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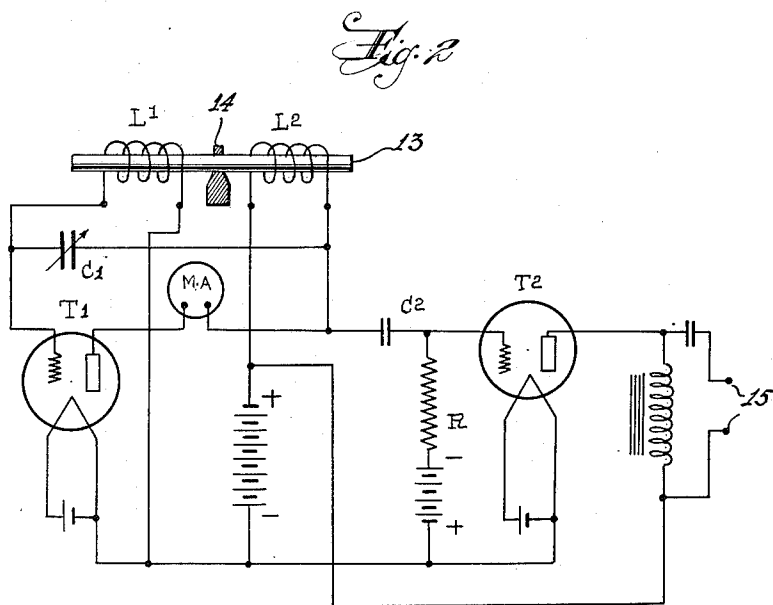
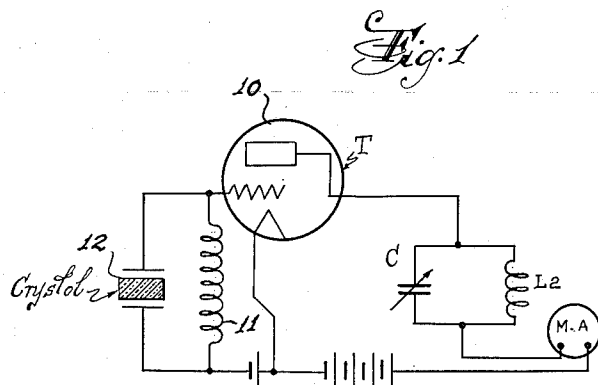
A. VANG

2,393,131

MATERIAL FORMING AND DRAWING WITH THE AID OF VIBRATION

Filed Aug. 21, 1942

4 Sheets-Sheet 1



INVENTOR
Alfred Vang
BY *Peter W. Boesky*
ATTORNEY

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A. VANG

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MATERIAL FORMING AND DRAWING WITH THE AID OF VIBRATION

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4 Sheets-Sheet 2

Fig. 3

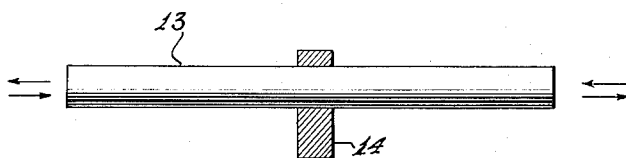
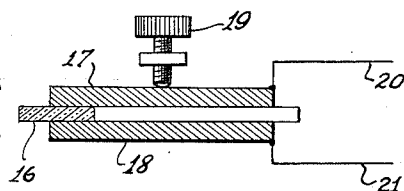


Fig. 4

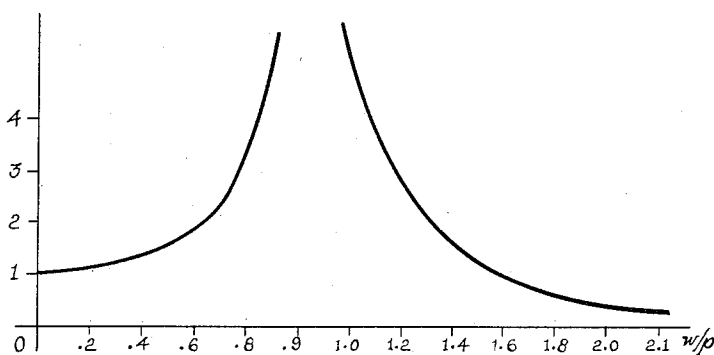


Fig. 5

INVENTOR
Alfred Vang
BY *Peter W. Boeson.*
ATTORNEY

Jan. 15, 1946.

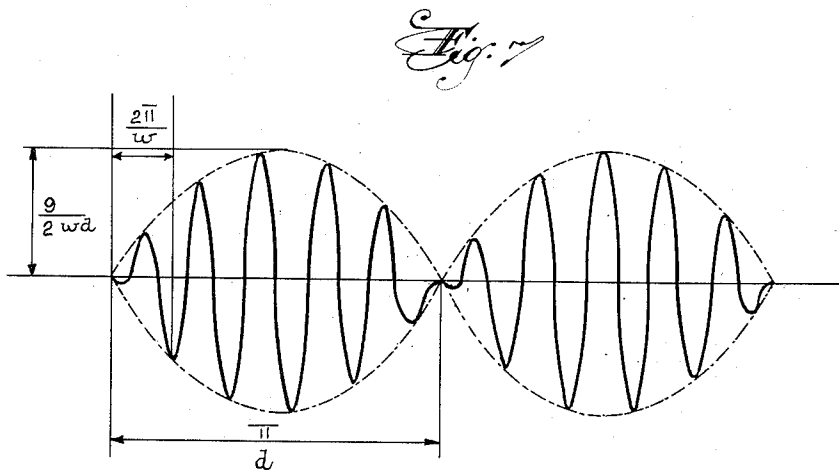
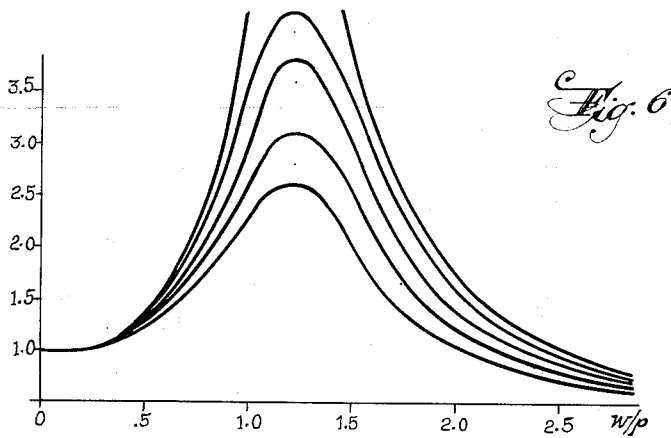
A. VANG

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4 Sheets-Sheet 3



INVENTOR
Alfred Vang
BY *Peter W. Boesen*
ATTORNEY

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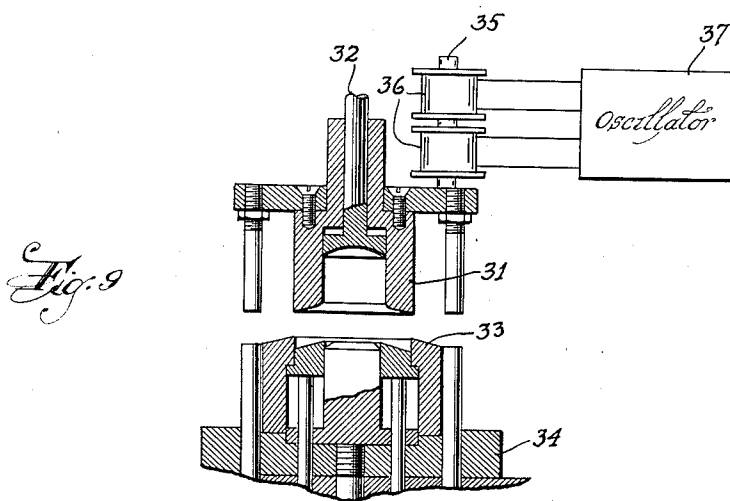
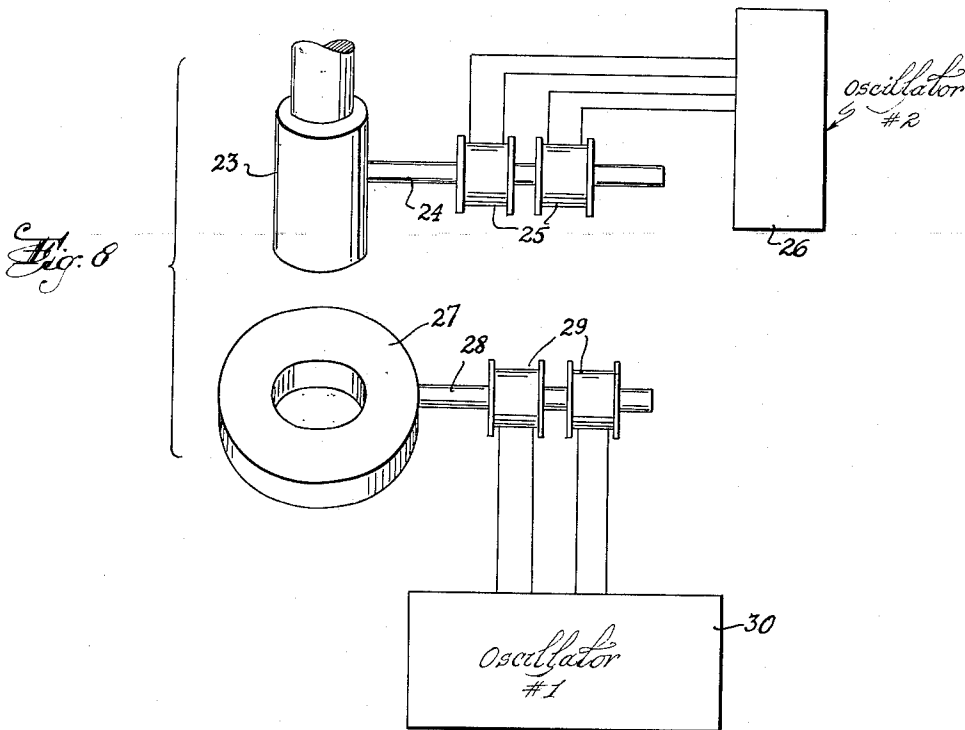
A. VANG

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MATERIAL FORMING AND DRAWING WITH THE AID OF VIBRATION

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4 Sheets-Sheet 4



INVENTOR
Alfred Vang
BY *Peter M. Boesen.*
ATTORNEY

UNITED STATES PATENT OFFICE

2,393,131

MATERIAL FORMING AND DRAWING WITH
THE AID OF VIBRATIONAlfred Vang, Newark, N. J., assignor to Conti-
nental Can Company, Inc., New York, N. Y.

Application August 21, 1942, Serial No. 455,642

8 Claims. (Cl. 113—46)

This invention relates to apparatus and methods for reducing the work of formation and deformation in the working of various metals and plastic materials by means of elastic vibrations, and more particularly it refers to a method and means for the drawing of deep shells and tubular vessels in drawing dies with a smaller number of steps than heretofore possible, with less energy expended and with greater speed effected by the introduction of vibratory energy of a suitable frequency.

It is well known that all so-called elastic materials can be expanded and contracted a certain definite amount without any permanent deformation of the material. In such cases the expansion or compression of the fibres or particles of the material are subject to certain strains and stresses and these strains and stresses must, of necessity, be inside of the elastic limit for the given material. Under the action of external forces an elastic body undergoes a deformation during which the forces do a certain amount of work. This work is transformed into strain energy, or potential energy of deformation of the body. If, as mentioned supra, the stresses do not exceed the elastic limit of the material, the amount of work or labor for formation or deformation of the material can be easily calculated, as will be hereinafter described.

Due to the molecular structure of elastic materials the stresses and strains caused by the action of external forces upon a given elastic body will store up a certain amount of potential energy similar to the energy stored in a compressed spring. If the external forces are released this spring energy bounces back, and the material immediately takes on its original form and size. To illustrate this one may consider the simplest form of deformation of an elastic body in the form of a rod fastened vertically at its upper end and with a load applied to its lower end. As the load is increased, the rod will be stretched ever so little and it becomes longer and longer the greater the load is, that is applied to its lower end. The load may be increased, and increased until the elastic limit has been exceeded, at which time a rupture of the rod will occur and a permanent deformation will be present. If, however, the elastic limit has not been exceeded, the removal of the load will bring the rod back to its original length. It is obvious that in a simple case of this type the work of formation or deformation will be equal to the amount of the load times the increment of increase in the length of the rod as long as the increase is proportional to the load applied. This, however, is not always so and in general one may state that

the total work performed in the lengthening of a rod of length l and cross-section F is expressed by the following equation:

$$A = Fl \int_0^s s_x de_x \quad (1)$$

where e_x designates the incremental increase in the length of the rod at any given point x , and s_x denotes the instantaneous stress at any given point x . If the stress curve of the material is known this labor of deformation can easily be calculated. If for further development it is assumed that the expansion and stress are proportional in a given material, Equation 1 may be simplified because it is easily seen that the integral represents the area of the stress curve. If proportionality is present this area will take the form of a triangle of the area $se/2$. If furthermore, we designate the volume of the rod as $V=Fl$ the formula for the work of deformation as expressed in Equation 1 may now be written:

$$A = \frac{V s^2}{2E} \quad (2)$$

This formula, Equation 2, represents the amount of work necessary to stress a rod with the volume V from zero stress, until every particle of the same is under a uniform tension s . This represents the basic formula for the amount of work or energy necessary to deform a given material. In more complicated applications, this work may be present as a potential energy of both strain and compression forces, such as in bending, or it may be in the form of shear forces, such as in the shearing of materials. The basic problem, however, is always the same and consists in overcoming the elastic strength of the material.

The present invention is particularly concerned with the deep drawing and forming of materials in dies such as, for instance, in the drawing of shells and tubular vessels for many purposes from metals and from plastic materials. It is well known that in such deep drawings it is ordinarily not possible to draw the full depth of the shell in one operation. If one tried to do so the elastic limit of the material would be exceeded, and a rupture of the material would result. To avoid such ruptures and breakages, which would be highly undesirable, it is necessary to draw deep shells with a great many steps. This requires complicated dies and elaborate and time consuming operations, and it is one of the objects of this invention to reduce the number of steps necessary and thereby speed up the production of such articles.

To obtain the desired simplification of the draw-

ing of such articles, as mentioned supra, and thereby speed up the production of same, I use vibratory energy in the form of sonic and super-sonic vibrations. To illustrate how this can be done it is necessary to keep in mind the above described elastic nature of metals and other materials. Any drawing of a material in a die in the usual manner results in a continuous series of increased and decreased stresses upon the material. These stresses are caused by the punch and the die, and are created by the gradual forcing of the punch into the die with the material to be drawn wedged in between the two. During this process the external force which presses the punch into the die has to provide the work of deformation required to gradually stress the material to be drawn until it takes the desired shape. Due to the elastic forces described supra, this process results in a series of quick changes in the stress which may be likened to elastic vibrations, or to the vibrations of a spring. In other words, the punch, being forced down into the die, causes the stress in the material, which stress increases up to a point where the material "gives in," i. e., at the point where the external force exceeds the elastic limit of the material. It is important to note, however, that the progress of the punch down into the die is characterized by a large number of successive operations of this type, or one may say that the punch is subject to a continuous series of elastic vibrations, which are caused and overcome by the external force of the drawing press. The basic theory of my present invention is that by applying vibratory energy from the outside, at the proper frequency, the material to be drawn will perform elastic vibrations which will be of a similar frequency to that of the vibrations caused by the punch being forced into the die. In this manner I can reduce the work of deformation and make the drawing quicker and easier with less expenditure of energy from the outside. The explanation of this phenomenon is to be found in the molecular structure of the material and in the elastic nature of the same, as described supra by supplying vibrations from the outside of a frequency similar to those caused by the mechanical force of the punch entering the die. The vibration furnished from the outside will supply a part of the energy required for the deformation of the material, and it will set the molecular structure of the same in vibratory motion in such a manner that the punch will virtually slip through every time the vibration is at its peak amplitude.

It is well known that an elastic body may be given vibrations of various frequencies by outside vibratory forces. These forces may be of various nature, such as a piezoelectric force, or magnetostriction forces, or simply vibrations induced by magnetic or electric forces, or finally vibrations induced by contact with another vibrating body. Such vibrations, if caused by uniformly varying forces, are called harmonic vibrations. These vibrations may be either free or forced. A spring, for instance, will carry out free vibrations for a considerable time after being excited. The theory of such vibrations is well known, and it is well established that the frequency at which a given elastic body will vibrate most intensely is dependent upon the size, weight, and shape of the same. Each elastic body has what is called a natural frequency, which may be illustrated as an analogy of the well known resonance of electrical circuits. At this natural resonant frequency an elastic body will, when excited, vi-

brate with great intensity and at this frequency it may be excited into vibration with a much smaller amount of energy than at any other frequency. In my present invention I have taken advantage of this fact and by applying vibratory energy from outside at the proper frequency, I am able to give the punch and the die the proper vibrations to effect the desired reduction of deformation energy in the deep drawing of materials, as described supra.

The object of my invention, therefore, is to provide means for supplying vibratory energy of the proper frequency to drawing dies for the reduction of work of deformation.

Another object of my invention is to speed up the production on deep drawn shells and tubular vessels by eliminating the necessity of step drawing of the same or by reducing the number of steps otherwise required.

Further objects and advantages of my invention will be apparent during the course of the following description and claims.

In the accompanying drawings, forming a part of this specification, and in which like numerals are employed to designate similar parts throughout the same:

Figure 1 illustrates a schematic wiring diagram of a piezoelectric oscillator.

Figure 2 illustrates a schematic wiring diagram of a magnetostriction oscillator.

Figure 3 shows a cross section through a piezoelectric crystal.

Figure 4 is a side view of a magnetostriction rod vibrating longitudinally.

Figure 5 represents a curve indicating the amplification factor of a forced vibration.

Figure 6 shows a series of curves of forced vibrations with viscous damping.

Figure 7 represents a curve illustrating the beating of free harmonic vibrations.

Figure 8 illustrates a schematic arrangement of a punch and die with vibrators embodying my invention, while the

Figure 9 represents a cross section through a drawing die for drawing shells with an oscillator applied in an arrangement embodying my invention.

In the drawings, wherein for the purpose of illustration, is shown a preferred embodiment of my invention, the numeral 10 in Figure 1 designates a triode which is arranged in an oscillating circuit with the coil 11 and the crystal 12 in the grid circuit, and with the condenser C and the coil L2 and the milliammeter MA in the plate circuit. As hereinafter described, the crystal 12 is capable of making piezoelectric vibrations of a definite frequency thereby creating a minute electromotive force which works on the grid of the triode 10 and which is amplified by the same and thereby sets up a secondary oscillation in the tuned circuit represented by C and L2.

Referring to Figure 2, which illustrates a schematic wiring diagram of magnetostriction amplifier with the magnetostriction rod 13 supported at its center by the support 14 and having coils L1 and L2 at its free ends. The coils L1 and L2 are tuned to resonance by means of the condenser C1, and the oscillation set up in this circuit works upon the grids of the tuned triodes T1 and T2. This oscillation is, thereby, amplified and may be utilized at the output terminals 15.

Referring to Figure 3, the crystal 16 is clamped between the two plates 17 and 18 by means of the clamping screw 19 and is connected to an

electric circuit by means of wires 20 and 21. It is well known that rock crystals of a certain type, when properly ground and subjected to the correct pressure, will create a very slight electromotive force between its two faces. When ground to the proper thickness, the crystal will have a very definite natural frequency at which it will vibrate mechanically in a transverse direction as indicated by the arrows in Figure 3. In other words, the crystal, when excited, will carry out elastic vibrations, which are accompanied by a small periodic electromotive force of the same frequency as the elastic vibrations in the crystal. A crystal of this type is commonly called a piezoelectric crystal. In the circuit shown in Figure 1, the characteristics of a crystal of this type have been taken advantage of, and are used in the grid circuit of the triode 10 to excite oscillations of a fixed frequency which are amplified by the triode and used to excite the tuned circuit represented by the condenser C and the induction coil L2. It is well known that the frequency of the elastic vibrations in the piezoelectric crystal 12 are dependent upon its temperature and will change considerably with the same. In cases where a fixed frequency is desired, the crystal is usually enclosed in a temperature controlled enclosure. It is obvious that, inasmuch, as a piezoelectric crystal will oscillate as mentioned supra, the process may also be reversed and one may obtain elastic vibrations from the crystal by directly exciting the same through the natural frequency of the crystal.

In Figure 4 is illustrated the magnetic rod of a magnetostriction amplifier of the type illustrated in Figure 2. The operation of this amplifier is based upon the well known phenomenon of magnetostriction according to which the rod 13, supported in the fixed support 14 will vibrate longitudinally, as indicated by the arrows in Figure 4, when excited by two electromagnetic coils L1 and L2, as shown in Figure 2. In this case, too, the rod 13 has a very definite natural frequency which may be determined from the equation:

$$v=2lf \quad (3)$$

Where l is the length of the rod, f the frequency and v is the velocity of sound in the material of which the rod is made. It is obvious from Equation 3 that the frequency is directly proportional to the velocity of sound in the material of which the said rod is made, and it is inversely proportional to the length of the rod. It is obvious, of course, that Equation 3 will not suffice to express the natural frequency of more complicated bodies, such as, for instance, the steel body of a die. In such cases I use a variable oscillator having a wide frequency band and with a power amplifier associated with the same for the creation of powerfully forced vibrations. In connection with this power amplifier I use an output meter and calibrated frequency indicating means, whereby it is possible to determine the natural frequency of any body in question, because at the natural frequency a much greater degree of vibration will be observed and with less expenditure of power.

The determination of the natural frequency is an important factor in the practical utilization of my invention, because only at the natural frequency is it possible to obtain the greatest amount of vibration with a small expenditure of vibrating power.

Figures 5, 6 and 7 illustrate the behavior of bodies subject to forced vibrations, such as, for instance, the die hereinafter described. This as has been illustrated in Figure 5 shows the amplitude of the vibrations for a simple forced vibration without damping, and in Figure 6 for the same vibration with various degrees of damping. Figure 7, furthermore, illustrates the beating, resulting when two or more frequencies are caused, due to multiple exciting forces, or due to elastic vibrations set up by the main distributing force. In such cases the two or more frequencies which are beaten together may result in one single harmonic vibration, as indicated in Figure 7. This is important to consider in connection with the present invention, because of the complexity of the parts involved in practical applications, and also because it illustrates that the resulting harmonic vibration will usually be of a lower frequency.

In Figure 8 is illustrated a schematic arrangement of a simple punch and die embodying my invention. The punch 23 is excited with one suitable frequency by means of the frequency exciting rod 24 and coils 25 which are operated by oscillator 26. The die 27 is excited through another suitable frequency by means of rod 28 and coils 29 which are operated by oscillator 30.

In Figure 9 is shown an actual drawing die for drawing shells or thin walled vessels. This die consists of an upper die body 31 with a central plunger 32 and a lower die shoe 33 mounted upon the base 34. The upper die body 31 is given a forced vibration by means of the vibration rod 35, excited by coils 36 which are driven by the oscillator 37.

The operation of my invention is evident in part from the description given supra, and more particularly by reference to the operation of dies, as illustrated in Figures 8 and 9. The best function of the same is obtained by applying suitable vibrations either to the moving part alone, or both to the moving and stationary parts. For a given die the natural or resonant frequency would have to be determined in advance by means of the apparatus described supra, and also the amount of power necessary to vibrate the die sufficient to give a smooth and efficient draw. As mentioned above, the drawing of deep shells is greatly facilitated by the forced vibrations, which are generated in the die, and which are also transmitted from the same to the work piece. It is my contention that the vibrations will cause a temporary increase in the ability of the material to flow under stresses and the drawing of the material will thereby be greatly facilitated, requiring a lesser number of steps for a given depth of draw, and requiring a smaller amount of total power expended. For the same reason the die will run cooler and will wear less, thereby increasing the life of the die and permitting greater production speed, as well as fewer die grindings and replacements. It is obvious that the frequencies to be applied will vary considerably according to the various factors involved, and in practice I have found that in some cases the frequency may be in the lower audio range, and in other cases it may be in the supersonic range.

It is to be understood that the form of my invention, shown and described herein, is to be taken as a preferred example of the same, and that various changes in the shape, size, and arrangement of parts may be resorted to, without

departing from the spirit of my said invention, or the scope of the subjoined claims.

Having thus described my invention I claim:

1. A method of drawing and forming metallic materials in dies, comprising operating the dies to draw and form the material, and simultaneously with the operation of said dies applying forced vibrations from an external source of vibrations to at least one of the moving and stationary parts of the mechanical system at a frequency higher than the vibration frequency of the dies in normal use.

2. Method as defined in claim 1 wherein the frequency of the applied vibration is in the supersonic range.

3. Method according to claim 1, wherein the forced vibrations are applied transversely of the longitudinal axis of the dies.

4. Method according to claim 1, wherein the forced vibrations are applied in the direction of relative movement of the dies.

5. In an apparatus for die-shaping thin walled metallic shells, the combination with the coacting movable and stationary dies and the means for operating said dies to effect shaping of the metallic material worked upon, of mechanism for imparting to the movable die forced vibrations of supersonic frequency.

6. A method of drawing and forming metallic materials in dies having a moving part and a stationary part, comprising operating the dies to draw and form the metallic material, and simultaneously with the operation of said dies applying vibratory power of substantially the natural frequency to the moving part of the die from an external source of vibration and in addition to any normal vibrations occurring during

the drawing operation of said dies and likewise applying a second vibratory power of substantially the natural frequency to the stationary part in addition to any normal vibration of such part occurring during the drawing operation of the die, whereby the friction between the die parts and the material during the operation of the die is reduced and a smoother and quicker draw is obtained.

7. A method of drawing and forming metallic materials in dies comprising operating a drawing die to draw and form the material, and simultaneously with the operation of the die applying vibratory power thereto of substantially the resonant frequency of the die structure from an external source of vibration and in addition to any normal vibrations occurring during the drawing operation of the die, whereby the friction between the die and the material being drawn is reduced and a smoother and quicker draw is obtained.

8. Apparatus for drawing thin walled metallic articles comprising a movable punch member, a stationary die member coacting with said punch member during the drawing operation, an electric oscillator having an output frequency substantially equal to the resonant natural frequency of said punch and die members, and means operated by said electric oscillator for applying said oscillatory power in the form of forced mechanical vibrations in said die and punch members, whereby the friction between the punch member and the metallic material being worked upon is reduced and a quicker and smoother draw is obtained.

ALFRED VANG.