduced in one pass to dimensions of 0.1994-inch O.D. and 0.01365-inch wall thickness, representing an area reduction of 55.0 percent. To accomplish this result without vibratory activation of the transducer-coupling system required a drawing tension of 220 pounds at a drawing rate of 66 inches per minute, whereas with vibratory activation at the same drawing rate an average drawing force of only 155 pounds was required, representing a reduction in pulling force of about 29.6 percent, although the same lubricant (conventional in drawing copper commercially)<sup>1</sup> was used in both instances.

#### Example 2

Using a transducer-coupling system operating at 20,000 cycles per second and a power input to the transducer of 600 electrical watts, copper tubing having initial dimensions of 0.250-inch O.D. and 0.025-inch wall thickness was reduced in one pass to dimensions of 0.200-inch O.D.

<sup>1</sup> Petrolard-112.

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and 0.0135-inch wall thickness, representing an area reduction of 55.2 percent achieved at a drawing rate of 26 inches per minute. Cessation of activation of the transducer-coupling system while making a 55.2 percent reduction, on the other hand, resulted in failure of the tubing. The same lubricant was used as in Example 1.

#### Example 3

The application of vibratory energy in accordance with the present invention enabled the successful drawing without prior annealing of strain-hardened aluminum alloy tubing, the attempted drawing of which without vibratory activation with otherwise like apparatus and identical conditions resulted in failure. Thus, drawing of 2024 aluminum alloy tubing which had been strain-hardened by prior cold working was attempted with the following results when working with tubing having initial dimensions of 0.250-inch O.D. and 0.025-inch wall thickness:

|              | Percent Initial Cold Work | Energy (watts) applied to transducer (15 kc.) | Rate of Draw (in./min.)              | Drawing Tension (lbs.) | Area Reduction |
|--------------|---------------------------|-----------------------------------------------|--------------------------------------|------------------------|----------------|
| Test I.....  | 25                        | 150                                           | 26                                   | 360 (Avg.)             | 51.6           |
| Test II..... | 25                        | 0                                             | (Tubing broke on initiation of draw) |                        |                |
| Test III.... | 49                        | 200                                           | 65                                   | 390 (Avg.)             | 47.9           |
| Test IV....  | 49                        | 0                                             | (Tubing broke on initiation of draw) |                        |                |

Other test data, not shown here, indicated that similar results were obtainable with 5086 aluminum alloy. It is to be noted that the above results were obtained with the same lubricant as was used in connection with Examples 1 and 2, and that it was not necessary to use a different lubricant for the aluminum.

#### Example 4

In connection with the one-pass drawing of Type 321 stainless steel having initial dimensions of 0.250-inch O.D. and a wall thickness of 0.020-inch, without vibratory activation of the transducer-coupling system of the present invention, an area reduction of 34.5 percent was obtained with a drawing tension of 1050-1150 pounds. However, with vibratory activation of the system having a frequency of 20,000 cycles per second with 600 electrical watts input to the transducer, a slightly greater one-pass area reduction of 36.0 percent was obtained with an average drawing tension of only 750 pounds, which is a reduction in force of about 32 percent.

Especially significant was the fact that the drawn tubing obtained as indicated above with vibratory activation was of commercially acceptable quality and had a surface finish which was better, whereas that obtained without vibratory activation was not commercially acceptable, the wall thickness being uneven because of the chattering encountered during drawing. The lubricant in both cases, was the same as that used in Examples 1, 2, and 3. Present commercial practice in connection with the drawing of steel involves the use of special lubricants, of special tubing having a conversion coating thereon, and generally of a solid rod corresponding in O.D. to the intended I.D. of the drawn tubing. When such a rod is used, it must be removed by means of expanding the tube after the drawing operation, and such expanding may change the properties, size, and surface finish of the steel. By means of the present invention, commercial grade tubing may be obtained without the use of the extra solid rod and without the use of specially chosen lubricants and/or special coatings.

#### Example 5

By means of the present invention, it was possible to obtain 49 percent one-pass wall area reduction of 1010 steel having initial dimensions of 0.250-inch O.D. and

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0.027-inch wall thickness. Attempts to obtain the same area reduction of the same kind and size of tubing, without the present invention but with otherwise identical conditions, resulted in no draw inasmuch as the tubing broke on initiation of the draw. Conditions used included: 560 pounds average drawing load, a drawing rate of 16.3 inches per minute and, with the present invention, 600 electrical watts input to the transducer.

#### Example 6

While a lubricant is preferable for use in connection with the present invention, particularly in commercial production, it is possible in some instances to dispense with a lubricant. Thus, with the present invention, a 50 percent wall area reduction of unlubricated copper tubing was obtained, using a 20 kc. transducer-coupling system, 600 electrical watts input to the transducer, 510 pounds average drawing tension, and a drawing rate of 24 inches per minute. Chatter marks were present on the tubing, indicating the need for adjustment of one or more of the conditions in order to produce commercial grade tubing.

#### Example 7

By means of the present invention, it was possible to obtain a 40 percent area reduction of 1010 alloy steel tubing, using a drawing speed of 25 inches per minute and an average drawing force of 245 pounds, with only one-tenth of the electrical power input to the transducer (100 watts vs. 1,000 watts) which was required to obtain the same results with an unactivated plug system used with an activated (vibrating at the same frequency) die system. It was more difficult and expensive to arrange for resonant longitudinal vibration of the die (and die retaining elements).

Although, in the above examples, the power input to the transducer was 600 electrical watts or near the maximum permissible power input to the system used, it was found that power input could be varied according to the operating conditions utilized, including the material being drawn, and also according to the type of transducer employed. That is depending upon area reduction desired per pass and/or the drawing tension or force used and/or the drawing rate—up to the point at which the tubing could no longer be drawn without breaking—power input could be varied. The present invention was, for example, used in producing drawn copper tubing at the rate of from about 100 to about 200 feet per minute, using wall area reductions of from about 25 to about 56 percent per pass, with average drawing tension in the range of from about 50 to about 200 pounds, with power ranging from about 20 to about 600 watts and being approximately linear in relation to both drawing tension and area reduction.

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 determination 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 type of 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 a ceramic transducer, 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.

For those desiring to insure continued transmission efficiency of 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 about 3.0 to 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 about 1.5 to 5. This ratio depends in part upon the material or materials of which the coupling system member or members is made.

It has been found that drawing behavior in a given application in accordance with the present invention may be predicted by use of the following general equation:

$$\frac{T}{A_2} = \frac{1}{\eta} Y_m \ln \frac{A_1}{A_2}$$

where

T is drawing tension (lbs.);

A is cross sectional area (in.<sup>2</sup>) of the material being drawn, with A<sub>1</sub> being the condition before the draw and A<sub>2</sub> the condition after the draw;

Y<sub>m</sub> is yield strength of the material being drawn, measured in the maximum work hardness condition (lb./in.<sup>2</sup>);

ln is the natural logarithm to the base e; and

η is an empirically determined constant for the drawing equipment and represents the "drawing efficiency."

It can be shown that there is a linear dependence of η with vibratory activation power, of the form:

$$\eta = \eta_0 + kP$$

where

η<sub>0</sub> is the "drawing efficiency" without vibratory activation; k is an empirically determined constant for the drawing equipment; and

P is the acoustic power (expressed in electrical watts input to transducer).

Both of the constants η and k are characteristic of the apparatus and are affected in the case of vibratory activation by such factors as acoustical transformation ratio and the properties of the material of the acoustical coupling system, and these constants are valid values so long as the elastic limits of such material are not exceeded.

Thus, in utilizing the apparatus and method of the present invention in connection with the size range of tubing indicated in the examples, and for a wide range of values of Y<sub>m</sub> ranging from 46,000 p.s.i. for copper to 141,000 p.s.i. for stainless steel, without vibratory activation there was an average value for drawing efficiency of 1.46, while with 600 watts vibratory activation there was an average value of 1.29 for drawing efficiency.

Also, for this particular apparatus, k (in the case of apparatus including an acoustical coupler made of 4130 steel) was found to be equal to  $1.5 \times 10^{-4}$  watts<sup>-1</sup>; with a more efficient transmission material (beryllium-copper), there was a larger value of k, namely, a value of  $3.1 \times 10^{-4}$  watts<sup>-1</sup>.

In connection with the examples above provided, a tapered tungsten carbide plug was used, although other geometries and materials may be suitable for the purpose. A beryllium copper acoustical element ( $\frac{3}{8}$ -inch in diameter at 15 kc.; λ/2=4.9 inches in length) attached to the plug was more efficacious than a steel element for reasons of more efficient acoustical power delivery also;

although having (in conjunction with the plug) the same acoustical wavelength (57 one-half wavelengths in a typical instance), it was physically somewhat shorter than the steel element.

As aforesaid, this invention is not limited to any particular sequence of steps in seating the plug, and the order of 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 plug system 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 plug may then be advanced into the tubing and seated as desired. Advance activation of the plug system before seating may serve to simplify production operations. It may also minimize likelihood of undesirable tubing metal pickup by the unenergized plug 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 (including the jaws 46 and 48) 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 herein 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.

It is claimed:

1. Apparatus for drawing tubing comprising a die having an orifice therein, a plug partially disposed in said orifice, an acoustic transmission element having an end coupled to said plug, a transducer-coupling system coupled to the other end of said element, an acoustically non-responsive means for pulling tubing in an axial direction through said die, said die being disposed between said pulling means and said transducer-coupling system, said transmission element and plug being a resonant member, and said plug being coupled to said element so that a vibratory loop occurs in a portion of said plug within said orifice.

2. Apparatus in accordance with claim 1 wherein said other end of said transmission element is coupled to said system by an adjustable connection providing for adjustment of the length of said element.

3. Apparatus in accordance with claim 1 including a frame member, a resonant mount coupling said frame member and said system, and means for adjusting said frame member with respect to said die.

4. Apparatus in accordance with claim 1 wherein said plug is removably connected to said transmission element, and the juxtaposed end surfaces of said plug and transmission element being of substantially the same configuration and cross-sectional area.

5. Apparatus in accordance with claim 1 wherein said transducer-coupling system includes a coupler axially connected to the outer end of said transmission element, and a transducer axially connected to the outer end of said coupler, whereby said coupler, transmission element and plug are adapted to vibrate in axial direction.

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 plug extending at

least partly into said orifice from one side of said die and defining with said die a restricted passageway for an article to be drawn, an acoustically non-responsive means associated with said die on a side thereof opposite said plug for pulling an article through said passageway, a transducer-coupling system including a transducer operative at a frequency of between 59 and 300,000 cycles per second, a coupler, an acoustic transmission element coupled at one end to the coupler and at the other end to said plug; said coupler, said transmission element and said plug being constructed and arranged so as to vibrate in axial direction and so that a vibratory loop occurs in a portion of said plug disposed within said orifice.

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