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VIBRATORY SQUEEZE-FORMING OF METALS IN THE
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Fig. 1A

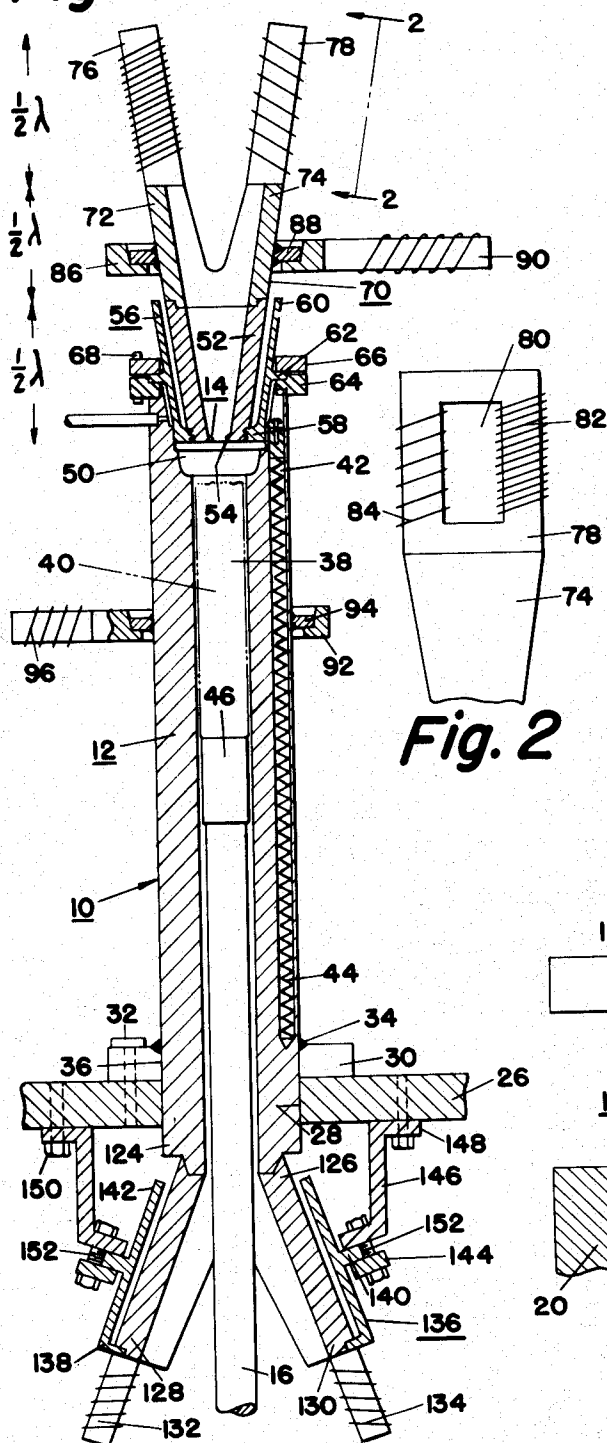


Fig. 2

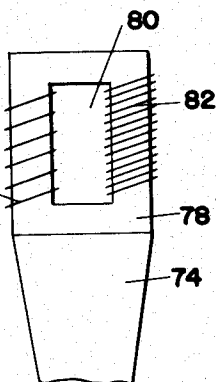
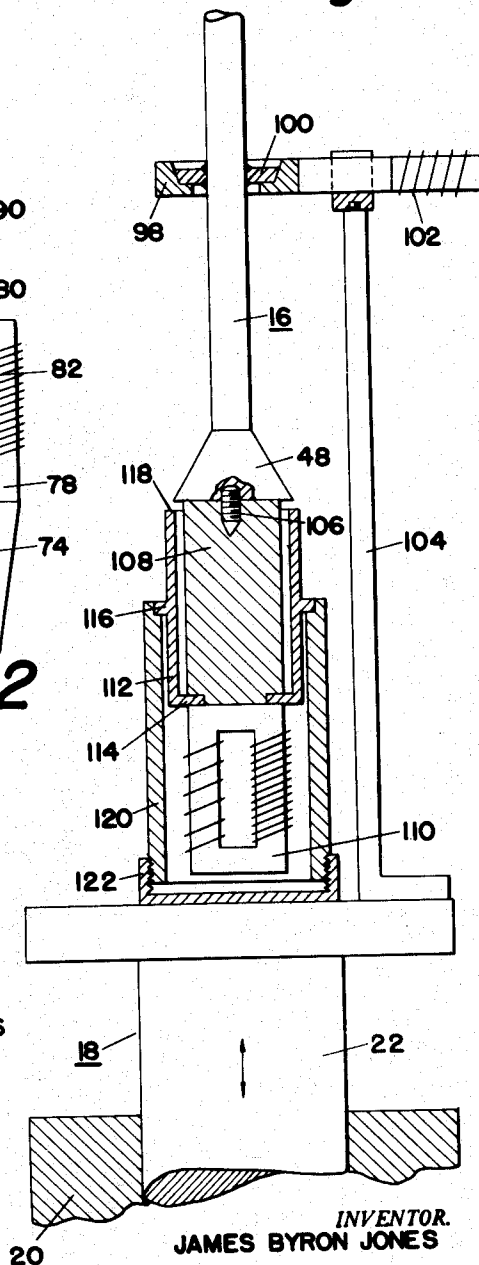


Fig. 1B



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VIBRATORY SQUEEZE-FORMING OF METALS IN THE SOLID STATE AND APPARATUS THEREFOR

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The present invention relates to a process for vibratory squeeze-forming of metal in the solid state and to apparatus therefor.

In particular, the present invention is directed to a process in which a metal in the solid state is squeeze-formed into a particular shape through the simultaneous application of pressure and vibratory energy. The present invention also comprises apparatus for squeeze-forming metals in the solid state into desired shapes, and comprises metal-shaping means comprising a housing, a die in communication with said housing, and means for squeezing the metal while in the solid state into the die, and means for applying vibratory energy to at least a portion of said metal-shaping means. By "housing" as used herein is meant to include the guide means for the die and is not to be construed as limited to a closed vessel.

The squeeze-forming of metals in the solid state has in recent years assumed great industrial importance. A wide variety of commercial methods for squeeze-forming solid state metals have been developed and are in use. These methods include both hot and cold extrusion, forging, impact extrusion, drawing, cupping, etc. In most of these methods, the solid state metal is raised to an elevated temperature, so that it is softened during squeeze-forming. However, a number of methods and a variety of apparatus for squeeze-forming metals in the solid state at ambient temperatures have been developed, and are being used commercially.

Prior methods and apparatus for the squeeze-forming of metals in the solid state suffer from a number of serious handicaps, the minimization of which comprises a principal goal of the present invention. Thus, prior methods and apparatus for squeeze-forming metals in the solid state require the use of means for producing enormous pressures. For example, in commercial extrusion methods wherein large billets are shaped, it is frequently necessary to employ pressures of the order of many thousands of pounds per square inch, and in some cases pressures of hundreds of thousands of pounds per square inch are required. The cost of presses and other means for producing and transmitting such enormous pressures to the solid state metal undergoing forming frequently renders such methods and apparatus feasible only for the largest installations. Moreover, in many cases even where adequate squeeze-forming equipment is available, the production of the squeeze-formed articles is accomplished only at an undesirably low rate.

In addition to the foregoing, prior squeeze-forming methods and apparatus for producing shapes from metals in the solid state frequently yield articles having undesirable characteristics. For example, the surface finish of many extruded metals is apt to be unsatisfactory. With other metals, the resultant squeeze-formed articles may suffer from yet other inadequacies.

I have discovered that the squeeze-forming of metals (and by "metals" as used herein is meant to include elemental metals, such as pure copper, and metallic alloys such as mixtures of a plurality of elemental metals) in the solid state, such as hot and cold extrusion, may be effected under relatively low pressures, and/or may be effected at a relatively high rate when vibratory energy

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is applied to at least a portion of the shaping means simultaneously with the application of pressure. Moreover, I have found that the resultant squeeze-formed metal may possess superior characteristics, when compared with metals squeeze-formed in the solid state solely by the application of pressure.

I have invented a variety of means for introducing vibratory energy to the shaping means in the apparatus of the present invention; and may introduce axial and/or flexural vibratory energy to the housing, and/or die, and/or ram means for squeezing the metal into the die, and/or radial vibratory energy to the housing. I have found that different results may be secured depending upon the manner in which the vibratory energy is introduced, with certain constructional arrangements being superior to others. For the sake of completeness and clarity I am including herein a number of the various embodiments of the process and apparatus of my invention, although certain of these embodiments are preferable to other embodiments.

The process of the present invention may be accomplished both with the metal undergoing squeeze-forming maintained at ambient temperature, or with the metal raised to an elevated temperature below its melting point, as for example to a temperature at which the metal is appreciably softened.

This invention has as an object the provision of a novel extrusion method.

This invention has as a further object the provision of novel extrusion apparatus.

For the purpose of illustrating the invention, there is shown in the drawings a schematic illustration of an apparatus embodiment useful for the extrusion of a metal in the solid state.

FIGURES 1A and 1B comprise a longitudinal section through the illustrated apparatus embodiment.

FIGURE 2 is a view taken from 2-2 of FIGURE 1A.

Referring to the drawings, the extrusion apparatus schematically illustrated therein is designated generally by the numeral 10, and includes a cylinder 12, a die 14, a ram 16, and a press designated generally by the numeral 18.

The press 18 comprises a hydraulic cylinder 20 provided with a piston 22 of conventional design. It is, of course, to be understood that in place of cylinder 20 and piston 22, other means for exerting pressure may be utilized. The press 18 may comprise a plurality of upright braces of conventional design (which for the sake of clarity are not shown in the accompanying drawings) and a cross-head 26 for joining such upright braces together adjacent their upper ends.

The cross-head 26 is provided with an aperture 28 in its central portion within which the cylinder 12 is received. A mounting plate 30, which embraces cylinder 12, is secured by bolts 32 to cross-head 26, and is secured by means of welding or brazing 34 to cylinder 12. An aperture 36 is provided in mounting plate 30, which mates with the aperture 28 in cross-head 26.

In order to provide for the heating of the metal billet to be squeeze-formed within bore 38 of cylinder 12 in those embodiments where the heating of the metal billet within cylinder 12 is necessary or desirable, a plurality of longitudinal chambers 42 may be provided in the wall of cylinder 12. Heating means, such as electric filament cartridges 44, may be positioned within the chambers 42 to effect the heating of billet 40. In place of the electric filament cartridges 44 which depend for their heating action on the resistance of a metal conductor to the flow of electricity, other means for effecting the heating of the metal billet may be provided, such as gas flames, etc.

The ram 16 comprises a rod of metal having fixedly

secured to its innermost end a smooth finished ram head 46 of somewhat larger diameter than the diameter of the ram 16 itself. The outermost end 48 of the ram 16 may be flared outwardly to provide size adaptation and end-to-end engagement with the coupling member 108. Preferably, a fair degree of clearance should be provided between the ram 16 and the cylinder wall of bore 38.

For convenience, the uppermost end of bore 38 may be enlarged to form the chamber 50. The die 14 comprises an inverted hollow generally conical die housing 52 having the die opening 54 at its face.

The die housing 52 is supported upon and fixedly secured to cylinder 12 by means of mount 56. The mount 56 is preferably a force-insensitive support as of the type disclosed in United States Letters Patent 2,891,180, issued June 16, 1959, in the name of William C. Elmore.

The mount 56 comprises an approximately cylindrical tube one-half wavelength long or unit multiples of one-half wavelength long at the applied frequency of the vibratory energy delivered by the magnetostrictive transducers 76 and 78. One end 58 of mount 56 is fixedly engaged as by threaded engagement or brazing to the die housing 52; the other end 60 of mount 56 remains free. An annular flange 62 is provided one-quarter wavelength from the free end 60 of mount 56.

The annular flange 62 of mount 56 is received in counterbored annular flange 64 and locked in place by annular flange 66; the flanges 64 and 66 being joined together by bolts 68. Counterbored annular flange 64 is fixedly secured as by brazing or welding to the end of cylinder 12.

A frustroconical coupler 70 is fixedly secured as by means of a brazed or soldered joint to the die housing 52. Coupler 70 is slotted at its uppermost end to provide a pair of horns 72 and 74. Each of the horns is secured by means of silver soldering, brazing or soldering or the like to a magnetostrictive transducer. Thus, horn 72 carries magnetostrictive transducer 76 and horn 74 carries magnetostrictive transducer 78.

The magnetostrictive transducers 76 and 78 as well as the magnetostrictive transducers 90, 96, 102, 110, 132, and 134 referred to below are formed from a magnetostrictive metal, such as nickel, the alloy 2-V Permendur (an iron-cobalt alloy), a nickel-iron alloy, or Alfenol (an aluminum-iron alloy), properly dimensioned to insure axial resonance with the frequency of the alternating current applied thereto, so as to cause it to decrease or increase in length according to its coefficient of magnetostriction. Transducers of this type constitute a preferred embodiment for operation at frequencies of up to about 75,000 cycles per second. In place of metallic magnetostrictive materials, the transducer may comprise almost any material which has good physical properties and which changes its physical dimensions under the influence of an electric potential. Thus it may comprise a piezoelectric ceramic, such as barium titanate, or lead zirconate, or a natural piezoelectric material, such as quartz crystals. Such materials are preferably used at high frequency operations, as at frequencies above 75,000 cycles per second. The transducer may also consist of an electromagnetic device, such as that which actuates a radio loudspeaker.

Each of the magnetostrictive transducers 76 and 78 in the illustrated embodiment comprises a laminated core of nickel or other magnetostrictive metallic material, and has a rectangularly-shaped opening 80 in its center portion. For the sake of clarity only magnetostrictive transducer 78 is shown in two views (see FIGURE 2), and will be described herein, but it is to be understood that the construction of magnetostrictive transducer 76 and that of magnetostrictive transducers 90, 96, 102, 110, 132, and 134 are similar to magnetostrictive transducer 78. The magnetostrictive transducer

78 includes a polarizing coil 82 and an excitation coil 84 which are wound about the laminated nickel core through the opening 80. Upon variations of the magnetic field strength of the excitation coil 84, there will be produced concomitant variations in the dimension of the transducer 78, provided the polarizing coil 82 is charged at a suitable level with D.C. current, with the frequency of the aforesaid variations, namely the expansion and/or contraction of the magnetostrictive transducer 78 being generally equal to the frequency of the alternating electric current flowing in the excitation coil 84.

Inasmuch as each of the excitation coils 84 of the magnetostrictive transducers 76 and 78 may if necessary be connected to the same source of high frequency alternating current, and each of the transducers 76 and 78 are dimensioned similarly, the transducers 76 and 78 will deliver vibratory energy of the same frequency in phase to their respective horns 72 and 74 of coupler 70.

The dimensioning of the transducer 76, coupler 70 and die housing 52 should be regulated so that their total length is an even number of one-quarter wavelengths, and preferably these elements should be dimensioned as shown in the drawings, namely each of these elements should be dimensioned to equal one-half wavelength.

In place of the magnetostrictive transducers 76 and 78 shown in the drawings, other materials such as those heretofore mentioned may be used, such materials being cut to physical dimensions which minimize electrical losses and insure axial resonance at the applied alternating frequency.

A coupler 86 embraces coupler 70, as at a point midway between the ends of coupler 70. The coupler 86 includes an aperture within which is secured by brazing or welding a split ring 88, which in turn is secured by brazing or welding to coupler 70. The split ring 88 is used to preclude the possibility of a sliding fit. A magnetostrictive transducer 90 is secured in end-to-end contact with coupler 86. Magnetostrictive transducer 90 is similar to magnetostrictive transducers 76 and 78.

A coupler 92 embraces cylinder 12. The coupler 92 is brazed or welded to a split ring 94 which is fixedly secured by brazing or welding to the outer wall of cylinder 12. A magnetostrictive transducer 96 is joined in end-to-end contact with coupler 92. The magnetostrictive transducer 96 is preferably of the same construction as magnetostrictive transducers 76, 78 and 90.

A coupler 98 embraces the ram 16 adjacent the end thereof remote from ram head 46. The coupler 98 is provided with an aperture within which split ring 100 is secured as by brazing or soldering, the split ring 100 being secured to ram 16 by brazing or soldering. A magnetostrictive transducer 102 is permanently joined in end-to-end contact with coupler 98.

The coupler 98 may be rest-supported and preferably not clamped upon the clevis or yoke 104 which is carried on the head of piston 22 so that the coupler 98 travels upwardly with the ram 16.

The base 48 of ram 16 is provided with a threaded stud 106. The base 48 is longitudinally engaged in end-to-end engagement with coupler 108, and is threadably joined therewith by means of stud 106. Coupler 108 is fixedly secured, as by brazing or soldering or the like, in end-to-end contact with magnetostrictive transducer 110. Magnetostrictive transducer 110 is of similar design and construction as magnetostrictive transducer 76, 78, 90, 96 or 102. Thus, magnetostrictive transducer 110 delivers vibratory energy of the same frequency as that delivered from the other magnetostrictive transducers to the coupler 108.

A mount 112 is fixedly secured at its end 114 to coupler 108. The mount 112 comprises a tube having a length equal to one-half wavelength, and includes an

annular flange 116 positioned one-quarter wavelength from the mount's free end 118.

The flange 116 of mount 112 is fixedly secured as by soldering or the like within an annular groove on the uppermost end of a metal tube 120. The end portion of tube 120 which projects beyond the free end of magnetostrictive transducer 110 is threaded and is provided with a matingly threaded cap 122. The cap 122 rests on the upper surface of the head of piston 22, and receives the upward thrust of the piston 22, and communicates it to the tube 120.

The lowermost end 124 of cylinder 12 is joined in mitred end-to-end contact with coupler 126 which generally resembles coupler 70 and is provided with a pair of horns 128 and 130.

Magnetostrictive transducers 132 and 134 are joined in end-to-end contact with respective horns 128 and 130. Each of the magnetostrictive transducers 132 and 134 are similar to magnetostrictive transducers 76, 78, 90, 96, 102 and 110, and transmit vibratory energy to the coupler 126.

The coupler 126 and its associated magnetostrictive transducers 132 and 134 are supported by means of tubular conical mount 136 which is joined at one end 138 to coupler 126. The mount 136 is one-half wavelength long or unit multiples of one-half wavelength long and includes a flange 140 positioned one-quarter wavelength from its free end 142.

The flange 140 of mount 136 is supported intermediate a face of supporting brace 146 and clamping ring 144 by bolts 152. Supporting brace 146 is provided with an annular flange foot 148 which is connected to cross-head 26 by means of bolts 150. A plurality of bolts 152 join clamping ring 144 to supporting brace 146 and provide for the engagement of flange 140 of mount 136 therebetween.

The coupler 70, die housing 52, cylinder 12, and ram 16, and the coupler 86 for the coupler 70 (which is fixedly secured to the die housing 52), the coupler 92 for the cylinder 12, and the coupler 98 for the ram 16 should be properly dimensioned so as to resonate at their associated transducer's operating frequency and should preferably be insensitive to applied forces, the same being accomplished by the use of the above-described mount where the vibratory energy is applied axially. Insensitivity to applied forces permits the transducers to operate efficiently under the force conditions existent in the illustrated extrusion apparatus.

In the illustrated embodiment, the process of the present invention contemplates introducing vibratory energy axially to the ram 16 from magnetostrictive transducer 110 and coupler 108; and/or axially to the die 14 through magnetostrictive transducers 76 and 78, and coupler 70, and/or axially to the cylinder 12 through magnetostrictive transducers 132 and 134 and coupler 126. The process of the present invention also contemplates the introduction of vibratory energy flexurally to the die 14 through magnetostrictive transducer 90 and coupler 86; and/or radially to the cylinder 12 through the magnetostrictive transducer 96 and coupler 92; and/or flexurally to the ram 16 through the magnetostrictive transducer 102 and coupler 98.

By axial vibratory energy (commonly called longitudinal vibration) is meant vibration wherein the motion of the particles of the medium being vibrated is along the direction of wave propagation or transmission, i.e., in the direction of the length of the medium. By flexural vibratory energy (which is a type of what is commonly called transverse vibration) is meant vibration wherein the motion of the particles of the medium being vibrated is at right angles to the direction of wave propagation or transmission and in which the strain is extensional on one side of the axis of bending of the medium and compressional on the opposite side. By radial vibratory energy is meant vibration wherein the motion

of the particles of the medium being vibrated is axially symmetrical and is in the direction of the radius vectors of the medium, which medium has a cylindrical, annular, or tube-like section, no nodes being involved, and the particle motion being of constant phase at any given radius. (See, for example, Warren P. Mason, *Physical Acoustics and the Properties of Solids* (New York: D. Van Nostrand Company, Inc., 1958, page 33, and Theodor F. Hueter and Richard H. Bolt, *Sonics* (New York: John Wiley & Sons, Inc., 1955), pages 146-147.

The process of the present invention contemplates the axial or flexural introduction of vibratory energy to the die, or the axial or flexural introduction of vibratory energy to the ram, or the axial or flexural introduction of vibratory energy to the cylinder. It is not feasible to introduce vibratory energy both axially and flexurally into the die or ram, or to introduce one type of vibration, such as axial vibration, into the die and another type of vibration into the ram. Thus, axial vibratory energy may be introduced simultaneously to both the die and ram, or flexural vibratory energy may be introduced simultaneously to both the die and ram, but both of these modes of vibratory energy should not be introduced simultaneously into the die and ram. Analogously, either axial vibratory energy or radial vibratory energy may be introduced into the cylinder 12 as alternatives, but both of these modes of vibratory energy should not be introduced simultaneously. Axial vibratory energy may be introduced into the cylinder 12 simultaneously with the introduction of axial vibratory energy into the die or ram.

The same mode of vibratory energy may be introduced into a plurality of elements, such as to the ram and die, or to the cylinder, die and ram, etc. either in phase, that is with the vibratory energy being delivered to the billet undergoing squeeze-forming in the same manner from each location, namely simultaneously subjecting the billet to compression and simultaneously subjecting the billet to expansion from each of a plurality of elements delivering vibratory energy to the billet; or the same mode of vibratory energy may be delivered to the billet undergoing squeeze-forming out of phase, namely subjecting the billet to compression by vibratory energy from one element and subjecting the billet to expansion by vibratory energy from another element. The aforementioned modes of application of vibratory energy to the billet produce different results, and are not to be regarded as equivalents and mere substitutes. However, all of the foregoing apparatus arrangements and processes are to be construed as included within the present invention.

The billet positioned within bore 38 and chamber 50 in the illustrated extrusion process is forced into and through die opening 54 at the base of die housing 52 due to the pressure exerted by piston 22 on ram 16 through cap 122, tube 120, and coupler 108. Simultaneously, vibratory energy is introduced axially or flexurally or radially to the cylinder as aforesaid.

I have found that due to unexplained forces, the effect of the vibratory energy may persist for a short time interval, the same occurring when the vibratory energy is interrupted or pulsed.

The squeeze-forming process of the present invention may be effected over a wide range of frequencies. Generally, the application of frequencies within the range 59 to 300,000 cycles per second or somewhat more than 300,000 cycles per second is operative, although for specific applications, particular frequency ranges within this operative frequency range may be preferred.

As a general rule, the beneficial effects achieved by the squeeze-forming process of the present invention, including squeeze-forming at relatively low pressures, or squeeze-forming at a relatively higher rate for a given pressure, are generally a function of the power level of the vibratory energy applied during the process and not

of the specific frequency of the applied vibratory energy. Thus, I have found that as a general rule the increase of the power level for the vibratory energy, other factors remaining constant, produces a greater reduction in necessary force and an increase in the rate of extrusion.

The process of the present invention comprehends the inclusion of the various techniques used by those skilled in the art of conventional squeeze-forming processes to facilitate squeeze-forming. For example, the process of the present invention comprehends the addition of conventional lubricants and/or coatings to the billet and/or die.

Beneficial changes may be effected in the physical characteristics in metals processed in accordance with the process of the present invention. For example, the surface finish characteristics of metals extruded in accordance with the process of the present invention appear to be markedly improved.

I do not believe that it is possible to satisfactorily explain the subject invention by existing theoretical physics. In my opinion, and I do not wish to be bound hereby, it is my belief that the process of the present invention takes advantage of a plurality of phenomena whose nature is not as yet understood, namely changes in the interfacial contact areas of metals effected through the application of vibratory energy (with such changes probably affecting both the billet undergoing forming and the juxtaposed surfaces of the apparatus of the present invention which engage such billet), a conversion of the vibratory energy into a form of energy useful for overcoming friction, the last-mentioned phenomenon being perhaps somewhat analogous to the fundamental physical maxim that dynamic friction is always lower than static friction; and to other effects about which present-day physics furnishes no information. In particular, the apparent persistence of the effect of the vibratory energy for a short time after the introduction of such energy has been interrupted cannot be satisfactorily explained by present-day physics concepts.

The present invention permits the application of squeeze-forming techniques for metals in the solid state beyond the limits of all prior equipment. Moreover, the present invention permits the squeeze-forming of metals in the solid state at pressures appreciably below those necessitated by conventional techniques, or where conventional pressures are utilized, permits a marked improvement in the rate of squeeze-forming.

By "wavelength" as used in the annexed claims is meant the conventional definition for the term as used in the ultrasonic art, namely as the distance in the line of advance of a wave from any one point to the next point at which, at the same instant, there is the same phase. If N is the frequency of the waves and λ their wavelength, their velocity of advance is the product $N\lambda$. The wavelengths of sound in common materials at commonly used ultrasonic frequencies have been charted, see for example, Ultrasonic Engineering by Alan E. Crawford, 1955, Table III, at page 10.

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

I claim:

1. An extrusion process which comprises extruding a solid state metal rod through a die opening whose maximum dimension is appreciably less than the minimum dimension of said solid state metal rod by simultaneously applying pressure to said solid state metal rod and vibra-

tory energy to said solid state metal rod, said vibratory energy being applied by a plurality of vibrating devices at least two of which vibrate out of phase with one another, the amount of applied pressure being less than the requisite amount of pressure required to extrude said solid state metal rod through the die opening in the absence of the applied vibratory energy.

2. Extrusion apparatus including a housing having a cavity, a die having an orifice of smaller cross-sectional area than the cross-sectional area of the cavity of the housing in communication with the cavity of said housing, means for extruding a solid state metal from the cavity of said housing through said die, means for applying vibratory energy to at least a portion of said extrusion apparatus, and support means for supporting said means for applying vibratory energy including a member having a length equal to a unit multiple of one-half wavelength in the material of which the support means is made at the applied vibratory frequency, said support means having one free end and including a flange positioned an odd unit multiple of one-quarter wavelength from the free end of the support means for securing said support means to the extrusion apparatus.

3. Extrusion apparatus including a housing having a cavity, a die having an orifice of smaller cross-sectional area than the cross-sectional area of the cavity of the housing in communication with the cavity of said housing, means for extruding a solid state metal from the cavity of said housing through said die, and means for applying vibratory energy to at least a portion of said extrusion apparatus, with said means including a substantially V-shaped vibration-transmitting coupler, and said means further including two transducers, each capable of delivering 59 to about 300,000 cycles per second, each mounted on a respective arm of said coupler so that vibrations emanating from said transducers are transmitted down the respective arms of said coupler to join at the coupler base to be transferred therefrom to said portion of said extrusion apparatus against said base is fixedly mounted.

4. Extrusion apparatus in accordance with claim 2 in which the vibratory energy is introduced so as to axially vibrate a portion of the extrusion apparatus.

5. Extrusion apparatus in accordance with claim 2 in which the vibratory energy is introduced so as to flexurally vibrate a portion of the extrusion apparatus.

6. Extrusion apparatus in accordance with claim 2 in which the vibratory energy is introduced so as to radially vibrate the housing.

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