Dec. 22, 1970 S. V. CHELMINSKI 3,548,630

APPARATUS FOR FORMING MATERIAL BY SUDDEN IMPULSES

Original Filed Aug. 16, 1965 4 Sheets-Sheet 1

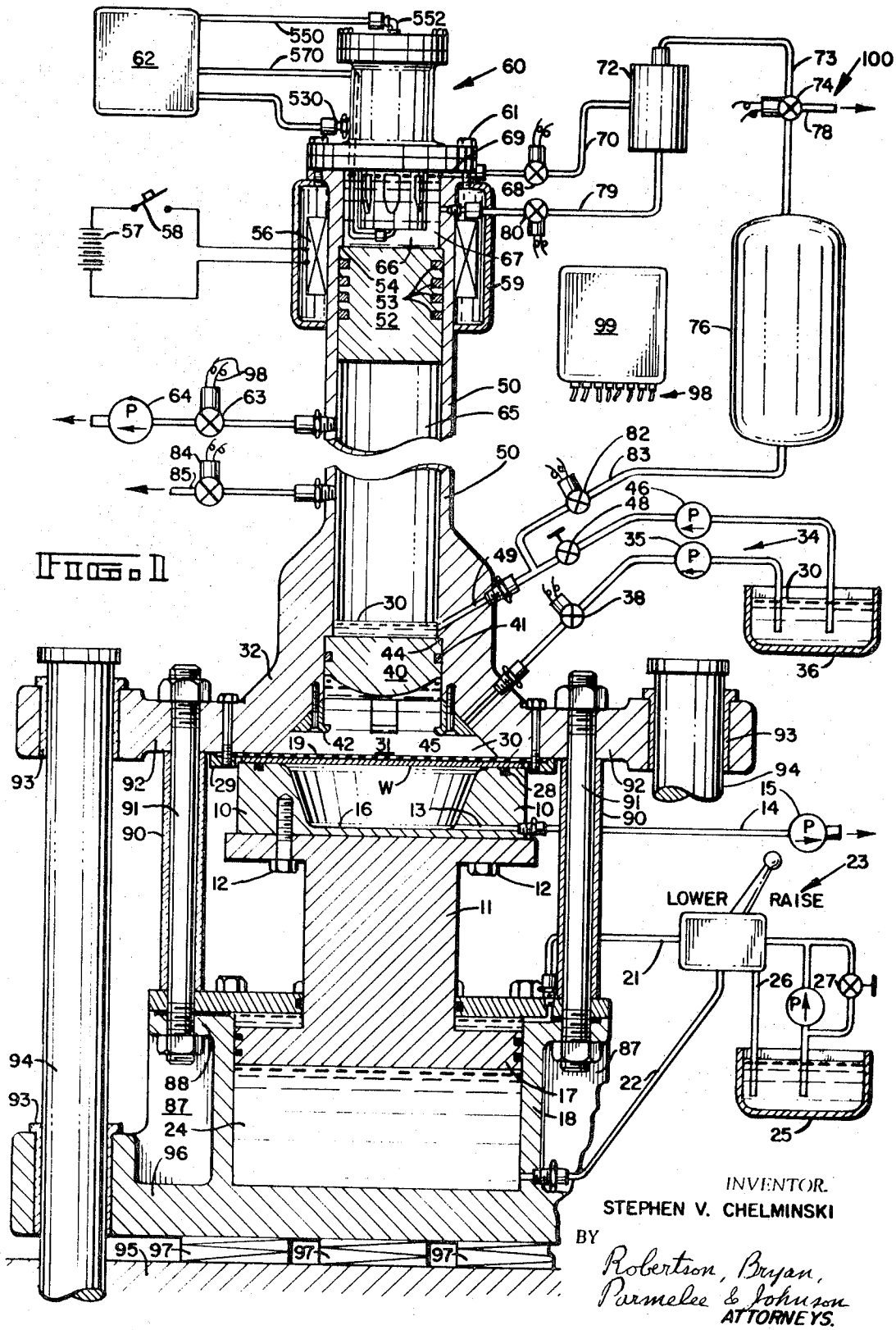



FIG. 1

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APPARATUS FOR FORMING MATERIAL BY SUDDEN IMPULSES

Original Filed Aug. 16, 1965 4 Sheets-Sheet 2

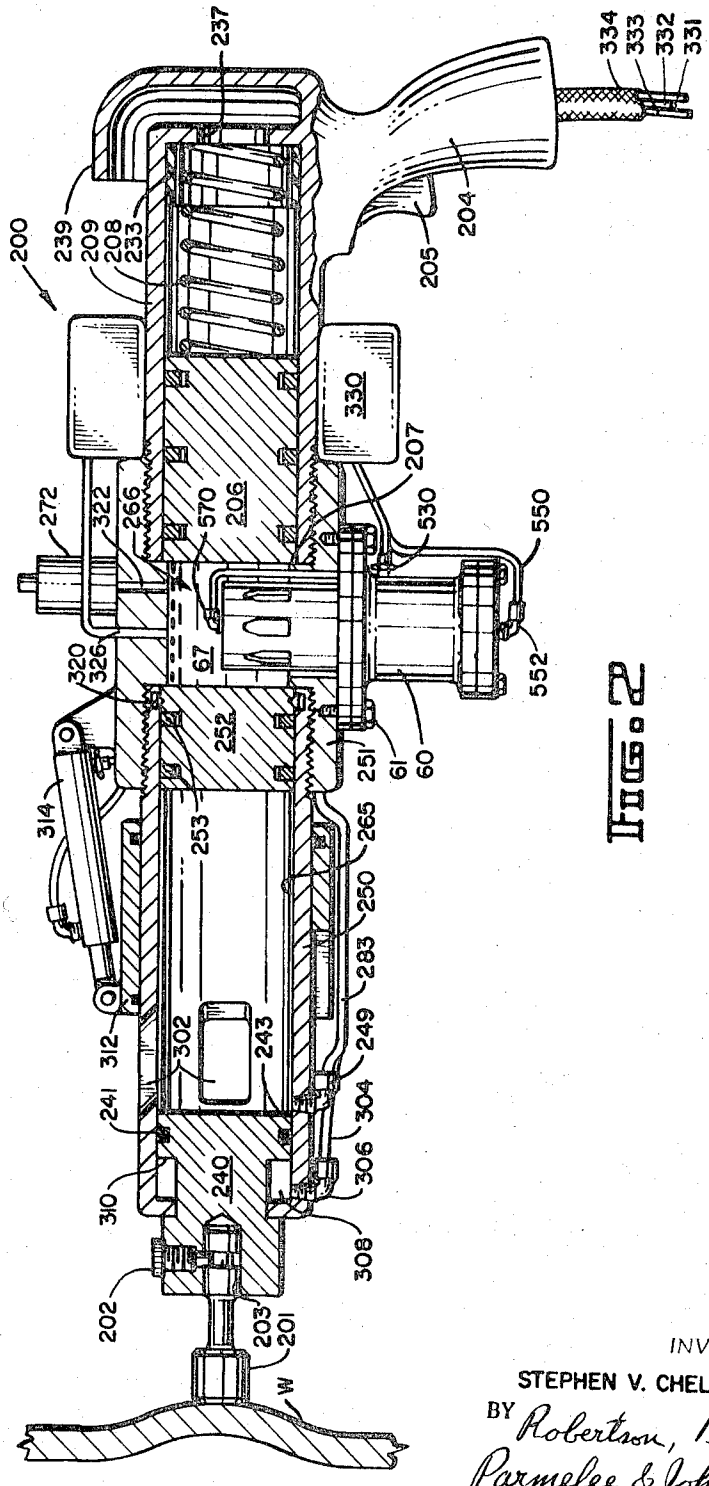



FIG. 2

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APPARATUS FOR FORMING MATERIAL BY SUDDEN IMPULSES

Original Filed Aug. 16, 1965 4 Sheets-Sheet 3

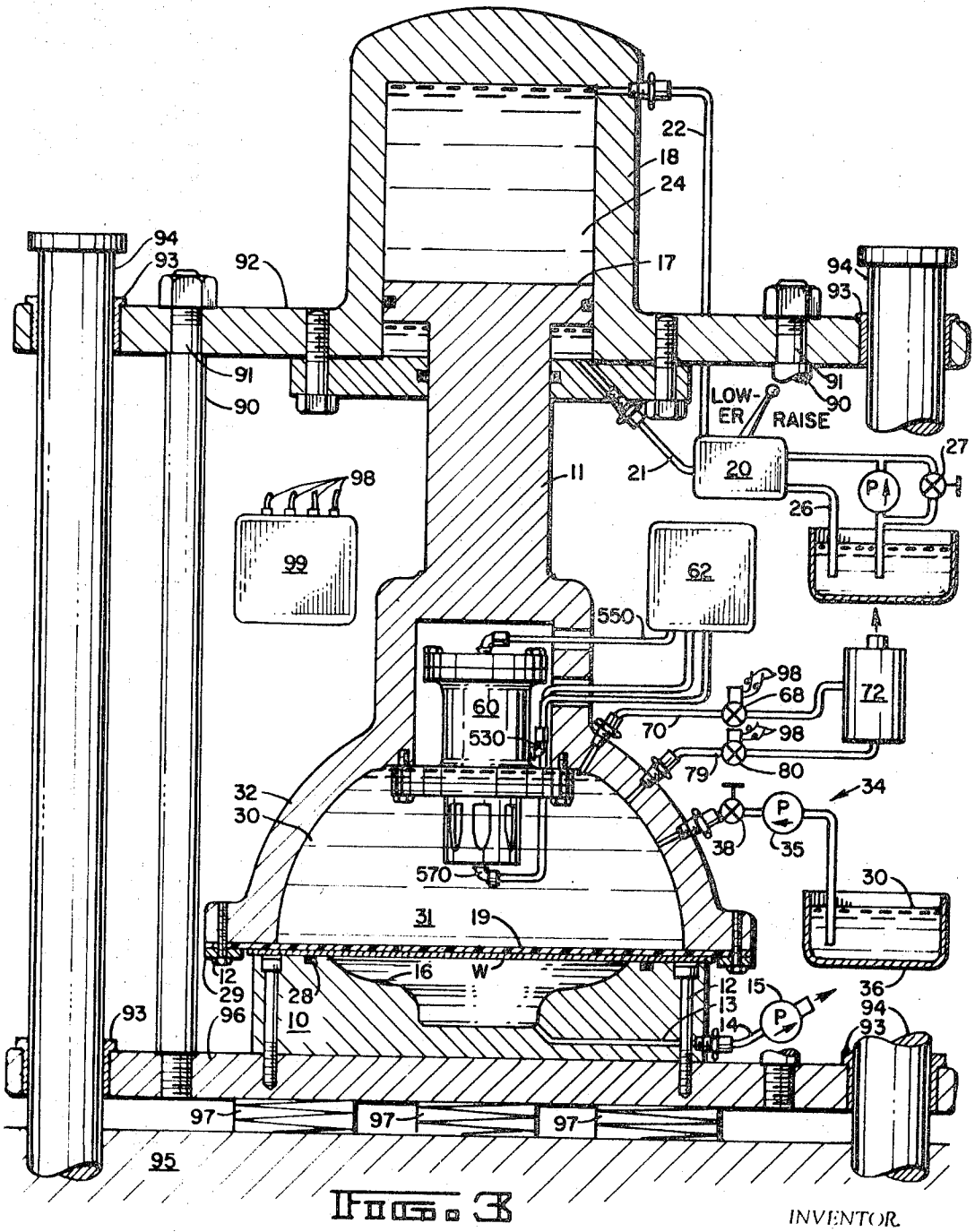



FIG. 3

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APPARATUS FOR FORMING MATERIAL BY SUDDEN IMPULSES

Original Filed Aug. 16, 1965 4 Sheets-Sheet 4

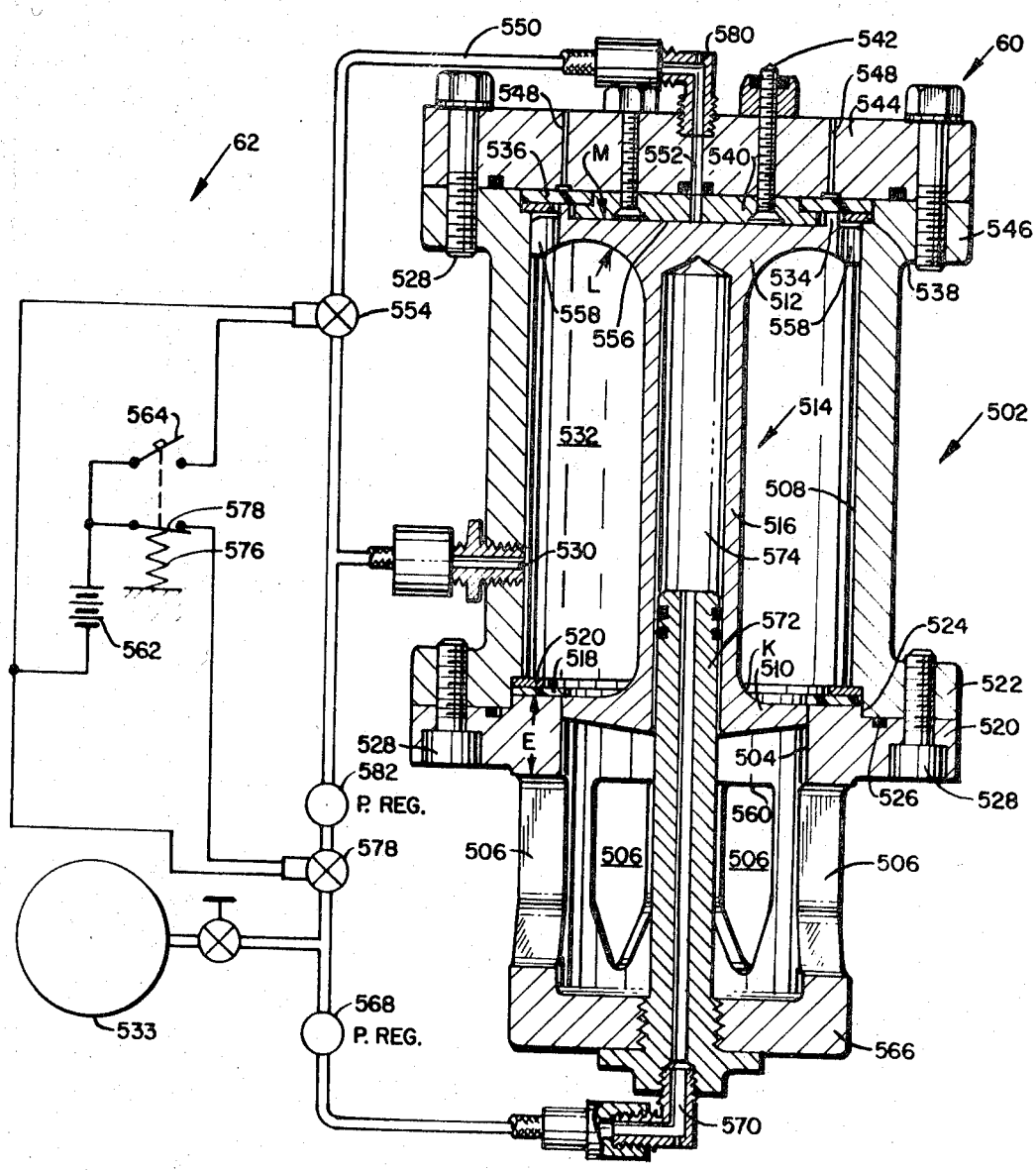



FIG. 4

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United States Patent Office 3,548,630
Patented Dec. 22, 1970



3,548,630

# APPARATUS FOR FORMING MATERIAL BY SUDDEN IMPULSES

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Original application Aug. 16, 1965, Ser. No. 479,771, now Patent No. 3,376,723, dated Apr. 9, 1968. Divided and this application Nov. 17, 1967, Ser. No. 703,806
Int. Cl. B21d 26/06
U.S. Cl. 72—430 14 Claims

## ABSTRACT OF THE DISCLOSURE

A device for forming material by sudden impulses. The device comprises a chamber for gas under high pressure, which gas is abruptly released into a chamber provided with liquid. The sudden release of gas in the liquid creates an impulse which is transmitted by the liquid to effect the desired working.

The present application is a division of application Ser. No. 479,771, filed Aug. 16, 1965, now U.S. Pat. No. 3,376,723, granted Apr. 9, 1968.

This invention relates to methods and apparatus for forming materials by sudden impulses, and particularly to such methods and apparatus for forming or shaping materials by the creation of sudden high energy impulses in a liquid adjacent to the material to be formed. The methods and apparatus of the present invention are well suited for forming various materials, such as metals and alloys, which are capable of being plastically deformed by the application of high energy pressure waves thereto.

In accordance with this invention the material to be formed is placed adjacent to a liquid, a gas is confined under high pressure and then the gas is abruptly released for generating a high energy, intense pressure impulse in the liquid so as to produce the desired shaping of the material. Additional gas is confined under high pressure and is released to provide a successive high energy impulse if desired to produce further shaping of the material. The liquid itself may be prepressurized. This invention is adaptable to form the material into, against, or around a die and is also adaptable for the various ways of forming materials, for example, such as by bulging, stretching, compacting, extruding, drawing, sizing, expanding, or shrinking.

While explosives have been used to put a high energy intense pressure impulse into a liquid for forming materials, they do have drawbacks. They are dangerous to handle and use, and a substantial cost is involved in the explosives and detonating devices which are consumed. Also, in the past electrical discharges through a wire have been used to create pressure impulses in a liquid for forming materials. These discharges require high voltage and large currents provided from numerous bulky, expensive electrical capacitors arranged in a bank. The wire itself is vaporized by the discharge, so the equipment must be opened up to replace the wire in the liquid after each "shot." The same requirement of opening up the equipment to replace a consumed energy source is a drawback of using explosives.

Among the many advantages of the material forming methods and apparatus which are described herein as illustrative of the present invention are those resulting from the fact that they are very versatile in application; they are safer and much more convenient to use than explosives or high voltage discharges. Low tooling and low operating costs are provided by these embodiments of the invention. There are no expendable parts to be removed, discarded



and replaced after each impulse. Also, a rapid cycle time is enabled to be attained so that the intense impulses can be supplied at frequent intervals, for example such as every two seconds for producing successive deformations of heavy sections. When large pieces of material are being formed, several consecutive impulses can be applied to the piece to produce progressive shaping of the piece while it remains held in place in the apparatus. Moreover, the illustrative methods and apparatus are easy to control, and the relative amount of energy released in each successive impulse can be varied as may be desired in a sequence to provide various forming effects. In addition it is noted that the illustrative apparatus is adaptable to be used with present presses so that it can be applied as an attachment in many types of existing equipment.

It is an object of the present invention to provide improved methods and apparatus for the high energy rate forming of materials.

A further object of this invention is to provide methods and apparatus for the high energy rate forming of materials which are advantageous and convenient to be used in a wide variety of applications.

In this specification and in the accompanying drawings, are described and shown illustrative embodiments of my invention in methods and apparatus for forming materials by sudden impulses and various modifications thereof are indicated, but it is to be understood that these are not intended to be exhaustive nor limiting of the invention, but on the contrary are given for purposes of illustration in order that others skilled in the art may fully understand the invention and the manner of applying the method and apparatus in practical use and so that they will understand how to modify and adapt these methods and apparatus in various forms, each as may be best suited to the conditions of a particular use.

The various objects, aspects, and advantages of the present invention will be more fully understood from a consideration of the following specification in conjunction with the accompanying drawings, in which:

FIG. 1 is an elevational sectional view of apparatus embodying the present invention and for carrying out the process of the present invention, with certain control circuits being schematically illustrated;

FIG. 2 is an axial sectional view of a hand tool embodying this invention;

FIG. 3 is an elevational sectional view of a modified apparatus for carrying out the process of this invention; and

FIG. 4 is an axial sectional view, shown on an enlarged scale, of apparatus for abruptly releasing compressed gas. This gas release apparatus is also shown in FIGS. 1, 2 and 3.

In the illustrative embodiment shown in FIG. 1, the work material to be formed is shown as a plate of metal W. This work material W is clamped adjacent to a die **10** detachably secured to movable support means **11** by bolts **12**. There is a suction passage **13** in the die **10** connected by a line **14** to a pump **15** for evacuating air from the region near the die surface **16**. This pump **15** withdraws air from beneath the work W before the work is formed against the die surface **16**. A large double acting piston **17** in a cylinder **18** serves to clamp the work W up against a flexible diaphragm **19** shown as a rubber sheet.

Control means **23** are connected to the cylinder **18** by hydraulic lines **21** and **22** so as to raise and lower the die **10**. A pressure source P for the hydraulic liquid **24** is shown as pump P connected from a reservoir sump **25** to the control means **23**, and a discharge is provided from the control means **23** back through a line **26** to the reservoir. The pump P has a bypass pressure regulator **27** so as to set the maximum pressure of the hydraulic liquid

delivered from the pressure source means P. Extending around the rim of the die **10** in a channel is a sealing gasket **28**, and a frame **29** secures the diaphragm **19** in place.

In order to apply an intense high pressure impulse to the work W, there is a substantially incompressible fluid **30**, for example, such as water, oil, hydraulic liquid, or the like, held by a chamber **31** in a very strong high pressure container **32**. This container **32** is in opposed relationship to the die **10** with the work W positioned therebetween. In operation the incompressible fluid **30** is placed under an initial high pressure by pressure source means **34** including a high pressure pump **35** supplied from a reservoir **36** and connected through a valve **38** into the chamber **31**. By raising the pressure in the chamber **31** to an initial high level, while the die **10** has been evacuated by the pump **15**, the work W is prestressed almost to its yield point.

The liquid **30** is held in the chamber **31** by a piston **40** which serves as means for transmitting an intense impulse into the liquid **30**. The pulse transmitting means **40** includes sealing means **41** shown as a piston ring, this transmitting means **40** being adapted to be driven downwardly toward the diaphragm **19**. A plurality of retainers **42** prevent the pulse transmitting piston **40** from falling completely into the chamber **31** before it is pressurized. When this chamber is prepressurized, the piston **40** rests up against stop means **44** shown as an internal shoulder. A small quantity of incompressible liquid **30** may be introduced into the container **32** on top of the piston **40** by a pump **46** and a valve **48** feeding through a passage **49**.

There is a long acceleration cylinder **50** extending down into the high pressure container **32**. Within this cylinder **50** is a massive piston **52** having a plurality of sealing rings **53**. This piston **52** is mounted for free travel in the long cylinder **50** and is adapted to be accelerated to a very high velocity therein.

The purpose of this massive piston **52** and the functionally associated elements of this apparatus, as will be explained in detail, is to transform a first pressure impulse ($I_1$) having a first pressure level ($P_1$) and a first period of time duration ($T_1$) into a second pressure impulse ($I_2$) having a second pressure level ($P_2$) which is many fold higher than $P_1$ and with a second period of time duration ($T_2$) which is many fold shorter than $T_1$.

Before this piston **52** is accelerated, it is held stationary against a stop shoulder **54** by energization of electromagnetic coil means **56** surrounding the cylinder **50**. This coil **56** is energized from an electrical source **57** when a switch **58** is in its closed position. The piston **52** is made of magnetically permeable material, for example, steel and a permeable housing **59** surrounds the coil **56** so as to provide a low reluctance return path for the magnetic flux.

While this impulse transformer piston **52** is being held against the stop **54**, the valves **38** and **48** are closed, and an apparatus **60** for abruptly releasing gas is charged up with gas under high pressure, for example from 1000 to 10,000 p.s.i. This apparatus **60** is attached to the upper end of the cylinder **50** and is shown in detail in FIG. 4 together with the control and high pressure gas supply means which are generally indicated at **62** in FIG. 1.

At the same time as the gas release apparatus **60** is being charged, a vacuum pump **64** serves to evacuate the bore **65** of the long cylinder **50**. The purpose of this evacuation is to reduce substantially the amount of gas in the bore **65** between the pistons **52** and **40** so as to maximize the ultimate velocity of the piston **52**. Also, this absence of gas in the bore **65** increases the shock which is created at the instant of impact of the piston **52** against the small layer of liquid **30** over the piston **40**.

When it is desired to produce the high energy impulse for forming the work W, the control and supply means **62** is actuated, causing the gas-release apparatus **60** to abruptly release a large quantity of high pressure gas into a release region **66** at the top of the long cylinder **50** directly above the piston **52**. This release region **66** contains a liquid **67** for the purpose, among others, of reducing the available volume for the gas to enter, thus maximizing the initial pressure level. This abrupt release of high pressure gas into the region **66** accelerates the piston **52** down the bore **65** with a great rate of acceleration so as to attain a high velocity during its free travel along this cylinder.

As the massive piston **52** impacts at very high velocity against the liquid **30** above the piston **40**, this latter piston is driven substantially instantaneously down into the chamber **31** so as to create an intensely high pressure shock wave therein which forms the work W against the die surface **16**.

In order to return the piston **52** to its initial position, a valve **68** is opened so as to allow the gas in the bore **65** to escape through a top passage **69** and through a line **70** into a gas-liquid separator **72**. The gas passes out of the top of separator **72** and down through a line **73** and through a two-way valve **74** and through a line **75** into a pressure storage tank **76**. As soon as pressure equilibrium between the bore **65** and tank **76** is reached, then the two-way valve **74** is turned so as to shut off the line **75** while connecting the line **73** to a discharge pipe **78**. This allows the remaining gas to escape from the bore **65** bringing the bore pressure down to atmospheric pressure. A valve **80** is also opened to allow any of the liquid **67** to drain down from the separator **72** back into the cylinder **50** into the region **66** above the piston **52**.

Now that the bore **65** is down to atmospheric-pressure, a valve **82** is opened so that the gas stored under pressure in the tank **76** passes through a line **83** and through the passage **49** into the lower end of the bore **65**. This raises the pressure container beneath the piston **52** so as to lift it back up into its initial position where it is held by the electromagnet **56**.

As soon as the piston **52** has been returned to its initial upper position, the valve **82** is actuated to shut off the line **83**, and a valve **84** is opened so as to discharge the gas from the bore **65** through a pipe **85**. This valve **84** and also the valves **68** and **80** are all closed before the vacuum pump **64** is operated.

It is noted that the top passage **69** is positioned up at the top so as to allow all of the gas to escape from the region **66** while the piston **52** is being lifted up the bore **65**. Also, there is sufficient liquid **67** to fill both of the lines between the region **66** and the valves **68** and **80**. Thus, there is substantially no gas available in the region **66** to push down on the piston **52** when the bore **65** is being evacuated by the pump **64**.

If the work W requires more than one high energy impulse to complete its forming operation, then the cycle is repeated, including the step of opening the valve **38** so as to introduce sufficient liquid **30** into the chamber **31** to prepressurize this chamber.

When the forming operation is complete, the control **23** is operated to lower the die **10** for removing the completed work and inserting a new plate W to be formed.

The cylinder **18** is braced by a plurality of web members **87** having a large flange **88**. This flange **88** is rigidly fastened by means of spacer tubes **90** and large tension bolts **91** connected to a large mounting frame **92** at the lower end of the high pressure container **32**. The mounting frame **92** is slidably secured by sleeve bearings **93** to a plurality of rigid columns **94** which are anchored in a foundation **95**. Similarly, a base **96** on the cylinder **18** is slidably secured by sleeve bearings **93** to these same columns. For reducing undesired vibrations or tremors in the foundation **95**, the base **96** is supported by a plurality of shock-absorbing pads **97** set on the foundation **95**. Also, the slidable bearings **93** allow the whole machine to move up and down as the vibration and tremors are absorbed by the shock-absorbing pads **97**. For example, these pads

may be formed of alternating layers of lead, asbestos and steel plates.

It is noted that the piston **40** has a convex forward surface **45** facing into the chamber **31**. The purpose of this convex surface is to direct the intense shock pressure wave toward the entire area of the diaphragm **19** so that this high energy pressure shock wave is applied to the whole of the work W to be formed thereby. The action of the impulse transformer piston **52** in its high velocity impact against the liquid layer **30** is to transform the original pressure level $P_1$ which occurred in the region **66** into a many fold higher pressure level $P_2$ in the chamber **31**. The duration of this very high pressure level $P_2$ in chamber **31** is so brief that it appears as a high energy shock wave in the liquid **30** in chamber **31** which produces plastic deformation of the work W against the die surface **16**. The valves **38, 63, 68, 74, 80, 82** and **84** are solenoid valves which are connected by electrical circuits **98** to the main control means **99** for controlling these valves in proper sequence. This control means **99** includes a plurality of cam-actuated switches which are individually connected by the various circuits **98** to these respective solenoid valves. A plurality of cams are ganged onto a common shaft so that each cam can control a respective one of the switches to produce the desired duration of open and closed condition for each valve. A timing motor running at the desired speed drives the common cam shaft. The valve **48** is operated manually from time to time to supply the desired level of the liquid layer **30**. When the main control means **99** has completed one full cycle, then the apparatus is ready to be fired again. The firing switch in the control means **62** is automatically actuated by one of the control cams in the main control means **99**, and this firing will be explained in further detail in connection with FIG. 4.

In the other embodiments of this invention the same elements have the same reference numbers as in FIG. 1, and components performing functions corresponding to those of similar components in FIG. 1 have the same reference member increased by multiples of 200. The hand tool **200** (FIG. 2) is adapted to provide intense blows from a tool bit **201** which is detachably secured by a set screw **202** in a socket **203** in a pulse transmitting piston **240**. Other shapes of tool bits can be inserted into the socket **203** depending upon the particular material forming operation being performed by this tool, for example such as forming material for forging, bending, indenting, riveting, chiseling, by driving or hammering harder elements into other material, for example studs into concrete, and the like.

In operating this hand tool **200** (FIG. 2) the user holds a handle **204** and fires the tool by squeezing a trigger **205**. The return of the operating elements to their initial positions is produced by allowing this trigger to move forward to its normal position as urged by a trigger spring (not shown). When the trigger is squeezed, an apparatus **60** abruptly releases a charge of high pressure gas into a release region **266** containing liquid **67** positioned between an impulse transformer piston **252** and a recoil absorbing piston **206**. This recoil piston **206** has substantially more weight than the piston **252** and is normally held in its forward position against a stop shoulder **207** by means of a spring **208**. This piston **206** slides back within a cylinder **209** when the tool **200** is fired, and at the rear of this cylinder is a tubular resilient stop pad **233**. The air in the cylinder **209** is allowed to escape from behind the moving piston **206** through a port **237** and is deflected forwardly by a deflector shield **239**. Thus, the outrush of air is kept away from the user's face or body.

The impulse transformer piston **252** accelerates forwardly at a high rate during its free travel along the bore **265** of the long cylinder **250**, and is travelling at high velocity at the instant when it impacts against the surface **243** of the pulse transmitting piston **240**. Thus, the tool bit **201** is driven forward substantially instantaneously to provide a high energy shock impulse to the work material W, which is shown here as a heavy section of metal being formed. As a result, plastic deformation of this work material W is produced to cause the deisred forming of this material.

As the piston **252** accelerates forwardly at high rate, the air within the bore **265** is allowed to escape through a plurality of forward directed ports **302** which are located immediately adjacent to the impact surface **243** of the piston **240**.

In order to return the piston **240** to its initial position, the trigger **205** is released. This opens a valve momentarily so that compressed air is supplied through a line **304** and through a passage **306** into a tool-return cylinder **308**. The pressure of the air on a shoulder **310** of the piston **240** returns it to its initial position.

For purposes of returning the piston **252** to its initial position, the ports **302** are temporarily closed by means of a slidable sleeve **312** which is moved forward to cover these ports by a small double acting cylinder **314**. Then, compressed air is fed through a return line **283** and through a passage **249** into the forward end of the bore **265** for returning the piston **252** to its initial position. The piston **252** is held in its initial position by a retainer detent spring ring **320** which engages in a groove extending around the piston **252**.

The gas release apparatus **60** is secured by detachable mounting means **61** onto a cylinder body portion **251**. During return of the pistons **252** and **206** to their initial positions, the gas which was previously released into the region **266** is allowed to escape into the atmosphere through a very small diameter passage **322** and through a gas-liquid separator **272**. The passage **322** is so small that an insignificant amount of the high pressure gas can escape during the very brief instant while the piston **252** is accelerating forward in its impulse stroke. The liquid **67** is introduced into the region **166** through a passage **326**.

After an appropriate time delay which is sufficient to return the pistons **252** and **206**, the double-acting cylinders **314** are actuated to open the ports **302**. This reverse movement of the sleeve **312** signals the user that the tool **200** is ready to be fired again.

It will be appreciated by those skilled in the art that the feeding of compressed air through the various lines **283, 304**, and to the double-acting cylinders **314** is controlled by suitable solenoid valves in a housing **330**. The trigger **205** operates switches to control these solenoid valves. The electrical power for energizing the solenoid valves is supplied by a power line **331**. Low pressure air is fed through a line **332** for supplying the return lines **283** and **304** and for operating the double-acting cylinders **314**. High pressure air for charging the apparatus **60** is fed through a line **333**, and all three lines **331, 332**, and **333** are encased in a flexible armored sheath **334**.

The retainer detent ring **320** (FIG. 2), and the electromagnet coil **56** (FIG. 1) serve as means for holding the pulse transformer piston (**52, 252**) in its initial position. It will be understood that any similar holding means may be used which will retain the pulse transformer piston in its initial position and then will release it to be accelerated freely to a high velocity.

In FIG. 2 the apparatus **60** for abruptly releasing the high pressure air is identical to that in FIG. 1 except that it is smaller in size and is adapted to be charged with high pressure compressed air in a range from 400 to 3,000 p.s.i.

In FIG. 3 is shown a modified system for carrying out the process of this invention. The apparatus **60** is identical to that in FIG. 1 and is adapted to release abruptly a charge of highly compressed gas directly into the chamber **31** for creating an intense pressure impulse in the liquid **30** which is effectively adjacent to the work material W. The incompressible fluid **30** is prepressurized by the high-pressure source means **34**, which includes the pump **35** and valve **38**. The work material W

is shown as a metal plate to be formed against the die surface **16**. After the high energy pressure impulse has been applied to the material W the gas is discharged through a valve **68**, line **70** and gas-liquid separator **72**. For forming thicker sections a succession of pulses can be applied before the work is unclamped.

The high pressure bell-shaped container **32** is held firmly in opposed relationship to the die **10** by pressurized liquid **24** within the cylinder **18** above the large piston **17**. When the work has been formed, the container **32** and the movable support means **11** are raised by feeding hydraulic liquid through the line **21** into the lower portion of the cylinder **18**. Thus, the formed work W can be removed and another plate positioned on the die **10** in readiness to be formed. The valves **68** and **80** are solenoid valves which are connected by circuits **98** to the main control means **99** for providing the desired sequence and duration of operation of these valves, similar to the control system described in connection with FIG. 1.

As shown in detail in FIG. 4, the apparatus **60** for abruptly releasing gas comprises container means **502** adapted to hold gas therein under high pressure and to discharge the gas suddenly in a very brief time period in response to an external control signal. The container means **502** includes a plurality of axially aligned cylinders each having a piston in sliding engagement therewith. These pistons are rigidly interconnected so that they are capable of movement with very great acceleration over a predetermined distance before suddenly discharging the high-pressure gas through vent means from the apparatus **60**. One of these pistons serves as opening and closing means for containing and then releasing the high pressure gas, and another piston serves as operating means for the first piston for holding it closed and then for releasing it in response to the external firing signal so that the pistons then move with very great acceleration before the first piston opens the vent means for discharging the high-pressure gas.

Consequently, the vent means are opened very abruptly, for the first piston is travelling very fast at the instant when the vent means are opened, thus advantageously providing an effectively instantaneous transition from fully closed to fully open condition.

As shown illustratively in FIG. 4, the container means **502** includes a first cylinder **504** which extends toward vent means **506** and a second cylinder **508** which is axially aligned with the first cylinder **504**. A first piston **510** travels along the cylinder **504** and serves as closing means for blocking the discharge port so as to contain the high pressure gas within the container means **502**.

For operating the first piston **510** there is a second piston **512** which travels along the cylinder **508**, and these two pistons are rigidly interconnected to form a shuttle **514** which is constructed so as to be as light as possible while being sufficiently strong to withstand a very great acceleration and subsequent very great deceleration in the axial direction. A hollow piston rod rigidly interconnects these two pistons **510** and **512**.

When the shuttle **514** is in its normal position prior to firing, the first piston **510** is located at the upper end of the cylinder **504** remote from the vent means **506**. The rim of this first piston **510** is in sealing engagement with a first annular resilient seal **518** which is clamped in place by a metal clamping retainer ring **520**. The seal **518** is formed of a very tough, resilient material, for example, tough, solid polyurethane, and it has sufficient ability to be bent and yet to return to its original shape so as to enable it to be slid over the perimeter of the piston **510** when the shuttle **514** and seal **518** are being assembled and sufficient durability to withstand the operating conditions. From experiments I have found that it is desirable to machine the two pistons **510** and **512** and the hollow connecting rod **516** as an integral member so as to provide sufficient strength and durability to withstand the very great acceleration and deceleration forces and pressures encountered during operation repeatedly over thousands of operating cycles.

The cylinder **504** includes a strong flange **520** mating with a strong flange **522** on the lower end of the cylinder **508**. The upper end of the cylinder **504** projects somewhat above the top surface of the flange **520** so as to form a lip engaging with the lower end of the upper cylinder for precisely aligning the two cylinders. The flange surface **520** has an annular groove containing an O-ring **526** abutting against the flange **522** preventing leakage of high pressure gas from the housing **502**. A bolt circle **528** holds the flanges **520** and **522** tightly together.

In preparation for firing, gas under pressure, for example 1,000 to 10,000 p.s.i. is supplied from a high pressure source **533**, such as a multistage compressor, through a fill port **530** into the chamber **532** within the cylinder **508**. The pressure of the gas upon the upper surface K of the piston **510** is tending to drive this piston down along the cylinder **504**.

In order to hold this piston in place, the second piston **512** has a surface L exposed to the pressure of gas in the container and of larger effective area than area K and facing in the opposite direction from area K. This second piston has an annular lip sealing element **534** engaging up against a second annular tough resilient seal **536**. This seal **536** may be formed of the same material as the seal **518**. A clamping retainer ring **538** holds the outer edge of the seal **536**. The inner edge of the seal **536** is held by a retainer disc stop **540** having a rabbeted edge overlapping the seal. A plurality of bolts **542** secure the disc stop **540** against the cylinder head wall **544**. This end wall **544** is fastened by a bolt circle **528** to a flange **546** on the cylinder **508**. The wall **544** includes an annular groove containing an O-ring **526** for preventing leakage.

As will be explained, when the apparatus **60** is fired, the pressure within the chamber **532** drops very abruptly. Consequently, it is desirable to prevent the accumulation of any high pressure gas behind the seal **536**, because any such pocket of gas would tend to blow the seal **115** away from the end wall **544** upon firing. Accordingly, a small diameter bleed hole **548** passes through the end wall **544** and communicates with a channel behind the seal **536**. The outer diameter of the sealing lip element **534** is greater than the diameter of the piston **510**. The upper surface M of the piston engages against the stop disc **540** as the lip **534** begins to press into the resilient seal **536**. This stop **540** prevents the large thrust of the piston from embedding the lip element **534** deeply into the seal **536**.

The shuttle **514** is in effect in unstable equilibrium, being temporarily held in place by the differential in areas, but as soon as the pressure nears equalization on opposite surfaces of the operating piston **512**, then the shuttle is released and accelerates violently.

In order to fire the apparatus **60**, communication is provided between the chamber **532** and the upper surface M of the piston **512** so as to tend to equalize the pressures against opposite sides L and M of the operating piston **512**. A passage is completed from the fill port **530** through a line **550** to a firing port **552** by opening a solenoid actuated firing valve **554**. There is a small chamber **556** surrounding the firing port **552** adjacent to the surface M, and the high pressure gas enters through the firing port into this chamber **556** thus tending to equalize the pressure against opposite surfaces M and L. The high pressure gas pressing against the surface K of piston **510** soon overbalances the holding force of the piston **512**, so that the piston **510** begins to accelerate rapidly down the cylinder **504**. Thus, the lip element **534** is moved away from the seal **536**.

Immediately, the gas in the chamber **532** is free to rush up through multiple bypass openings **558** in the scalloped periphery of the piston **512** so as to equalize completely

the pressure against opposite sides M and L of this piston **99**. The lands between the bypass openings **558** serve as guide means travelling along the cylinder surface **508**.

The two pistons **510** and **512** accelerate downwardly with very great acceleration along the acceleration distance E, but the high pressure gas is prevented from escaping through the vent means **506** until after the rim of the piston **510** has passed below the upper end of the vent means. The vent means **506** comprise a plurality of openings to the exterior of the housing means **502** communicating with the lower end of the cylinder **504**, and the longitudinally extending areas between each of the vent openings serve as guide surfaces for guiding the piston **510**.

As the piston **510** travels along the acceleration distance E, it accelerates extremely rapidly to a high velocity so that it passes the end **560** of the cylinder **504** extremely fast and traverses past the vents **506** almost instantaneously so that they become fully open in a small fraction of a second. The high pressure gas is thus released with effectively an extremely abrupt discharge which approaches explosive abruptness.

The apparatus **60** is operated and controlled by the supply and control means, generally indicated at **62**, including the high pressure source **533**. The firing valve **554** is a solenoid valve which is energized from a source of electrical energy **562** by closing a trigger switch **564**. After the apparatus **60** has been discharged, the first piston **510** is down in the housing **566** near the lower ends of the vents **506**, the shuttle **514** having been decelerated by the liquid **67** which is expelled from the lower end of the housing **566** through the vents **506**. This piston deceleration is another function of the liquid **67**, shown in FIGS. 1 and 2, and of the liquid **30** in FIG. 3.

The shuttle **514** is returned to its initial position by gas from the source **533** which passes through a pressure reducer **568** and through a return passage **570** and up through a pedestal **572** into a return chamber **574** within the hollow piston rod **516**. When the trigger switch **564** is released, a spring **576** opens this switch **564** and closes a fill switch **578** which is mechanically ganged with the trigger switch. Thus, a fill solenoid valve **578** is energized so as to supply gas through the fill port **530** for quickly recharging the apparatus **60**. A bleed hole **580** communicating with the firing port **552** prevents any build up of pressure in the passage **552** so as to prevent accidental firing until the trigger switch **564** is actuated. The trigger switch **564** and the fill switch **578** may desirably be actuated by cam means which are included in the main control means **99**, as is shown in the systems of FIGS. 1 and 3. Alternatively, the switches **564** and **578** may be manually actuated as indicated in the apparatus of FIG. 2.

It will be appreciated that these methods and apparatus are very flexible in operation. A different pressure level in the chamber **532** can be used for each impulse when a succession of impulses are being used to form the work material W. The pressure level of the high pressure gas in the chamber **532** is adjusted by setting a pressure regulator valve **582**.

Also, it is to be noted that these apparatus can be incorporated in existing presses as attachments thereto. The existing presses being used to provide the powerful clamping forces which are here being provided by the large piston **17** and cylinder **18**.

From the foregoing it will be understood that the material forming methods and apparatus of the present invention described above are well suited to provide the advantages set forth, and since many possible embodiments may be made of the various features of this invention and as the method and apparatus herein described may be changed in various parts, all without departing from the scope of the invention, it is to be understood that all matter hereinbefore set forth or shown in the accompanying drawings is to be interpreted as illustrative and not in a limiting sense and that in certain instances, some of the features of the invention may be used without a corresponding use of other features, all without departing from the scope of the invention as defined by the following claims.

What is claimed is:

**1.** Apparatus for forming material by high energy impulses comprising a cylindrical barrel, a piston movable along said barrel, pressure means for returning said piston to an initial position in said barrel, means for introducing liquid into a region behind said piston when said piston is in said initial position, means for abruptly releasing high pressure gas into said region containing said liquid for accelerating said piston along said barrel to a high speed, a pulse transmitting member at the end of said barrel positioned to be struck by said piston, and a material forming tool controlled by said pulse transmitting member for forming material by the high energy impulse resulting from the impact of said piston upon said pulse transmitting member.

**2.** Apparatus for forming material by high energy impulses as claimed in claim **1** in which a gas-liquid separator is provided being connected to said region behind said piston, said gas-liquid separator allowing the gas to escape while retaining the liquid during the return of said piston to its initial position in said cylindrical barrel.

**3.** Apparatus for forming material by high energy impulses comprising a cylindrical barrel, an impulse transformer member freely movable along said barrel, first pressure means for returning said impulse transformer member to its initial position in said barrel, a movable recoil member positioned in opposed relationship to said impulse transformer member and arranged to define a region therebetween, liquid supply means for introducing liquid into said region when said impulse transformer member is in its initial position, means for abruptly releasing high pressure gas into said region defined by said impulse transformer member and said movable recoil member for accelerating said impulse transformer member along said barrel to a high speed, and said movable recoil member being accelerated in the opposite direction away from said impulse transformer to absorb the recoil, a pulse transmitting member at the end of said barrel, positioned to be struck by said impulse member, second pressure means for returning said impulse transmitting member to its initial position, and a material forming tool controlled by said pulse transmitting member whereby material is formed from the high energy impulse resulting from the impact of said impulse transformer member upon said pulse transmitting member.

**4.** Apparatus for forming material by high pressure impulses as claimed in claim **3** including a passage connecting said region behind said impulse transformer member to a gas-liquid separator, said passage being adapted to prevent any significant amount of high pressure gas from escaping from said region during the release of said high pressure gas, but allowing the gas to escape while said impulse transformer member is being returned to its initial position, said gas-liquid separator preventing the liquid from escaping through said passage, but allowing the gas to escape during return of said transformer member.

**5.** Apparatus for forming material by high energy impulses comprising a cylindrical barrel, an impulse transformer member freely movable along said barrel, first pressure means for returning said impulse transformer member to its initial position in said barrel, means for abruptly releasing high pressure gas into a region behind said impulse transformer for accelerating said impulse transformer member, a pulse transmitting member at the end of said barrel positioned to be struck by said impulse transformer member, second pressure means for returning said pulse transmitting member to its initial position, a material forming tool controlled by said pulse transmitting member whereby material is formed from

the high energy impulse resulting from the impact of said impulse transformer member upon said pulse transmitting member, passage means connecting with said region behind said impulse transformer member, said passage means adapted to prevent any significant amount of high-pressure gas from escaping from said region during the release of said high pressure gas, but allowing the gas to escape while said impulse transformer member is being returned to its initial position.

6. Pneumatic actuated impulse apparatus comprising container means adapted to hold high pressure compressed air therein and to discharge the compressed air suddenly in a very brief time period in response to an external control signal, said tool apparatus including a cylinder with discharge ports therein and a piston in said cylinder adapted to be accelerated toward said ports, a movable sleeve surrounding said cylinder, said sleeve being movable between a first position in which said sleeve surrounds said ports for closing said ports and a second position in which said sleeve opens said ports, and control means for moving said sleeve to close and open said ports.

7. Pneumatic actuated impulse apparatus as claimed in claim 6 in which said control means is operated to move said sleeve from its first to its second position to open said discharge ports before said piston is accelerated along said cylinder toward said discharge ports.

8. Apparatus for forming material by high energy impulses comprising a cylindrical barrel, an impulse transformer member freely movable along said barrel, a recoil member positioned in opposed relationship to said impulse transformer member defining a region between said members, said recoil member being movable in the opposite direction from said impulse transformer member, means for abruptly releasing high pressure gas into said region between said members for accelerating said impulse transformer member along said barrel to a high speed, and for accelerating said recoil member in the opposite direction for absorbing the recoil, gas removing means associated with said region and adapted to remove said high pressure gas after said impulse transformer member is accelerated, a pulse transmitting member at the end of said barrel positioned to be struck by said impulse transformer member, and material forming means controlled by said pulse transmitting member for forming material by the high energy impulse resulting from the impact of said transformer member upon said pulse transmitting member.

9. Apparatus for forming material by high energy impulses as claimed in claim 8 including exhaust means associated with said recoil member allowing air to escape from behind said recoil member when said recoil member is accelerated and arranged to deflect said air away from the face of a user, means for returning said recoil member to an initial position adjacent to said region.

10. Apparatus for forming material by high energy impulses as claimed in claim 8 including first pressure means for returning said impulse transformer member to its initial position in said barrel, second pressure means for returning said pulse transmitting member to its initial position in said barrel.

11. Apparatus for forming material by high energy impulses comprising a cylindrical barrel, an impulse transformer member movable along said barrel, means for abruptly releasing high pressure gas into a region adjacent to said impulse transformer member for accelerating said impulse transformer member along said barrel to a high speed, a pulse transmitting member controlling a tool at the end of said barrel positioned to be struck by said impulse transformer member, a plurality of ports located in said barrel, said ports allowing air in front of said impulse transformer member to escape as said impulse transformer member is accelerated, return means for returning said impulse transformer member to an initial position in said barrel, port closing means capable of closing said ports during actuation of said return means and opening said ports after said impulse transformer member has returned to its initial position.



12. Apparatus for forming material by high energy impulses comprising a cylindrical barrel, a piston movable along said barrel, means for returning said piston to an initial position in said barrel, means for introducing liquid into a region behind said piston when said piston is in said initial position, means for abruptly releasing high pressure gas into said region for accelerating said piston along said barrel to a high speed, a movable pulse transmitting member at the end of said barrel positioned to be struck by said piston, a material forming tool controlled by said pulse transmitting member for forming material by the high energy impulses resulting from the impact of said piston upon said pulse transmitting member, and fluid pressure means for returning said pulse transmitting member to its initial position.

13. Tool apparatus for forming material comprising a cylindrical barrel, a first piston movable along said barrel, a second piston at the end of said barrel including means for holding a tool, said first piston sliding along said barrel and impacting against said second piston, said second piston being adapted to transmit the resulting pulse to the tool, container means for holding compressed air under high pressure, means for introducing liquid into a region behind said first piston, and means for instantaneously releasing the compressed air communicating with said region behind said first piston for accelerating said first piston along said barrel toward said second piston.

14. Tool apparatus for forming material comprising a cylindrical barrel, a first piston movable along said barrel, a second piston at the end of said barrel including means for holding a tool, a third piston movable in the opposite direction from said first piston for absorbing recoil, said third piston having a larger mass than said first piston, said first piston sliding along said barrel and impacting against said second piston, said second piston being adapted to transmit the resulting pulse to the tool, container means for holding compressed air under high pressure, and means for instantaneously releasing the compressed air communicating with a region between said first and third pistons for accelerating said first piston along said barrel toward said second piston.


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