(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 251 660 B1**

(12) # EUROPEAN PATENT SPECIFICATION

(45) Date of publication of patent specification: **04.11.92**

(51) Int. Cl.[5]: **E02F 3/92**, E02F 3/88, E02F 5/28

(21) Application number: **87305583.4**

(22) Date of filing: **23.06.87**

(54) **Method and apparatus for soil excavation and the like.**

(30) Priority: **23.06.86 US 877280**

(43) Date of publication of application:
07.01.88 Bulletin 88/01

(45) Publication of the grant of the patent:
04.11.92 Bulletin 92/45

(84) Designated Contracting States:
AT BE CH DE ES GB IT LI LU NL SE

(56) References cited:
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Description

THIS INVENTION relates generally to the excavation of soil and other granular materials by a high velocity gas stream. More particularly, the invention relates to a method and apparatus utilizing a stream of gas, preferably air, for the excavation of granular materials such as soil around buried objects. The present invention is particularly suited for excavation in close proximity to and in contact with subterranean utility lines, conduits and the like where conventional mechanical and hand excavation techniques could cause damage to the buried pipes, wires or cables and, in some cases, create explosion hazards.

Heretofore, when excavation has been required in close proximity to gas lines, water and sewer pipes, underground power and television cables, telephone lines and the like, it has been necessary to convert from the usual mechanized equipment, such as power shovels or backhoes, and employ hand excavation tools such as picks and shovels to complete the task. Hand excavation not only results in a dramatic reduction in the material removal rate, but it also does not completely solve the problem of inadvertent striking and rupturing of buried utility lines and pipes. Such mishaps result in potentially expensive property damage and troublesome service interruptions. In addition, in the case of natural gas lines, there is also a continual threat of bodily injury to the workmen resulting from the explosion hazards created by the use of hand tools in and around the cast iron pipes. In such an environment, sparks caused by a collision of the steel digging tools with a pipe or a stone can result in a gas explosion if a leak is present. In an attempt to overcome the reduced excavation rates of hand tools, attempts have been made to introduce various mechanized digging aids such as scrapers, power brushes, fluid sprays, and the like to minimize or completely eliminate the hand work. These devices have met with limited success in the field and, at best, are a marginal solution to the dilemma. In operation, the cleaning mechanisms quickly become dull and worn, requiring frequent maintenance and replacement. The soil usually adheres to the cleaning mechanism, reducing its effectiveness; brushes clog and scrapers become caked. In addition, the cleaning mechanism itself can damage the surface of the object being cleaned and a scraper or hoe can gouge or destroy a pipe or valve if the mechanism controlling the device is inadequate or improperly set. In the case of liquid hydraulic sprays, such as water, the disadvantages are also manifest. A large supply of water is usually required, which creates a disposal problem at the job site. In addition, the splashing of the water spray must be contained and generally coats surrounding equipment with a layer of mud. In cold weather operations, the water must be treated with an antifreeze or some other fluid must be employed so as to eliminate icing problems.

This invention seeks to solve many of the problems heretofore encountered in excavating around buried utility lines, pipe, conduits and the like, or for excavating to and in contact with fragile objects or structures, such as building foundations, which may be damaged by mechanized digging equipment.

US-A-3917007 discloses a method of sinking holes in the earth's surface. The method is primarily intended for use in drilling holes such as mapping and prospecting holes made during a geological survey. The method comprises the steps of directing a stream of gas discharged under a high pressure from a rocket engine, to form the hole. The Specification mentions a flow velocity of 80-100 metres per second, and indicates that the temperature of the gas discharged from the nozzle is about 1,000 °C. Such a device is thus ill-suited for use when excavating in close proximity to gas lines, water and sewer pipes, since such items should not be exposed to high temperatures.

US-A-4084648 discloses a combined digging and grouting machine. The machine, in use, forms a bore in the earth's crust which is grouted. The apparatus includes the use of a nozzle from which is discharged a high pressure liquid with a concentric surrounding stream of high pressure air. Reference is made in the Specification to the fact that the air jet has a velocity which is at least half the speed of sound.

According to one aspect of this invention there is provided a method of moving or dislodging a soil mass or similar granular material mass to effect excavation or cleaning, said method comprising the steps of directing, at said soil mass or like granular material mass a jet of gas having a velocity greater than Mach 1, wherein the jet is created by passing a stream of pressurized gas through a converging/diverging type nozzle having a ratio of outlet area section to throat section of greater than 1 so that the velocity of the gas stream is greater than Mach 1 at the outlet.

Conveniently the gas is air.

Preferably the velocity of the gas is greater than Mach 1.5 and most preferably greater than Mach 3.

Conveniently the ratio of pressure of the pressurized gas to ambient pressure is between 1.895 and 150.796.

Conveniently the gas stream is obtained from a source of gas having a pressure greater than 620 KNm^{-2}gauge.

Advantageously the gas stream has incorporated in it, prior to the gas stream being accelerated to

supersonic speed, a substance which solidifies on cooling, to form particles which are emitted with the said jet.

According to another aspect of this invention there is provided an apparatus for dislodging a soil mass or a similar granular material mass to effect excavation or cleaning, said apparatus comprising a source of pressurized gas, a duct, communicating with said source of pressurized gas and a nozzle wherein the nozzle is of the converging/diverging type having a throat section and an outlet section each of said sections defining a respective cross-sectional area, the ratio of the outlet section area to the throat section area being greater than 1.0 whereby said apparatus is adapted, in use, to produce a stream of gas at a velocity of greater than Mach 1 when pressurized gas from the reservoir passes through the nozzle.

Advantageously the apparatus comprises means for introducing, into the duct, upstream of the nozzle, a liquid or gaseous material which solidifies on cooling.

Preferably valve means are provided, associated with the duct means, adapted to regulate the flow of gas from the gas source to a nozzle the valve means comprising a valve body having a bore therethrough, positioned in communication with said duct and with source of gas said valve means further including a valve member having a head portion and a piston portion interconnected by a stem said head portion cooperating with a valve seat to cut off the supply of pressurized gas to said nozzle when said valve is in a deactivated position, said valve means further including a pilot bore adapted to communicate between the source of pressurized gas and the piston portion of the valve when said valve means is in an activated position, whereby said pressurized gas is adapted to pass through said pilot bore means to act on said piston portion to move said valve member and cause said head portion to unseat and permit the flow of pressurized gas to the nozzle.

Advantageously the valve means includes trigger means including a rotatable cylindrical portion having a pilot port therethrough which is adapted to communicate with said pilot bore means where said trigger means is in an activated position to permit pressurized gas to flow therethrough to unseat said valve head, and adapted to close off said pilot bore means when said trigger means is in a deactivated position.

Preferably the cylindrical portion of the trigger means also has a vent port formed therein to permit the escape of pressureized gas from the pilot bore means to the atmosphere when the trigger means is moved to the deactivated position.

It will be appreciated that the present invention is directed to a method and apparatus for excavating in and around these relatively fragile components which employs a jet-like stream of a gas, preferably air, at supersonic flow rates to provide a fast, efficient, and safe technique in this heretofore tedious task. The invention is suitable for use in the form of a hand-held tool or it may be frame mounted on an excavating machine or used in conjunction with an automated robotic excavator apparatus. The invention provides a supersonic jet of air which creates fissures and cavities when directed to a soil mass or to a mass of like granular material. The impacting, high-velocity air stream becomes instantaneously trapped or stagnated within these soil cavities, causing rapid fracture of the local sites due to the large momentum flux which results from the rapid release of the expanding high pressure air trapped within the cavities and fissures. The stagnated or trapped air must expand and, in doing so, causes the soil to fail in tension, its weakest attribute.

Thus a preferred embodiment of the invention comprises a device for safely excavating soil in close proximity to gas lines, water pipes, sewer lines, underground power cables, telephone lines and the like, which is very selective in its attack. The supersonic air stream provided is extremely agressive toward soil while being completely harmless towards buried objects, including those of a very fragile nature, such as underground television or telephone cable.

It is envisaged that preferred embodiments of the invention will provide significantly higher productivity than hand methods, with virtually no likelihood of accidental destruction, even in situations where the supersonic jet is directed against buried objects. The present invention provides a supersonic air jet, preferably about $1\frac{1}{2}$ to 3 times the speed of sound or higher, depending upon the operating pressures and nozzle diameters employed. The jet impacts upon surfaces, penetrates and breaks up the soil mass while being deflected by impervious surfaces such as plastic or iron pipe or electrical cable and conduit. Hence, in addition to excavation, the present invention is also useful in cleaning operations.

Still further, a preferred embodiment of the invention comprises an excavating or cleaning device which is simple to operate and safe to use and which is operable with standard commercial air compressors. The device of the present invention provides a high velocity gas stream capable of penetrating and fragmenting a wide range of soil types, from very hard and brittle, such as dry baked clay, to soils which are very rubbery or sticky. The device produces a supersonic jet which is effective at practical standoff distances from the nozzle, making it easy to operate when embodied in the form of a hand-held device.

A hand-operated embodiment of the present invention may incorporate a unique, low-torque trigger

valve mechanism which employs the reservoir gas at high pressure as a pilot to assist in opening the valve to the high pressure supply line. The valve body and covers provide a sealed environment against dust, mud and water or other hostile environments making it suitable for the demanding service experienced in the field.

In another embodiment of the present invention, small amounts of liquid water or gaseous CO_2 may be introduced into the device to produce an entrained flow of solid particles within the supersonic air stream to provide an abrasive cleaning action to the high speed jet. In this manner, the advantages of abrasives are gained without the related problems of abrasive wear in a hose and the problem of abrasive contamination. Various embodiments of the present invention may provide devices which are capable of producing supersonic gas streams of various cross-sectioned configurations depending upon the shape of the nozzle employed. Circular or square nozzles are preferred in excavation applications, while a thin, knife-like rectangular nozzle is particularly suited for cleaning operations, such as in cleaning caked substances from bulk material conveyor belts.

In a preferred embodiment of the present invention a reservoir of pressurized gas, preferably air, maintained at about 620 to 689 KNM^{-2} (90-100 psig) or higher, provides a flow of gas which is regulated through appropriate valve means to a barrel of the device which is fitted with a converging/diverging nozzle at the end of the bore thereof. The nozzle may possess a circular cross-section or a square or rectangular cross-section, depending upon the shape of the air jet desired. The converging/diverging configuration of the nozzle is critical in the creation of the supersonic air jet in accordance with known principles of fluid mechanics. In nozzles of this type, the boundary conditions of supply pressure and ambient or atmospheric pressure produce a choked sonic flow condition at the throat of the nozzle and a supersonic flow in the diverging section. The diverging section is flared such that the air accelerates smoothly, without shock waves, to produce a maximum velocity and Mach number at the nozzle outlet. The choked flow condition is a known phenomenon and occurs when the fluid mass flow rate attains a maximum value for a given throat area of the nozzle at given upstream conditions of temperature and pressure. The flow rate at the exit of the converging/diverging nozzle thus can be predicted by closely controlling the area ratio of the throat and outlet regions of the nozzle, along with the pressure ratio of the air within the reservoir with that of the ambient pressure, normally atmospheric.

In using the present invention, for excavating most soils, from wet clay to dry loam or sand, a gas stream velocity greater than just supersonic is required and, more particularly, a velocity at least about Mach 2 is preferred since it provides a more efficient digging tool. A nozzle for producing an exit velocity of Mach 2 employs an area ratio of about 1:1.685 outlet area to throat area, and a pressure ratio of about 7.8:1, reservoir pressure to ambient pressure. Thus, a Mach 2 exit velocity is feasible utilizing a conventional air compressor which usually is capable of generating between 620 to 758 KNm^{-2} (90 to110 psi) reservoir pressure at a sufficient flow rate of, for example, 3.5 cubic metres (125 cubic feet) per minute of air.

In a preferred hand-operated embodiment of the present invention, a trigger actuated valve, normally spring-biased to a closed or deactivated position, is provided to pilot flow of high pressure reservoir air around the valve to assist in overcoming the force of the pressurized reservoir air which normally maintains the valve in the closed position. The valve member comprises a valve stem positioned within the bore of a valve body or housing having a valve head positioned in sealing engagement with a valve seat at an inlet end which is in communication with the pressurized inlet air. The valve also includes a second end carrying a piston of a larger diameter than the valve head. An air inlet bypass bore is formed within the valve body of the handle member, communicating at a first end with the pressurized air channel upstream of the valve head and communicating at its second end with an interior space of the valve housing adjacent to the piston. Positioned in a space between the first and second ends of the air inlet bore is a rotatable trigger shaft which has a bore formed through its diameter which communicates with the aforementioned air inlet bore when the trigger shaft is rotated to a "firing" or activated position. In the activated position, the pressurized air from the inlet is fed to the spaced adjacent to the larger diameter piston causing the valve to unseat instantly, permitting the pressurized air from the reservoir to pass through the valve body into the bore of the barrel and thence to the converging/diverging nozzle. The trigger mechanism is spring-biased to return to the closed position when the operator releases his grip thereon. The trigger shaft is also provided with a vent orifice which communicates with the air inlet bore on the piston side thereof to permit the venting of the by-pass bore when the trigger is returned to its close position. In addition, an air pressure gauge is also preferably provided on the excavator device to insure that proper operating air pressure is maintained. The device is also preferably constructed of a noncorrosive and nonferrous material so that the device is rust resistant and also nonsparking to render it suitable for use in potentially explosive environments. The barrel may also be provided with an elongated pick element, outwardly projecting

beyond the nozzle, to permit the operator to dislodge any stubborn lumps of material during the excavating operation. The barrel of the device may be either a straight length of pipe or it may be fitted with a curved exit section for difficult-to-reach applications.

In addition to permitting excavation around various utility service lines to be effected quickly and safely, the present invention also has application in trenching; clearing plugged silos and chutes; excavating under sidewalks and roads; digging under foundations for underpinning; for cleaing out road potholes prior to patching; and for digging post holes in difficult terrain, and the like.

In a preferred method of the present invention, a reservoir of compressed gas, preferably air, is provided at a pressure of at least about 620 $KNm^{-3}g$ (90 psig). The flow of pressurized air is controlled and directed through appropriate duct or bore means to a converging/diverging nozzle positioned at the discharge end of the duct or bore. The converging/diverging nozzle includes a restricted throat section and a diverging section which terminates in an outlet section. The ratio between the cross-sectional area of the outlet section and the cross-sectional area of the throat section of the nozzle being greater than 1.0 and, preferably, greater than about 1.2, while the ratio of reservoir pressure to exit pressure is greater than about 1.9 and, preferably greater than about 3.7, whereby an air jet exits the nozzle, having a calculated isontropic velocity of greater than Mach 1.0 and, preferably, greater than Mach 1.5. The supersonic air jet is directed to a soil mass or the like, whereupon the jet penetrates the mass, stagnates, then expands and fractures the material. Liquid water or gaseous CO_2 may be introduced into the air stream upstream of the nozzle to produce ice particles or solid CO_2 particles entrained in the supersonic air jet as a result of a rapid temperature incursion when these materials pass through the nozzle.

In order that the invention may be more readily understood, and so that further features thereof may be appreciated the invention will now be described by way of example with reference to the accompanying drawings in which:

FIGURE 1 is a side elevation view of a hand-operated device constructed in accordance with the present invention;

FIGURE 2 is an enlarged cross-sectional view of the handle trigger valve assembly of the device of Figure 1;

FIGURE 3 is a cross-sectional side view of the handle and valve assembly taken along line III-III of Figure 4;

FIGURE 4 is a partial cross-sectional view of the trigger assembly taken along line IV-IV of Figure 2;

FIGURE 5 is a partial cross-sectional side view of a converging/diverging nozzle in place on a barrel with a pick-like tip in place thereon;

FIGURE 6 is a partial cross-sectional side view of a nozzle and barrel similar to Figure 5;

FIGURE 7 is a partial side view of a barrel with an angular discharge section;

FIGURE 8 is a pictorial representation of the hand operated device of the present invention being used in excavating around a buried utility pipe and electrical line;

FIGURE 9 is an enlarged, partial cross-sectional view taken along line IX-IX of Figure 10 showing the details of a converging/diverging nozzle of the type employed in the present invention;

FIGURE 10 is an end view of the nozzle of Figure 9;

FIGURE 11 is a partial plan view of a rectangular nozzle which may be employed in the present invention; and

FIGURE 12 is an end view of the rectangular nozzle of Figure 11.

Referring now to the drawings, wherein like reference numerals indicate the same parts throughout the various views, a hand operated excavator device is shown and designated generally by the reference numeral 2 therein. The excavator device 2 is suited for manual excavation of buried utility lines, such as the utility pipe or conduit 22 or the television, electrical, telephone or like cable 22′ shown in Figure 8. Referring to Figures 1 and 8, the device 2 is operably connected by way of a high pressure air hose 16 to a storage reservoir of high pressure air generated by compressor 20. The air compressor is preferably of a conventional type normally used in construction work and capable of delivering 3.5 cubic metres (125 cubic feet) per minute of air at a reservoir pressure of at least 620 KNm^2g (90 pounds per square inch gauge (psig)) at the outlet. The air hose 16 preferably has a minimum inside diameter of about 2.54 cms (1 inch) in order to handle the air volume required for the intended excavating purposes. Device 2 is operably connected to the air hose 16 by way of a conventional quick disconnect coupling 18 which may be threadably fitted to the handle member 10 at the base of conduit 24. (see Figures 2 and 3). The device 2 further includes a control valve body 4 with a trigger mechanism 12 for controlling the flow of high pressure air therethrough. The device 2 also includes a converging/diverging nozzle 50 fitted within a bore 7 of barrel 6 at the outlet end 8 thereof. As will be explained in detail hereinafter, the ratio of the outlet diameter to throat diameter of the nozzle 50, at a given supply pressure of air from the compressor 20, will produce a

choked sonic flow condition at the nozzle throat and supersonic air flow in the diverging section at the outlet of the nozzle 50 which provides the required energy for excavating. The device 2 also preferably contains a handle 14 for convenient gripping by the operator and also a pressure gauge 21 mounted on the rear face of the valve body 4 to enable observation of the operating air pressure.

The valve mechanism for regulating the flow of high pressure air through the hand operated excavation device 2 is depicted in Figures 2, 3 and 4. The conduit 24 has a bore 25 which communicates with air hose 16 and with the high pressure air within the reservoir generated by compressor 20. Conduit 24 is fitted within handle 10 and attached to the valve body 4 by way of threads, soldering, or the like to create an airtight fit therewith. Valve body 4 has an internal bore 5 extending therethrough in a generally T-shaped configuration from the inlet end adjacent conduit 24 to the outlet end adjacent the barrel 6. Barrel 6 has a bore 7 which is also in communication with the bore 5 of the valve body. Barrel 6 is rigidly attached to the valve body 4 in an airtight manner by sleeve fitting 82 which is secured by way of threaded section 83 to the valve body 4. A pair of O-rings seals 84 and 86 are provided around the sleeve fitting 82 and the barrel 6 to provide a mechanically strong and airtight seal.

The high pressure inlet air within the bore 25 is sealed-off from the bore 7 of the barrel by way of a valve member 28 which is movably positioned within the bore 5 of the valve body. Valve 28 includes a head portion 30 having a tapered edge which sealably engages the seat 34 of a venturi-type sleeve 32 which is seated within the bore 5. Sleeve 32 has a cylindrical bore formed therethrough which is sealed off when the valve 30 is in the closed position shown in Figure 2. In the closed position, the tapered edge of the valve head 30 sealably engages tapered valve seat 34 to prevent pressurized air from entering the barrel bore 7. A generally cylindrical piston 38 is mounted on valve stem 36 of the valve 28 at the opposite end from the head 30. Piston 38 is slidably positioned within a chamber 80 formed within the upper portion of the valve body 4 and is secured to the valve stem 36 by a nut and washer 40. The piston 38 also preferably contains an annular cutout portion 44 formed in the underside thereof to receive a coil spring 42 therein. A cylindrically shaped valve guide 46 is fitting within the valve body 4 and tightly receives the valve stem 36 therethrough. An O-ring 48 is fitted within the valve guide 46 to prevent air leakage around the moving valve stem which slidably moves therein. The coil spring 42 compressively engages the top of the valve guide 46 and the bottom of the piston 38 within portion 44 to bias the valve 28 and the attached head portion 30 to a closed position against the sealing seat 34 of the sleeve 32. An O-ring 47 is also provided around the periphery of the piston 38 to minimize air leakage therearound.

In the closed position depicted in Figure 2, the valve head 30 is firmly held in place against the valve seat 34 by the high pressure in the bore 25. By way of example, if the area of the valve head 30 is 6.45 sq cms (1 square inch) and the inlet pressure within the bore 25 is 689 KNm^{-2}gauge (100 psig), then a force of greater than 45 Kg (100 pounds) is required to unseat the valve head 30 to permit air to enter into the bore 7 of the barrel 6. In order to assist in overcoming the relatively large unseating force required to open the valve 28, a control valve is provided which is operated by pilot air pressure from the main air supply within the conduit 25. The pilot air flow is controlled by movement of the trigger mechanism 12 which is ported to selectively permit the air to enter the exhaust depending on the position of the trigger 12. The valve body 4 has a small diameter air inlet bore 62 formed therein which communicates with the bore 5 at one end thereof and is adapted to communicate with a first end of bore 64 formed in the cylindrical trigger shaft 26. When the trigger is in the deactivated position shown in Figure 2, the bore 64 does not communicate with the bore 62; hence, no pressurized pilot air is supplied to open the valve 28. In the activated position of Figure 3, the trigger 12 and its integral shaft 26 rotate in a counterclockwise direction to align the bores 62 and 64 to permit the flow of pilot air therethrough.

The valve body 4 also contains a bore 66 which is formed therein to communicate with the second end of bore 64 of the trigger shaft when the trigger 12 is in the activated position. Bore 66 communicates with a vertically extending bore 68 also formed within the body 4 which, in turn, communicates with a transversely extending bore 70 which communicates with circumferentially extending grooves 72 which are formed around the cylindrical outer sidewall of the sleeve 32 which, thence, communicate with a bore 74. Bore 74 communicates with a bore 76, also formed within the valve body 4, which, in turn, communicates with a passage 78 near the top of the valve body 4. Passage 78 communicates with the chamber 80 above the piston 38 of the valve 28. The surface area of the face of piston 38 which is exposed to chamber 80 is greater than that of the valve head 30. Hence, when the trigger 12 is in the activated position of Figure 3, pilot air, at line pressure, is supplied through bores 62, 64, 66, 68, 70, 72, 74, 76, 78 to the chamber 80. Chamber 80 is likewise contained within an airtight closure by way of a threaded cap 45 and an O-ring seal 49 affixed to the valve body 4. The pressurized pilot air supplied through the activation of the trigger 12 will cause the immediate downward movement of the valve 28 due to the unbalanced forces acting on the valve. Movement results from the fact that the surface area of the piston 38 is greater than that of the valve

head 30. Downward movement of valve 28 causes the valve head to unseat and permits the pressurized air from compressor 20 within the bores 25 and 5 to enter into the bore 7 of the barrel 6, and, thence, to the nozzle 50 and outlet 8 of the device 2.

When the trigger mechanism 12 is deactivated as in Figure 2, the pressurized air within the chamber 80 is vented through the aforementioned bores 78, 76, 74, 72, 70, 68, 66 and, thence, through bores 87 and 88 formed within the trigger shaft 26 which, in turn, communicate with a bore 89 formed within the valve body 4. Hence, the pressurized air within the chamber 80 above the piston 38 is instantaneously vented to the atmosphere when the trigger mechanism is deactivated to permit the valve head 30 to instantaneously move upwardly to seat against the sealing surface 34 of the sleeve 32 to halt the air flow through the device 2.

As seen in Figure 4, the trigger mechanism 12 and trigger shaft 26 are biased outwardly in the deactivated position by way of a torsion spring 27 which is attached to the trigger shaft 26. Pressurized air leakage from the bores 64 and 70 is minimised through a plurality of O-rings 33, 35 and 35′ which are fitted within slots formed in the periphery of the trigger shaft 26 to sealably engage against seating bore 37 formed within the valve body 4. A pair of cover plates 29 and 29' are secured to the valve body 4 by way of threaded fasteners 31. The plates 29, 29' seal the trigger shaft 26 and bore 64 of the valve mechanism against the environment. The only acess to the interior of the valve is through the small diameter pilot exhaust port (not shown) which blocks the entry of dust by emitting a constant stream of outflowing air which seeps between the inner face of the trigger shaft 26 and the seating bore 37 of the valve body 4. The valve body 4 also is fitted with a conventional air pressure gauge 21 which is mounted at the rear face of the body 4, operably attached to a bore 23 which communicates with the interior 5 of the valve body to permit the operator to monitor the line pressure when the device 2 is in use. If the pressure drops below a certain value, for example, 620 KNm^{-2}gauge (90 psig) the operator is alerted to take corrective action to ensure that the air compressor is operating properly.

The materials of construction of the valve body 4, the internal valve components and trigger assembly, as well as the barrel 6, are preferably of non-corrosive materials such as cast bronze, stainless steel, or high impact plastic. In situations where sparks may create an explosion hazard around natural gas fumes, the barrel 6 as well as the tip 58 may be constructed of a nonferrous, non-sparking material such as bronze. The gripping portions of the device 2, handles 10 and 14, may be constructed of a hard rubber, plastic, hard wood, or like material.

Referring to Figures 5-7 the outlet end 8 of the supersonic excavator device 2 may be provided with variously shaped fittings suitable for the particular work involved. Figures 1 and 5 show the outlet end 8 fitted with a pick-like tip 58 to permit the operator to loosen lumps of unusually stubborn material with the sharpened tip thereof. The barrel 6 may be straight or it may contain a curved or angled section 60 at the outlet end 8 thereof as shown in Figure 7. The curved section 60 provides additional manoeuverability in the device for difficult to reach tunneling applications and in areas beneath pipes and conduits.

The converging/diverging nozzle 50 is firmly attached, as for example, by silver solder or fine threads, to the end of the barrel 6 such that the inlet end 52 of the converging section of the nozzle smoothly blends with the bore 7 of the barrel. The converging section gradually tapers to a throat section 54 which presents the minimum diameter within the nozzle. The nozzle then gradually increased in diameter to terminate at an outlet portion 56. The nozzle 50 has a reduced outer diameter section 51 near its inlet end 52, which is snugly received within the bore 7 of the barrel 6. If the pick-like tip 58 is employed, as in Figure 5, the nozzle 50 has a second reduced outer diameter section 53 formed around the outlet end 56 thereof, to permit the attachment of the tip 58 thereto. Attachment can be made by a solder or threaded joint or the like.

In the science of fluid mechanics, it is known that the maximum flow rate for an ideal gas in frictionless adiabatic or isotropic flow (without heat addition or substraction) through a converging nozzle is at a Mach number of one, which occurs at the minimum section, i.e. at the throat of the nozzle. The Mach number is defined herein as the ratio of velocity of the air jet at the outlet 56 of the nozzle 50 to the velocity of sound at that point. It is also known that supersonic flow will occur if the nozzle area downstream from the nozzle throat increases, thus forming a converging/diverging nozzle of the type employed in the present invention. Hence, it is known in the field of fluid mechanics that it is possible to obtain supersonic steady flow from a gas, such as air at rest in a reservoir, by first passing it through a converging nozzle section and then a diverging nozzle section. it is also known that the Mach number achieved by an air jet at the outlet of a converging/diverging nozzle is influenced by a number of variables, such as the boundary conditions of pressure, namely, the supply pressure and the ambient or atmospheric pressure, as well as by the ratio of the area of the outlet to the area of the throat of the nozzle. When the supply pressure reaches a given threshold value, a choked sonic flow condition is achieved at the throat of the nozzle, indicated as 54 in the

drawings. The gas undergoes isotropic expansion from the sonic condition at the throat 54 to the diverging section 55 of the nozzle wherein the flow enters the supersonic regime, assuming the pressure and temperature conditions are satisfied.

In order to reach the sonic threshold, it is thus necessary to provide a ratio of the area at outlet 56 to the area of the throat 54 greater than the value 1. Through known formulas and sets of calculations, tables have been created which list certain nozzle ratios which are needed to achieve a given Mach value at given pressure and temperature ratios for the isotropic flow of dry air through a converging/diverging nozzle section. Higher Mach numbers are achieved as the ratio of the reservoir pressure to local pressure increases. Table 1 is illustrative of this principle, for the isotropic flow of dry air:

TABLE 1

Mach No.	Po/P	A/A*
1.0	1.895	1.00
1.5	3.675	1.176
2.0	7.830	1.685
2.5	17.075	2.629
3.0	36.644	4.213
3.5	75.926	6.739
4.00	150.796	10.612

where: Po = Reservoir pressure
p = Ambient pressure at exit
A = Area of nozzle at outlet
A*= Area of nozzle at throat

It has now been surprisingly discovered that a gas stream, such as air, travelling at a velocity greater than Mach 1 provides a surprisingly effective medium for excavating soil or other granular materials due to its ability to create and infiltrate small fissues and cavities therein. It is hypothesized that the supersonic jet penetrates the soil structure until complete stagnation occurs within these local cavities which, in effect, act as reservoirs for the momentary storage of high pressure, decelerated air. The stagnated air must then expand and, in so doing, causes the soil to fracture in tension, its weakest directional attribute. These local reservoir sites of high pressure provide the energy source for the final fracture of the material in tension and the nearly instantaneous initiation of a pneumatic explosion due to the rapid expansive release of high pressure air to the atmosphere. It is thus understood that the present invention provides a method and apparatus for transferring the pressure energy produced by the air compressor 20 to a local excavation site where its destructive power is utilised and further provides, through its large momentum flux, the aforementioned cavities for the instanteous storage and release of such pressure energy.

In order to illustrate the above principle, a nozzle suitable for use in soil excavation in accordance with the present invention is shown in greater detail in Figures 9 and 10. Nozzle 50 is circular in cross section and includes an inlet 52 having a bore diameter equal to that of the barrel 7 which may, in this example, be about 2.22 cms (0.875 inch). The nozzle profile then converges to the throat section 54, with a diameter "A" of, for example, 0.64 cms (0.250 inch). The nozzle bore then gradually expands in the diverging section 55. By way of further example, dimension "D" may be 0. 68 cms (0.269 inch) where "E" is equal to 0. 44cms (0.172 inch). The illustrative nozzle outlet 56 diameter is represented by dimension "B" which is 0. 72 cms (0.283 inch). Dimension "C", the distance between the throat 54 and the outlet 56 is, in this example, 1.08

cms (0.425 inch). Utilizing a compressor 20 having a flow rate capacity of 68 g/sec (0.15 lb/sec) at a reservoir pressure to ambient pressure ratio n(Po/P) of about 4.5, at 21 ° C (70 ° F) ambient temperature, calculations demonstrate that the above-dimensioned nozzle 50 is capable of producing a supersonic jet of air at a velocity of about Mach 1.64. Once again, the calculations are based on the assumption that the flow is isentropic, i.e. the flow takes place without friction and without heat addition or subtraction. The tests indicate that a circular nozzle is advantageous over other shapes with respect to the frictional effects in relation to stand-off distance versus flow decay. It has also been determined that there appears to be a threshold pressure below which many soils are not amenable to efficient excavation. This threshold pressure appears to be about 551 KNm^{-2}gauge (80 psig). Dramatic increases in excavation capability result as the reservoir pressure (Po) is increased, with a 25% improvement having been observed in going from 55 KNm^{-2}gauge (80 psig) to 689KNm^{-2}gauge (100 psig).

The profile of the supersonic jet can be changed from the above-described circular shape to a square or rectangular shape if desired. Figures 11 and 12 depict a nozzle 94 which is capable of producing a rectangularly shaped, supersonic air stream which finds application in cleaning flat surfaces, as for example, conveyor belts which transport bulk materials. Nozzle 94 includes a body 95 with tapered side plates 102 and 102' with a tapered divider plate 104 disposed therebetween. The plates 102, 102' and 104 are held in place by cover plates 101 and 103 which are secured by fasteners 106. As seen in Figure 11, the tapered plates 102 and 104 form a converging nozzle section 98, a throat at 96 and a diverging section which terminates at outlet 100. An identical shape is formed adjacent thereto by tapered plates 102' and 104 with a rectangularly shaped jet of air emitted from outlet 100'. In operation, the side by side jets exiting from outlets 100 and 100' would merge together a short distance from the nozzle to provide a single, thin knife-like profile ideally suited for cleaning operations where soil or other caked or lodged materials must be removed from flat surfaces. The same ratios of outlet area to throat area apply to the rectangular nozzle 94 as previously discussed in relation to the circular nozzle 50.

In still another embodiment of the invention, as shown in Figure 6, a substance which solidifies upon cooling, such as liquid water or gaseous carbon dioxide, may be introduced into the bore 7, ahead of the nozzle 50′, through a feed passage 59, shown in phantom lines in the drawing. A water mist or stream of gaseous carbon dioxide from passage 59 is entrained within the air stream and is nearly instantaneously solidified as it passes through the converging/diverging nozzle 50′ due to the great temperature decrease which naturally occurs as the air stream is accelerated through the nozzle. Ice particles or solid CO_2 particles are then emitted with the high velocity jet of air to provide an additional abrasive aid in excavating and cleaning applications. As used herein, the terms "excavating" and "cleaning" may be used interchangeably with respect to the intended use environment for the invention. It can be appreciated that carbon dioxide is a unique additive since it presents no residue or disposal problems after it desolidifies.

In order to further demonstrate the effectiveness of the invention, a test was run in the field comparing the manual device 2 of the present invention with conventional hand work using a pick and shovel. For purposes of comparison, three common types of excavation holes were made, namely, a face notch, a vertical hole, and a horizontal tunnel. The results are reported in the percent improvement in the volume of material excavated in the same time period for the device 2 of the present invention over conventional hand work. These results are set for in Table II.

TABLE II

Type of Excavation	% Improvement Air Jet v. Hand Work
Face Notch	260%
Vertical Hole	240%
Tunneling	327%

The test reported in Table II was run at a calculated air jet velocity of Mach 2 with an air compressor 20 running at about 689 KNm^{-2}gauge (100 psig). Hence, from the above results, the advantages of the present

invention over commonly employed hand work methods are readily apparent.

It is further apparent to those skilled in the art that the hand-operated device 2 can be modified so as to be fitted on a piece of mechanized digging equipment such as a backhoe or the like. It is also understood that apparatus according to the present invention can be incorporated into automated robotic digging equipment, for which the invention is particularly suited. In such applications, it would, of course, be desirable or necessary to modify the valve mechanism from hand-actuated to a pneumatic, hydraulc or like actuation means.

While specific embodiments of the invention have been described in detail, it will be appreciated by those skilled in the art that various modifications and alternatives to those details could be developed in light of the overall teachings of the disclosure.

Claims

1. A method of moving or dislodging a soil mass or similar granular material mass to effect excavation or cleaning, said method comprising the steps of directing, at said soil mass or like granular material mass a jet of gas characterised in that said jet has a velocity greater than Mach 1, and in that the jet is created by passing a stream of pressurized gas through a converging/diverging type nozzle having a ratio of outlet area section(56) to throat area section(54) of greater than 1 so that the velocity of the gas stream is greater than Mach 1 at the outlet.

2. A method according to Claim 1 wherein the gas is air.

3. A method according to Claim 1 or 2 wherein the ratio of pressure of the pressurized gas to ambient pressure is between 1.895 and 150.796.

4. A method according to any one of the preceding Claims wherein the gas stream is obtained from a source of gas having a pressure greater than 620 KN m^{-2} gauge.

5. A method according to any one of the preceding Claims wherein the gas stream has, incorporated in it, prior to the gas stream being accelerated to supersonic speed, a substance which solidifies on cooling, to form particles which are emitted with the said jet.

6. An apparatus for dislodging a soil mass or a similar granular material mass to effect excavation or cleaning, said apparatus comprising a source (20) of pressurized gas, a duct(6), communicating with said source of pressurized gas and a nozzle (50), characterised in that the nozzle is of the converging/diverging type having a throat section (54) and an outlet section (56), each of said sections defining a respective cross-sectional area, the ratio of the outlet section area to the throat section area being greater than 1.0 whereby said apparatus is adapted, in use, to produce a stream of gas at a velocity of greater than mach 1 when pressurized gas from the reservoir passes through the nozzle.

7. An apparatus according to Claim 6 comprising means (59) for introducing, into the duct, upstream of the nozzle (50), a liquid or gaseous material which solidifies on cooling.

8. An apparatus according to Claim 6 or Claim 7 wherein valve means (4) are provided, associated with the duct means (6), adapted to regulate the flow of gas from the gas source (20) to a nozzle (50), the valve means comprising a valve body having a bore (5) therethrough, positioned in communication with said duct (6) and with source of gas (20), said valve means further including a valve member (28) having a head portion (30) and a piston portion (38) interconnected by a stem (36), said head portion cooperating with a valve seat (34) to cut off the supply of pressurized gas to said nozzle when said valve is in a deactivated position, said valve means further including a pilot bore (66, 68, 70, 72, 74, 76, 78) adapted to communicate between the source of pressurized gas and the piston portion of the valve when said valve means is in an activated position, whereby said pressurized gas is adapted to pass through said pilot bore means to act on said piston portion to move said valve member and cause said head portion to unseat and permit the flow of pressurized gas to the nozzle.

9. An apparatus according to Claim 8 wherein the valve means (4) includes trigger means (12) including a rotatable cylindrical portion (26) having a pilot port (64) therethrough which is adapted to communicate with said pilot bore (66, 68, 70, 72, 74, 76, 78) means when said trigger means is in an activated

position to permit pressurized gas to flow therethrough to unseat said valve head, and adapted to close off said pilot bore means when said trigger means is in a deactivated position.

10. An apparatus according to Claim 9 wherein the cylindrical portion (26) of the trigger means (12) also has a vent port (87, 88) formed therein to permit the escape of pressureized gas from the pilot bore means to the atmosphere when the trigger means is moved to the deactivated position.

Patentansprüche

1. Verfahren zum Bewegen oder Entfernen von Erdreich oder ähnlichem körnigen Material zum Zwecke des Aushebens oder Reinigens, wobei das Verfahren den Verfahrensschritt des Richtens eines Gasstromes auf das Erdreich oder dergleichen körnige Material beinhaltet, dadurch **gekennzeichnet,** daß der Gasstrom eine Geschwindigkeit von mehr als Mach 1 hat und daß der Gasstrom dadurch erzeugt wird, daß eine Strömung unter Druck stehenden Gases durch eine Auslaßöffnung vom konvergierenden/divergierenden Typ mit einem Verhältnis von Auslaßquerschnittsfläche (56) zu Einschnürquerschnittsfläche (54) von mehr als 1 durchgeführt wird, so daß die Geschwindigkeit des Gasstromes an dem Auslaß größer als Mach 1 ist.

2. Verfahren nach Anspruch 1, wobei das Gas Luft ist.

3. Verfahren nach Anspruch 1 oder 2, wobei das Verhältnis des Drucks des unter Druck stehenden Gases zu dem Umgebungsdruck zwischen 1,895 und 150,796 liegt.

4. Verfahren nach einem der vorangehenden Ansprüche, wobei der Gasstrom von einer Gasquelle stammt, die einen Manometerdruck von mehr als 620 kNm^{-2} aufweist.

5. Verfahren nach einem der vorangehenden Ansprüche, wobei der Gasstrom in sich selbst, bevor der Gasstrom auf Überschallgeschwindigkeit beschleunigt wird, eine Substanz erhält, welche bei Abkühlung härtet, um Partikel auszubilden, die mit dem Gasstrom herausgeschleudert werden.

6. Vorrichtung zum Entfernen von Erdreich oder ähnlichem körnigen Material zum Zwecke des Aushebens oder Reinigens, mit einer Quelle (20) unter Druck stehenden Gases, einem Kanal (6), der mit der Quelle unter Druck stehenden Gases und einer Auslaßöffnung (50) in Verbindung steht, dadurch **gekennzeichnet,** daß die Auslaßöffnung vom konvergierenden/divergierenden Typ mit einem Einschnürungsbereich (54) und einem Auslaßbereich (56) ist, wobei jeder der Bereiche einen entsprechenden Querschnitt aufweist und das Verhältnis des Querschnitts des Auslaßbereiches zu demjenigen des Einschnürungsbereiches größer als 1,0 ist, wodurch die Vorrichtung beim Gebrauch dazu geeignet ist, einen Gasstrom mit einer Geschwindigkeit von mehr als Mach 1 zu erzeugen, wenn unter Druck stehendes Gas von dem Reservoir die Auslaßöffnung durchströmt.

7. Vorrichtung nach Anspruch 6, mit Mitteln (59) zum Hineingeben in den Kanal, stromaufwärts von der Auslaßöffnung (50), eines Liquids oder eines gasförmigen Mediums, das beim Abkühlen härtet.

8. Vorrichtung nach Anspruch 6 oder 7, wobei Ventilmittel (4) vorgesehen sind, welche den Kanalmitteln (6) zugeordnet sind und den Gasstrom von der Gasquelle (20) zu einer Auslaßöffnung (50) überwachen, wobei die Ventilmittel einen Ventilkörper mit einer Durchgangsbohrung (5) darin umfassen, angeordnet in Verbindung mit dem Kanal (6) und der Gasquelle (20), wobei die Ventilmittel ferner ein Ventilteil (28) mit einem Kopfabschnitt (30) und einem Kolbenabschnitt (38) beinhalten, wobei die beiden Abschnitte über einen Stößel (36) miteinander verbunden sind und der Kopfabschnitt mit einem Ventilsitz (34) zusammenarbeitet, um die Versorgung der Auslaßöffnung mit unter Druck stehendem Gas zu stoppen, wenn das Ventil in nicht-aktivierter Position steht, wobei die Ventilmittel ferner eine Führungsbohrung (66, 68, 70, 72, 74, 76, 78) umfassen, welche die Quelle unter Druck stehenden Gases mit dem Kolbenabschnitt des Ventiles verbindet, wenn die Ventilmittel in aktivierter Position sind, wodurch das unter Druck stehende Gas die Führungsbohrung passieren kann, um auf den Kolbenabschnitt einzuwirken, so daß das Ventilteil bewegt und es dem Kopfabschnitt erlaubt wird, sich von dem Sitz zu lösen und es dem unter Druck stehenden Gas zu erlauben, zu der Auslaßöffnung zu strömen.

9. Vorrichtung nach Anspruch 8, wobei die Ventilmittel (4) Triggermittel (12) umfassen, beinhaltend einen

drehbaren zylindrischen Abschnitt (26) mit einer Führungsöffnung (64) darin, welche mit der genannten Führungsbohrung (66, 68, 70, 72, 74, 76, 78) in Verbindung steht, wenn die Triggermittel in aktivierter Position stehen, um es dem unter Druck stehenden Gas zu erlauben hindurchzuströmen, um den Ventilkopf vom Sitz zu lösen, und welche die genannten Führungsbohrungsmittel abtrennt, wenn die Triggermittel in nicht-aktivierter Position stehen.

10. Vorrichtung nach Anspruch 9, wobei der zylindrische Abschnitt (26) der Triggermittel (12) ferner eine Lüftungsöffnung (87, 88) darin umfaßt, um es unter Druck stehenden Gas zu erlauben, von der Führungsbohrung in die Atmosphäre zu entweichen, wenn die Triggermittel in die nicht-aktivierte Position gebracht sind.

Revendications

1. Procédé pour déplacer ou déloger une masse de terre ou une masse similaire de matériau granulaire, pour effectuer une excavation ou un nettoyage, ledit procédé comprenant les étapes de diriger, au niveau de ladite masse de terre ou de la masse analogue de matériau granulaire, un jet de gaz, caractérisé en ce que ledit jet possède une vitesse supérieure à 1 Mach, et en ce que le jet est créé en faisant passer un flux de gaz pressurisé à travers une tuyère de type convergente/divergente ayant un rap ort de la section de surface de sortie (56) à la section de surface d'étranglement (54) supérieur à 1, de sorte que la vitesse du flux de gaz est supérieure à 1 Mach au niveau de la sortie.

2. Procédé selon la revendication 1 dans lequel le gaz est l'air.

3. Procédé selon la revendication 1 ou 2 dans lequel le rapport de la pression du gaz pressurisé à la pression ambiante se situe entre 1.895 et 1 50.796.

4. Procédé selon l'une quelconque des revendications précédentes dans lequel le flux de gaz est obtenu à partir d'une source de gaz ayant une pression supérieure à la jauge 620 KN m_{-}^{2}.

5. Procédé selon l'une quelconque des revendications précédentes dans lequel le flux de gaz possède, incorporée en lui, avant que le flux de gaz ne soit accéléré à une vitesse supersonique, une substance qui se solidifie par refroidissement, pour former des particules qui sont émises avec ledit jet.

6. Dispositif pour déloger une masse de terre ou une masse similaire de matériau granulaire, pour effectuer une excavation ou un nettoyage, ledit dispositif comprenant une source (20) de gaz pressurisé, un conduit (6), communiquant avec ladite source de gaz pressurisé et une tuyère (50), caractérisé en ce que la tuyère est du type convergente/divergente ayant une section d'étranglement (54) et une section de sortie (56), chacune desdites sections définissant une surface de section transversale respective, le rapport de la surface de la section de sortie à la surface de la section d'étranglement étant supérieur à 1,0, par quoi ledit dispositif est adapté, en fonctionnement, pour fournir un jet de gaz d'une vitesse supérieure à 1 Mach quand le gaz pressurisé à partir du réservoir passe à travers la tuyère.

7. Dispositif selon la revendication 6 comprenant des moyens (59) pour introduire, dans le conduit, en amont de la tuyère (50), un matériau liquide ou gazeux qui se solidifie par refroidissement.

8. Dispositif selon la revendication 6 ou la revendication 7 dans lequel des moyens de soupape (4) sont prévus, associés avec les moyens de conduit (6), adaptés pour réguler le flux de gaz allant de la source de gaz (20) vers une tuyère, les moyens de soupape comprenant un corps de soupape ayant un trou (5) à travers lui, placé en communication avec ledit conduit (6) et avec la source de gaz (20), lesdits moyens de soupape incluant de plus un élément de vanne (28), comportant une partie de tête (30) et une partie piston (38) interconnectées par une tige (36), ladite partie de tête coopérant avec un siège de soupape (34) pour interrompre la fourniture de gaz pressurisé à ladite tuyère quand ladite soupape est dans une position de fermeture, lesdits moyens de soupape incluant de plus un trou de guidage (66,68,70,72,74,76,78) adapté pour communiquer entre la source de gaz pressurisé et la partie piston de la soupape quand lesdits moyens de soupape sont dans une position d'ouverture, par quoi ledit gaz pressurisé est adapté pour passer à travers lesdits moyens de trou de guidage pour agir sur ladite partie piston pour déplacer ledit élément de soupape et entrainer ladite partie piston à ouvrir la

soupape et permettre l'écoulement du flux de gaz pressurisé vers la tuyère.

9. Dispositif selon la revendication 8 dans lequel les moyens de soupape (4) incluent des moyens de déclenchement (12) comportant une partie cylindrique, capable de tourner (26), ayant à travers elle un orifice de guidage (64) qui est adapté pour communiquer avec lesdits moyens de trou de guidage (66,68,70,72,74,76,78) quand lesdits moyens de déclenchement sont dans une position d'ouverture pour permettre au gaz pressurisé de s'écouler à travers lui pour ouvrir ladite tête de soupape, et adapté pour fermer lesdits moyens de trou de guidage quand lesdits moyens de déclenchement sont dans une position de fermeture.

10. Dispositif selon la revendication 9 dans lequel la partie cylindrique (26) des moyens de déclenchement (12) possède également, formé à l'intérieur, un orifice d'évacuation 87,88 pour permettre l'évacuation du gaz pressurisé issu des moyens de trou de guidage vers l'atmosphère quand les moyens de déclenchement sont déplacés vers la position de fermeture.

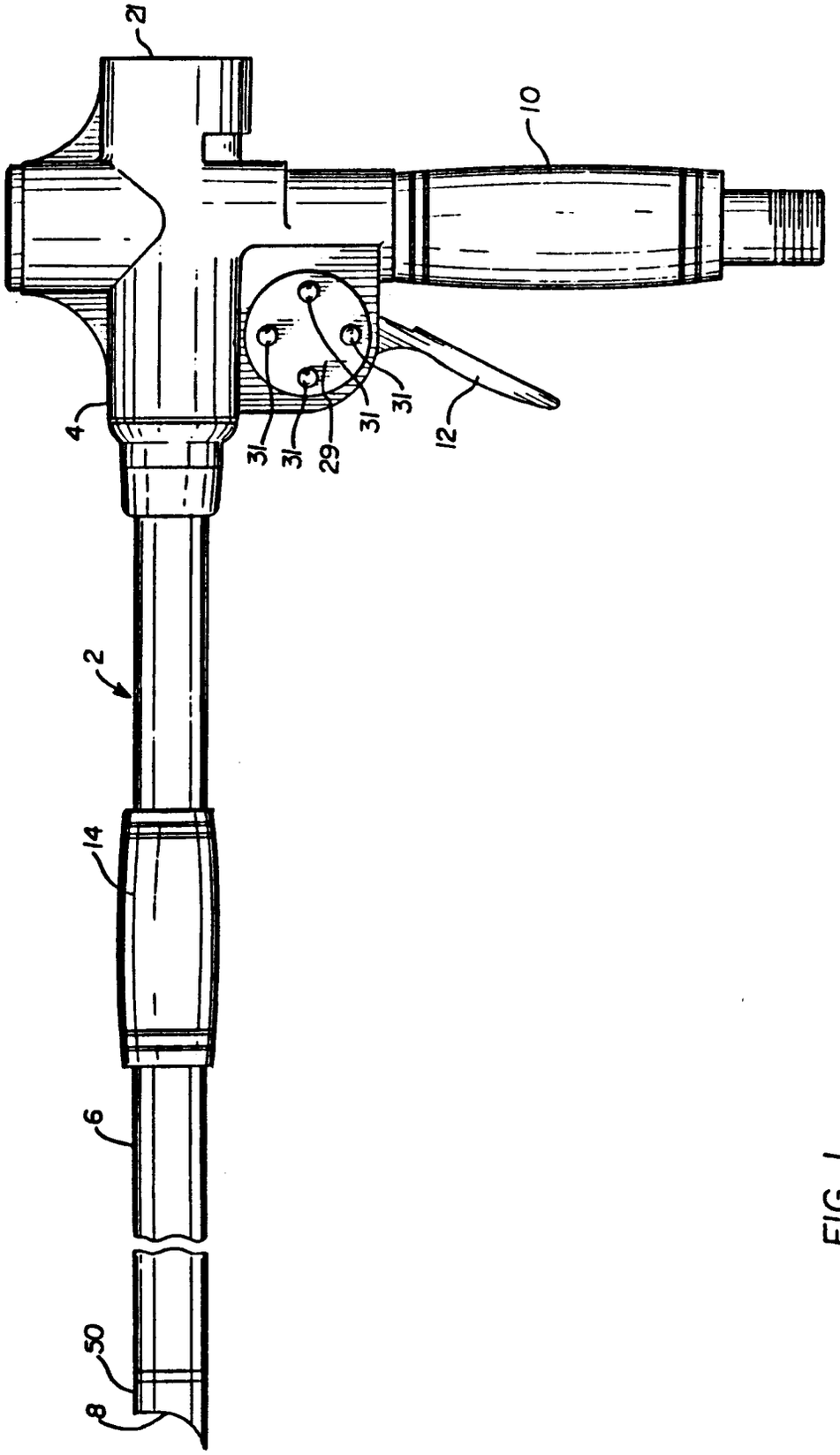


FIG. 1

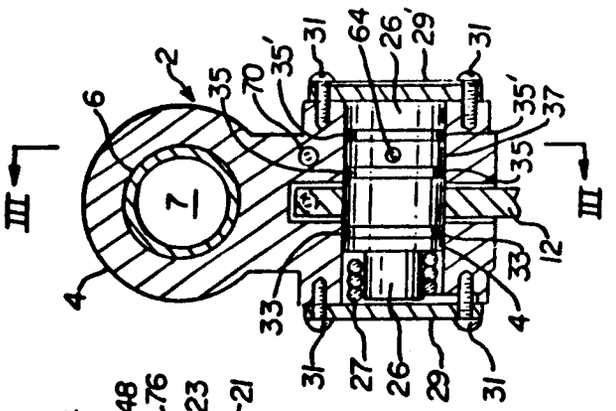


FIG. 4

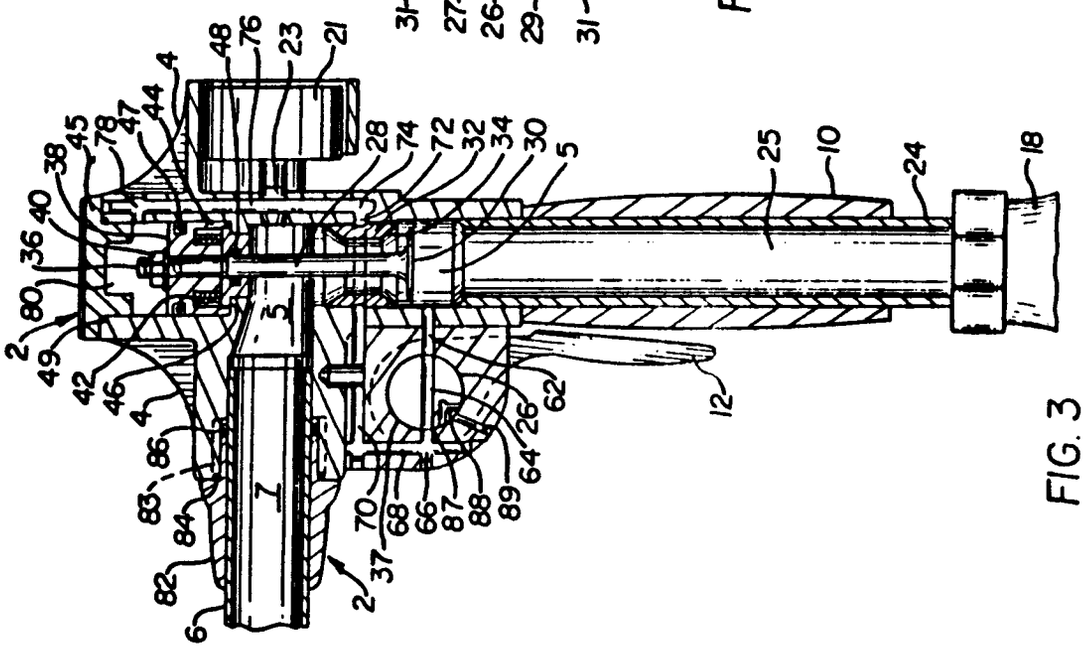


FIG. 3

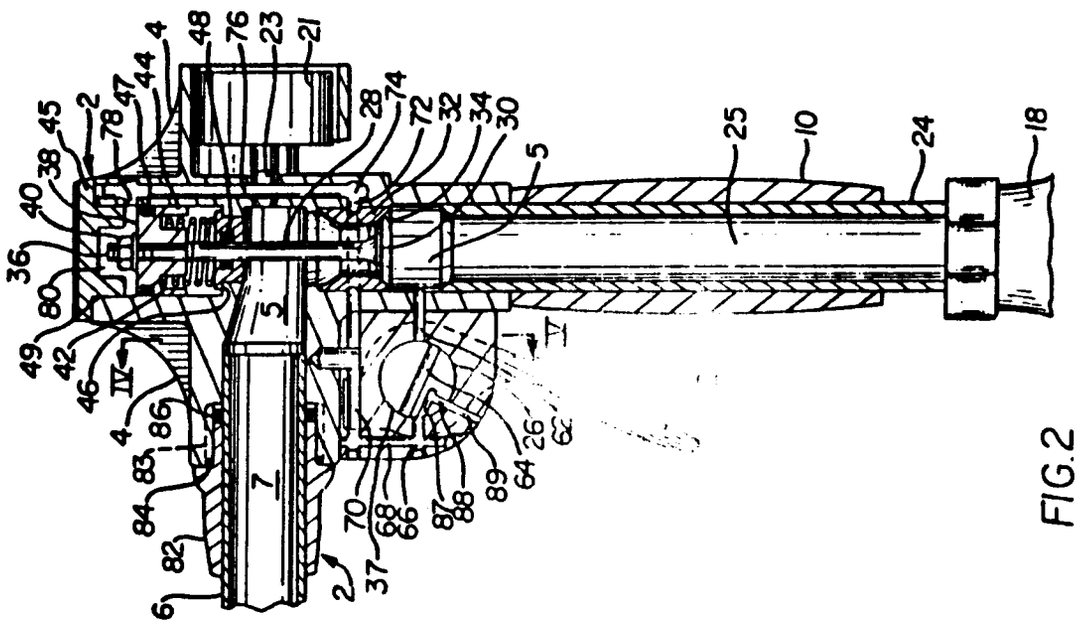


FIG.2

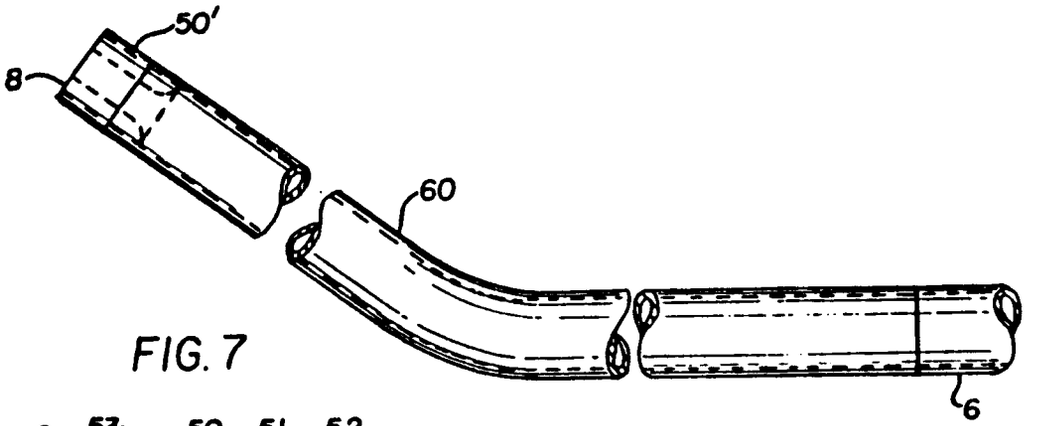


FIG. 7

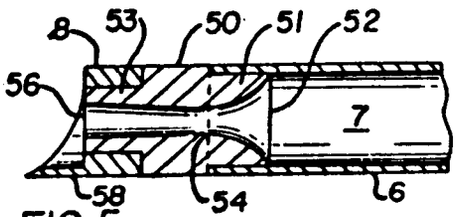


FIG. 5

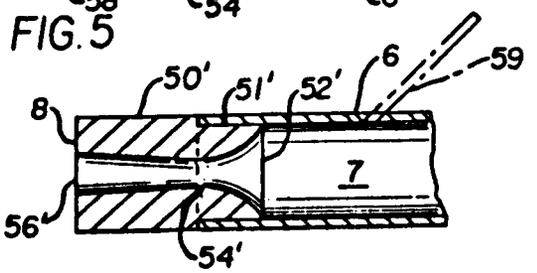


FIG. 6

FIG. 8

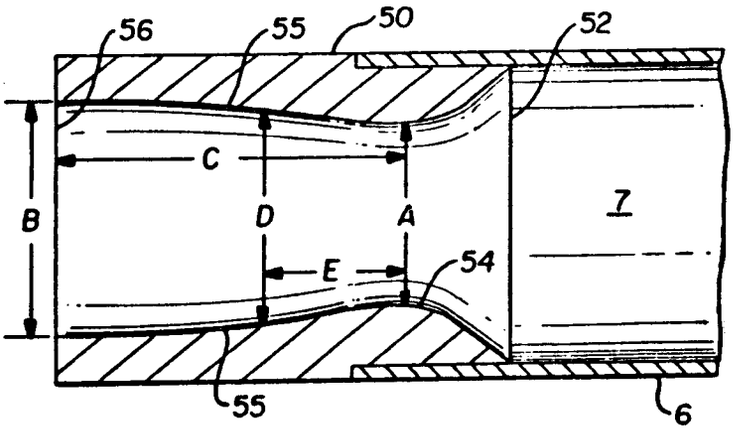


FIG. 9

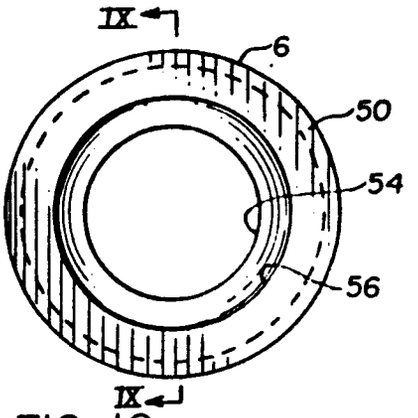


FIG. 10

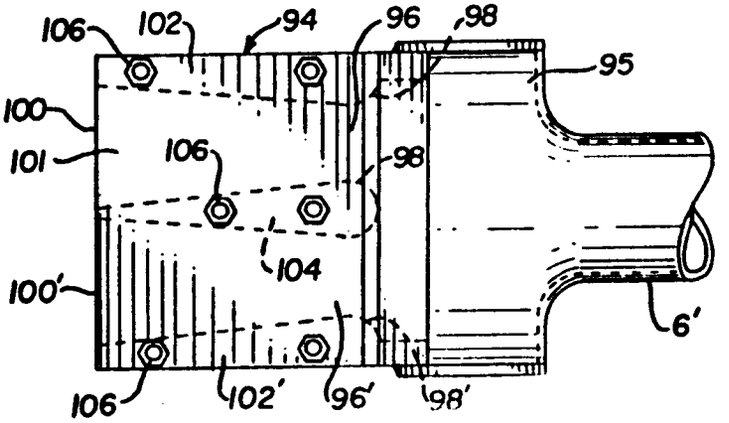


FIG. 11

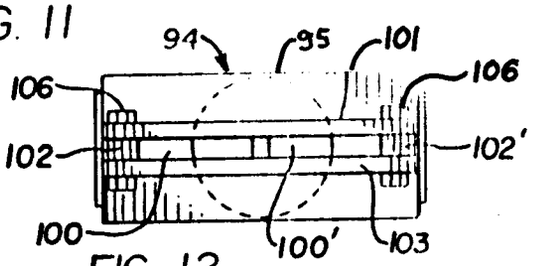


FIG. 12