

3,201,967

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METAL FORMING

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FIG. 4

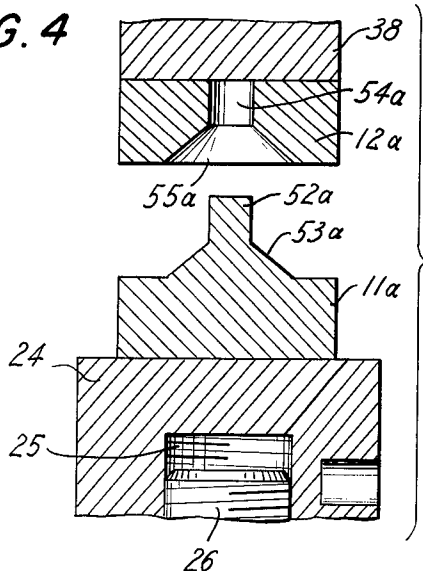


FIG. 5

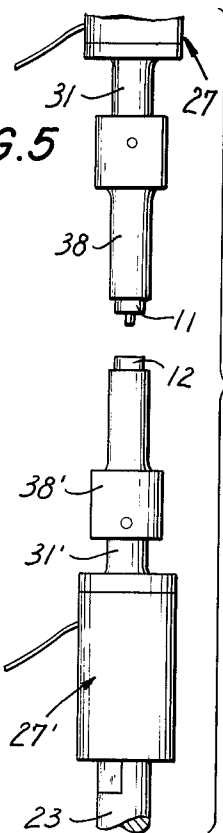


FIG. 7

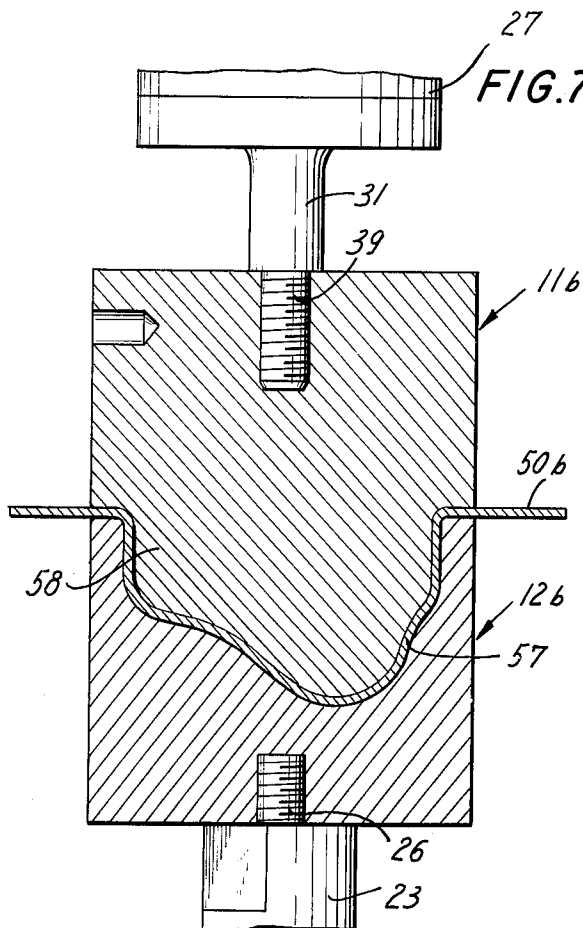
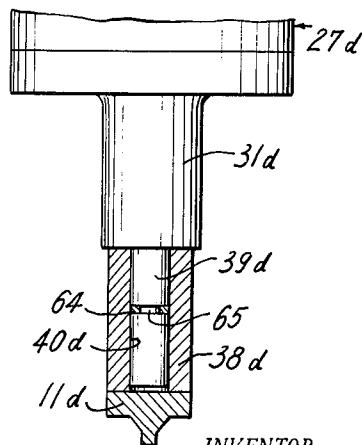


FIG. 6



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FIG. 8

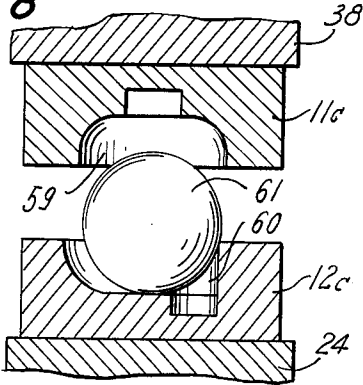


FIG. 9

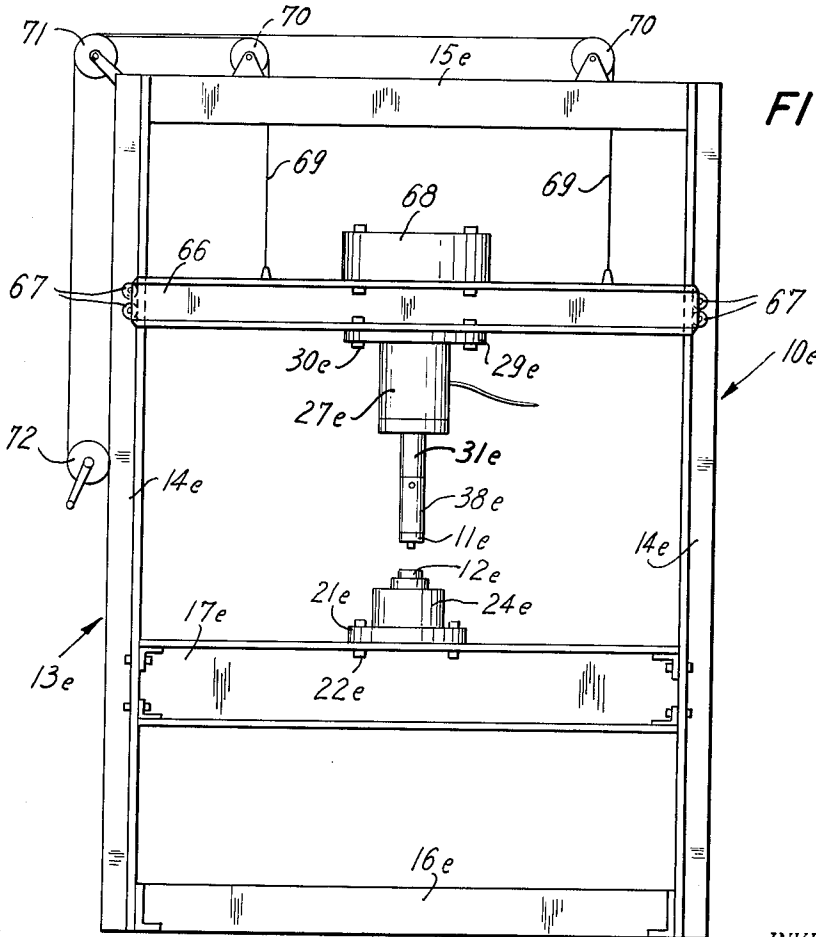
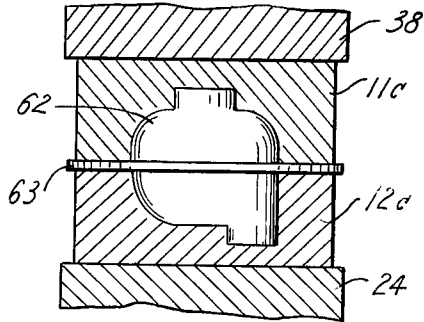


FIG. 10

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METAL FORMING

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2 Claims. (Cl. 72-359)

This invention relates generally to metal forming, and more particularly is directed to the provision of improved apparatus and methods for the forming or shaping of metals through the use of vibratory energy.

In existing methods and apparatus for forming metal, the metal to be shaped or formed is disposed between two cooperating die members having the desired configuration, and such die members are moved forcibly towards each other to shape the metal therebetween. Frequently, one or both of the die members are heated, or the metal to be shaped is initially heated, in order to soften the metal and thereby facilitate the shaping thereof by the die members. However, the shaping or forming of metals in the foregoing manner requires the use of very high pressures or forces urging the die members towards each other, and, even then, the existing methods and apparatus are not suitable for the forming or shaping of many metals which are either excessively brittle and thus tend to crack or exhibit surface failures at regions where they are sharply bent or made to flow excessively, or where the metals suffer an undesirable decrease in strength as a result of the heating required for the forming or shaping operation. The existing methods and apparatus for forming or shaping metals have the further disadvantage of limiting the shapes that can be formed, particularly with respect to the radii of curvature and the depth of the drawing of sheet metal formed thereby.

Accordingly, it is an object of this invention to provide methods and apparatus for forming or shaping metals by the exertion of a relatively moderate pressure or force urging together the die members, and which can be practiced at room temperature.

A further object is to provide methods and apparatus for forming or shaping metals that are suitable for use in connection with metals or alloys that have heretofore either completely resisted, or presented severe difficulties in, the forming or shaping by conventional methods and apparatus.

In accordance with an aspect of the invention, die members are urged toward each other by a moderate static force with the metal to be shaped or formed positioned between the die members, and acoustic or ultrasonic vibrations are transmitted to at least one of the die members by wave motion through a solid transmitting member or transformer, for example, at a frequency in the range between approximately 1 kc./sec. and 100 kc./sec. and with a small amplitude, for example, in the range between approximately .01 inch and .0001 inch, in directions generally parallel to the static force. Preferably, the vibrations transmitted to the die member impart to the latter a peak acceleration of at least 1000 g. It has been found that the combined action of the vibratory energy and of the applied static force makes it possible to form or shape metals at room temperature with a relatively small applied static force, and further makes it possible to avoid the numerous defects and failures encountered when shaping or forming metals by the previously existing procedures, particularly when shaping or forming brittle materials. It appears that the vibratory energy exerts a kind of forging action on the metal being shaped and further drastically reduces the surface friction between the metal being shaped and the die members. The reduction of surface friction facilitates flow-

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ing of the metal with respect to the active surfaces of the die members in order to permit the forming of relatively small radii of curvature and relatively deep drawing of the metal. Further, the reduction in the surface friction between the metal being formed and the die members by the action of the vibratory energy greatly facilitates the withdrawal of the formed article from the die members, and thereby permits the forming of articles with surfaces that may be practically parallel to the direction of separation of the die members.

In accordance with another aspect of the invention, the vibratory energy transmitted to one or both of the die members is employed for heating the related die member so that the forming or shaping of the metal can be conveniently effected by the combined action of the static force urging the die members towards each other, the vibratory energy and the heating of one or both of the die members.

The above, and other objects, features and advantages of the invention, will be apparent in the following detailed description of illustrative embodiments thereof which is to be read in connection with the accompanying drawings forming a part hereof, and wherein:

FIG. 1 is a front elevational view, partly schematic and partly broken away and in section, of a metal forming apparatus embodying the present invention;

FIG. 2 is an enlarged axial sectional view of the die members included in the apparatus of FIG. 1, with such die members being spaced apart preparatory to the forming of sheet metal therewith;

FIG. 3 is an axial sectional view similar to a portion of FIG. 2, but showing the die members engaged during the forming of the metal sheet;

FIG. 4 is a view similar to FIG. 2, but showing a different arrangement of the die members;

FIG. 5 is a fragmentary elevational view similar to a portion of FIG. 1, but showing another embodiment of the invention, wherein both die members have vibratory energy transmitted thereto;

FIG. 6 is an enlarged fragmentary elevational view, partly in axial section, and illustrating a modified arrangement for supporting a vibrated die member so that the transmission of vibrations to the latter will also effect heating thereof;

FIG. 7 is an enlarged, axial sectional view similar to that of FIG. 3, but illustrating the application of this invention to the deep drawing of sheet metal;

FIGS. 8 and 9 are sectional views generally similar to those of FIGS. 2 and 3, respectively, but illustrating the application of this invention to the forming of solid metal articles from metal billets, rather than from sheet metal; and

FIG. 10 is a front elevational view of an apparatus constructed in accordance with still another embodiment of the invention.

Referring to the drawings in detail, and initially to FIGS. 1, 2 and 3 thereof, it will be seen that a metal forming or shaping apparatus embodying the present invention and generally identified by the reference numeral 10 includes die members 11 and 12 which are urged forcibly toward each other during the forming or shaping of metal therebetween, while vibratory energy is applied to one or both of the die members.

In the apparatus 10 illustrated in FIG. 1, the die members 11 and 12 are supported within a frame 13 that includes parallel uprights 14 and top and bottom cross members 15 and 16 suitably secured to the opposite ends of the uprights. Intermediate cross members 17 are secured, at their opposite ends, to the uprights 14 at adjustably selected locations, for example, by pins 18 extending through openings in cross members 17 and through se-

lected openings of a series of openings 19 formed in each of the uprights.

A hydraulic cylinder 20 depends vertically between intermediate cross members 17 and has a mounting plate 21 at its upper end which is secured, as by bolts 22, to the cross members 17, and a vertically movable ram 23 projects upwardly from cylinder 20 through a suitable opening in mounting plate 21.

The die member 12 is brazed, soldered, or otherwise rigidly attached to an anvil 24 having a downwardly opening tapped bore or socket 25 for receiving a threaded extension 26 of the ram 23 (FIG. 2) so that the anvil 24 carrying the die member 12 can be securely attached to the ram for movement with the latter.

The other die member 11 is supported vertically above die member 12 by a vibratory machine 27 that includes an enclosure or casing 28 depending from a mounting plate 29 secured, as by bolts 30, to the top cross members 15. An acoustical impedance transformer 31 has an enlarged cross sectional part intermediate its opposite ends defining a radial flange 32 that is secured by bolts 33 to the lower end of casing 28, and a transducer 34 in the form of a stack of laminations of magnetostrictive material, for example, nickel or the like, is brazed or soldered at one end to the end of transformer 31 within casing 28 and is encircled by a winding 35 adapted to carry high frequency current. Conductors extend from winding 35 through a cable 36 to a suitable generator which is schematically illustrated at 37. The generator 37 is effective to generate a high frequency current and a biasing direct current which are supplied to the coil or winding 35, and the length of the transducer 34 is so selected with reference to the desired frequency of vibrations to be imparted to the die member 11 that the transducer will be resonant at such frequency and therefore standing waves will be set up therein with a loop of motion at each end. For this purpose, the length of the transducer 34 should be an integral number of half wave-lengths of such compressional waves induced by magnetostriction as a result of the high frequency current delivered to the winding 35.

In the embodiment of the invention illustrated in FIGS. 1, 2 and 3, the lower end of the acoustical impedance transformer 31 is securely attached to a tool holder 38, for example, by forming the lower end of transformer 31 with a threaded extension 39 which engages in a tapped bore 40 of the tool holder 38 (FIG. 2), while the die member 11 is rigidly attached, for example, by brazing or soldering, to the lower end of the tool holder.

The transformer 31 is dimensioned so as to effect the desired amplification of the amplitude of the vibrations transmitted thereto from the transducer 34, and the overall length of the transducer, transformer 31 and tool holder 38 is correlated to the frequency of the compressional waves generated by the transducer 34 so that a loop of motion occurs substantially at the die member 11. For the purposes of the present invention, the frequency and amplitude of the vibrations are selected so as to give the vibrated die member a peak acceleration of at least 1000 g and the frequency of the vibrations imparted to die member 11 may be within the range of approximately 1 kc./sec. to 100 kc./sec., while the amplitude of the vibrations is within the range of approximately .01 inch to .0001 inch.

Thus, the die member 11 of the apparatus 10 is held stationary and has acoustical or ultrasonic vibratory energy imparted thereto by the transmission of a wave motion through the transformer 31, while the other die member 12 is movable vertically toward and away from die member 11 by controlling the supplying of hydraulic fluid under pressure to the cylinder 20. As shown schematically in FIG. 1, the supplying of hydraulic fluid under pressure to cylinder 20 may be effected by an arrangement including a pump 41 having an inlet conduit 42 drawing hydraulic fluid from a supply tank 43 and an outlet conduit 44 extending from the pump to a dis-

tributor valve 45 suitably operated, for example, by a handle 46. The valve 45 is selectively operative to direct the fluid under pressure to one or the other of two flexible conduits 47 and 48 connected to the opposite ends of cylinder 20, while the other of such flexible conduits is placed in communication with a return pipe 49 extending from distributor valve 45 back to tank 43. Thus, in one position of the distributor valve 45, hydraulic fluid under pressure is supplied through conduit 47 to the upper end of cylinder 20 to move the ram 23 downwardly, and thereby space die member 12 from die member 11 so that metal to be formed can be inserted between the die members or so that the formed metal can be removed. In the other position of valve 45, flexible conduit 47 is connected to the return pipe 49, while conduit 48 is connected to the outlet 44 of pump 41 and conveys hydraulic fluid under pressure to the lower end of cylinder 20 for urging die member 12 upwardly toward the cooperating die member 11 which is simultaneously vibrated, as previously indicated, so that metal disposed between the die members will be suitably formed or shaped by the combined action of the static force, which is represented by the arrow F (FIG. 3) and which results from the hydraulic fluid under pressure within cylinder 20, and of the vibrations imparted to die member 11 and represented by the arrows V.

Referring in detail to FIGS. 2 and 3, it will be seen that the die members 11 and 12 there illustrated are intended for dimpling sheet metal 50 around a hole 51 formed in the sheet metal so as to receive the countersunk head of a rivet or other fastening and provide a flush surface. For this purpose, die member 11 is in the form of a male die member having a pin 52 projecting axially therefrom to pass slidably through the hole 51 of the metal sheet 50, and a flaring or frusto-conical portion 53 is formed at the base of pin 52 and corresponds to the shape of the dimple to be formed around the hole 51. The cooperating die member 12 is in the form of a female die member having a bore 54 intended to slidably receive the pin 52 below the metal sheet 50 and opening, at its upper end, into a countersink 55 corresponding to the shape of the underside of sheet 50 around the desired dimple.

Thus, when female die member 12 is urged toward male die member 11 by the static force F while male die member 11 is vibrated, as represented by the arrows V, the sheet 50 therebetween is formed with a dimple 56 around the opening 51 therein (FIG. 3). It has been found that, by reason of the vibratory energy imparted to die member 11, the desired dimple can be suitably formed by the exertion of a smaller static force than that required when the dimple is formed merely by the exertion of a static force, and that the grain structure of the metal sheet in the area of the dimple 56 is more desirable in the case of the forming of the metal by the combined action of the static force and vibrations. For example, when forming dimples in 52 SO aluminum sheet having a thickness of .032 inch, and employing an apparatus wherein the cylinder 20 has a piston therein with a diameter of 4 inches, it was found that the static force resulting from a pressure of 50 pounds per square inch acting in said cylinder against the piston was inadequate, by itself, to form a suitable dimple, whereas, that pressure was sufficient to form an acceptable dimple when the force resulting therefrom was combined with vibration of the die member 11 at a frequency of approximately 14 kc./sec. and an amplitude of vibration of approximately .0007 inch, peak to peak.

Further, it has been found that the combined static force and vibratory energy is suitable for shaping or forming metals that cannot be satisfactorily shaped or formed by static force alone. For example, a sheet A110AT titanium having a thickness of .025 inch was formed with a $\frac{5}{32}$ inch dimple using a static force of 500 pounds combined with vibrations having a frequency of approximately 14 kc./sec. and an amplitude of approximately

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.0007 inch, whereas an attempt to form a similar dimple in the same material using only a static force of 500 pounds resulted in visible cracking of the sheet material.

Although FIGS. 2 and 3 of the drawings show the male die member or punch 11 attached to the vibrated tool holder 38 while the female die member 12 is attached to the anvil 24, it is apparent that the positions of the male and female die members can be reversed. Thus, as shown in FIG. 4, the male die member 11a may be rigidly attached, as by soldering, brazing or the like, to the anvil 24 secured on the ram 23 of hydraulic cylinder 20, while the female die member 12a is similarly attached to the tool holder 38 and has vibratory energy transmitted thereto from the vibratory machine 27. In fact, it has been found that, where only one of the die members is vibrated, the static force required for forming the metal is decreased if the single vibrated die member is the female die member, as in FIG. 4.

Further, although the die members illustrated in FIGS. 2 and 3 and in FIG. 4 are intended for forming relatively shallow dimples in sheet metal, it is to be noted that the present invention may be very advantageously applied to the deep drawing of sheet metal. Thus, as illustrated in FIG. 7, the female die member 12b mounted on the ram 23 of the hydraulic cylinder is formed with a relatively deep, suitably shaped cavity 57, while the vibrated male die member 11b secured to the threaded extension 39 of the transformer 31 of vibrating machine 27 is formed with a projection 58 having a contour corresponding to that of the cavity 57, whereby the die members 11b and 12b will cooperate, upon the application of a suitable static force and vibrations, to form a deep draw of the metal sheet 50b within the cavity 57. By reason of the vibrations imparted to the die member 11b and the consequent reduction of surface friction, flowing of the metal within the cavity 57 is promoted to permit deep drawing of the sheet metal without the danger of tearing thereof, and further the reduced surface friction between the sheet metal and the active surfaces of the die members greatly facilitates the withdrawal of the formed sheet metal from engagement with the die members.

Although the previously described embodiments of the invention have related to the shaping or forming of sheet metal, it is to be noted that the invention can also be advantageously applied to the shaping or forming of solid metal articles. Thus, as illustrated in FIGS. 8 and 9, both of the die members 11c and 12c rigidly secured to the tool holder 38 and the anvil 24, respectively, may be formed with cooperating cavities 59 and 60 so that, when a billet 61 of the metal to be shaped, which may initially have a spherical or other configuration, is disposed in the lower cavity 60 and the die members 11c and 12c are forcibly moved towards each other while vibrations are imparted to the die member 11c through the tool holder 38, the combination of the vibrations and the static force causes the metal of the billet 61 to flow and thereby fill the cavities 59 and 60 cooperating to define an article 62 (FIG. 9) of the desired shape. By reason of the vibrations imparted to the die member 11c, surface friction between the formed article and the active surfaces of the die members is substantially reduced, and the formed article 62 can be easily removed from the die cavities upon separation of the die members, whereupon the flashing 63 which occurs at the line of separation of the two die cavities 59 and 60 can be easily ground away.

It is also apparent that only one of the die members may have a cavity or depression therein, while the other die member is in the form of a flat platen or anvil.

Although the above described embodiments of the invention have imparted vibratory energy only to one of the cooperating die members, it is to be understood that, in each case, the invention contemplates the vibrating of one or both of the die members. Accordingly as illustrated in FIG. 5, the ram 23 of the hydraulic cylinder 20 may

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carry a vibrating machine 27' which is similar to the previously described vibrating machine 27 and which includes an acoustical impedance transformer 31' having a tool holder 38' rigidly attached thereto and carrying the die member 12 so that, while die member 11 is vibrated by operation of the vibrating machine 27, the other die member 12 is simultaneously vibrated by operation of the vibrating machine 27'.

Thus, in the arrangement of FIG. 5, both of the die members 11 and 12 are simultaneously vibrated either in phase with each other or with the respective vibrations being varying degrees out of phase with respect to each other, either at the same frequency or at different frequencies effective to produce beats, and at the same amplitude or at different amplitudes, while such die members are forcibly urged together in order to effect the efficient forming of metal disposed therebetween.

In the previously described embodiments of the invention, the vibrated die member has been rigidly attached to the tool holder, and the latter has, in turn, been rigidly attached to the impedance transformer of the vibrating machine, thereby to avoid the generation of heat at the several joints. Although the present invention makes possible the forming of metals at room temperature by the combined action of a static force and vibrations, it may be desirable in some circumstances to either heat the metal to be formed or to apply heat to the metal during the shaping or forming thereof. The fact that vibratory energy is effective to generate heat when it is transmitted through a loose joint makes it possible to effect heating of the metal during the forming or shaping thereof through conversion of some of the transmitted vibratory energy into heat, thereby to avoid the necessity of using the conventional electrical heating elements frequently provided in metal forming apparatus. As shown in FIG. 6, the vibrating machine 27d, which is generally similar to the vibrating machine 27 described in connection with FIG. 1, has an acoustical impedance transformer 31d which is formed with a smooth, reduced diameter extension 39d in place of the threaded extension 39 of the first described embodiment. Further, the tool holder 38d having the die member 11d rigidly attached to its lower end, as by brazing, soldering or the like, is formed with a smooth, upwardly opening axial bore 40d adapted to slidably receive the extension 39d. The tool holder 38d is frictionally held upon the extension 39d by a spring circlet or split ring 64 received in an annular groove 65 formed in the surface of extension 39d and bearing radially outward against the surface of bore 40d.

By reason of the frictional attachment of the tool holder 38d to the extension 39d of transformer 31d, the acoustical or ultrasonic vibrations being transmitted from the transformer to the tool holder produce considerable frictional heating at the joint and such frictional heating is transmitted, along with the vibrations, to the die member 11d. Although FIG. 6 illustrates a connection for the die member 11d that is effective to produce heating of the latter, it is apparent that a similar connection may be provided for the other cooperating die member when the latter is also vibrated in order to achieve heating of both die members.

In FIG. 1, and in the other embodiments of the invention that have been described, it has been assumed that the static force cooperating with the vibrations to effect the forming or shaping of the metal has been applied by a hydraulically operated cylinder, for example, the cylinder 20 of FIG. 1. However, the static force may be otherwise applied, for example, as in the apparatus 10e illustrated in FIG. 10, where the lower die member is stationary and the upper die member is urged downwardly by the force of gravity.

In the apparatus 10e, the frame 13e once again includes uprights 14e and top and bottom cross members 15e and 16e. The intermediate cross members 17e are fixedly attached, at its opposite ends, to the uprights 14e, and the

lower die member 12e is supported by the anvil 24e which is carried by a mounting plate 21e secured, as by bolts 22e to the intermediate cross members 17e. The upper die member 11e is secured to the lower end of the tool holder 38e which is rigidly attached to the acoustical impedance transformer 31e of the vibrating machine 27e depending from a mounting plate 29e, and the latter is secured, as by bolts 30e to a vertically movable cross head 66. The vertical movements of the cross head 66 may be guided by rollers 67 at the opposite ends thereof engaging flanges of the uprights 14e, and the desired downward force for urging the die members 11e and 12e towards each other may be achieved by providing a suitable weight or weights 68 on the cross head 66. Thus, in FIG. 10, the static force combining with the vibrations to form or shape the metal between the die members is represented by the force of gravity acting on the assembly of the cross head 66, weight or weights 68 and the vibrating machine 27e.

Suitable means is also preferably provided for elevating the cross head 66 when metal is to be inserted, or removed from, between the die members. A suitable mechanism for that purpose is schematically illustrated in FIG. 10 and includes cables 69 extending upwardly from the cross head over pulleys 70 rotatably mounted on the top cross member 15e, and then running over a double pulley 72 rotatably mounted at the upper end of one of the uprights 14e before being taken up on a winch 72. It will be understood that, during the forming or shaping of metal between the die members 11e and 12e, the winch 72 is manipulated to permit lowering of cross head 66 and to provide slack in the cables 69 when the die members engage the metal therebetween so that the full weight of the vertically movable assembly can act to provide the desired static force.

Although illustrative embodiments of the invention have been described in detail herein with reference to the accompanying drawings, it is to be understood that the invention is not limited to those precise embodiments, and that various changes and modifications may be effected therein without departing from the scope or spirit of the invention, except as defined in the appended claims.

What is claimed is:

1. Metal forming apparatus comprising two die members movable rectilinearly toward and away from each other and having cooperative metal forming surfaces which, for the most part, are at substantial angles with respect to the direction of the relative movement of the die members, means applying vibrations to at least one of said die members substantially at the center thereof and in directions parallel to the direction in which said die members are movable toward and away from each other, said vibrations being at a frequency in the range between approximately 1 kc./sec. and 100 kc./sec. and an amplitude sufficient to impart peak accelerations of at least 1000 g. to the related die member, and means exerting a static force urging said die members toward each other

with an acceleration far less than said peak accelerations so that said static force and the impacts resulting from said vibrations combine to form metal disposed between said surfaces of the die members to the configuration of the latter while said peak accelerations ensure that at least the metal forming surface of said one die member is only in intermittent and relatively movable contact with the metal to very substantially reduce the frictional resistance to forming of the metal.

2. An apparatus for dimpling a metal sheet around a hole in the latter, comprising male and female die members respectively having convex and concave mating frusto-conical surfaces engageable with the opposite sides of the sheet around the hole in the latter; supporting means mounting said die members for relative rectilinear movement toward and away from each other, said supporting means for at least one of said die members including a magnetostrictive transducer extending parallel to the direction of said relative movement and being centered, transversely relative to said direction, with respect to said one die member, connecting means extending longitudinally from one end of said transducer to said one die member, means establishing a high frequency, biased alternating field around said transducer so that the latter produces longitudinal vibrations at a corresponding frequency transmitted to said one die member through said connecting means and having a loop of longitudinal motion substantially at said one die member, and a supporting structure secured to said connecting means substantially at a node of the longitudinal motion therein; said frequency of the vibrations being in the range between 1 kc./sec. and 100 kc./sec. and the vibrations having an amplitude sufficient to impart peak accelerations of at least 1000 g. to the related die member; and means exerting a static force by way of said supporting means for urging said die members toward each other with an acceleration far less than said peak accelerations so that at least said one die member is only in intermittent and hammering contact, at said frequency, with a metal sheet placed between said die members.

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