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1 Navy Case No. 72,461

2 LAUNCHING PROJECTILES WITH HYDROGEN GAS
3 GENERATED FROM TITANIUM-WATER REACTIONS

4 BACKGROUND OF THE INVENTION

5 This invention relates to methods of generating gases
6 and more particularly to methods of generating hydrogen
7 gas.

8 Acceleration of projectiles launched from gun, rocket,
9 and missile systems is limited by the sonic velocity of gas
10 products from propellants. Conventional gun propellants
11 (nitrocellulose) generate heavy gases like carbon dioxide,
12 carbon monoxide, nitrogen oxide, and water vapor whose
13 sonic velocity seldom exceeds 500 m/sec at ambient
14 temperature. The maximum speed of projectiles launched
15 from gun barrel by such gases barely reaches 1 km/sec. *Actual*

16 Hydrogen gas which outspeeds any other gases (under
17 same pressure and temperature), owing to its low molecular
18 weight, is an ideal fluid to impart its kinetic energy
19 efficiently to a projectile. For this reason hydrogen gas
20 is used in a two-stage gas gun (1) that launches a
21 projectile to hypervelocity (over 6 km/sec). This type of
22 gun is operated by a two step process. In the first stage,
23 gun powder charge is ignited to drive a piston against
24 hydrogen gas stored in a gas reservoir. In the next stage,
25 the rise of hydrogen gas pressure due to the compression
26 eventually actuates a valve mechanism at the base of the
27 launch barrel and pressurized hydrogen is released to push
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1 a projectile. Besides this multi-staged pressurization,
2 the whole operation of the device also includes storing of
3 the gas nearby and mechanisms for its transfer to the
4 reservoir. Although the staged gas gun routinely increases
5 the projectile velocity up to 7 km/sec, the complexity of
6 the operation makes it cumbersome and impractical for
7 routine uses.

8 Hydrogen gas can be generated chemically in such
9 reactions as decomposition of metal hydrides or oxidation
10 of metal like aluminum by water. When metal hydride is
11 mixed with a certain metal oxide, the decomposition of the
12 hydride is greatly accelerated and the overall reaction
13 accompanies a net energy gain. However, the amount of heat
14 and gas generated per unit mass or volume of the reactants
15 in the decomposition is not clearly advantageous over
16 conventional propellants. Energetically, the reaction of
17 aluminum with water is more favorable than combustion of
18 the propellants. However, due to the formulation of
19 passive oxide film on the metal surface, the oxidation
20 reaction is never sustained unless the temperature of the
21 metal is raised above the melting point of its oxide.
22 Therefore, such metallic systems need to be activated
23 energetically in order to generate hydrogen gas which is
24 clearly more energetic than the gases from the conventional
25 propellants, or to complete the hydrogen generating
26 reaction.

1 Woodrow W. Lee and Richard D. Ford in U.S. Patent
2 Application Serial No. 07/199,879 filed on May 27, 1988 and
3 titled, "Method for Launching Projectiles with Hydrogen
4 Gas," disclose a method in which a high power pulse of
5 electrical current is applied to a metal fuel element made
6 of aluminum, an aluminum-lithium alloy, or an aluminum-
7 magnesium alloy in the form of a wire or a foil causing the
8 metal fuel element to explode dispersing a mixture of
9 vaporized and molten metal into water surrounding the metal
10 fuel element. The dispersed fine metal particles react
11 with the water generating hydrogen gas at high pressure.
12 After the metal fuel element has exploded, the electrical
13 current is continued in order to drive the reaction between
14 the metal and water. After a preselected hydrogen pressure
15 is achieved, the hydrogen gas is used to propel a
16 projectile from a barrel. ^

17 The Lee et al. method described above has some
18 drawbacks. First, energization (melting, vaporization and
19 dispersion) of aluminum wire for its reaction with the
20 surrounding water solely depends on electrical energy.
21 Thus, it is a energy demanding process - about 10 KJ of
22 electrical energy for 1 gm of aluminum. Second, the volume
23 of water used in the above case is in far excess the
24 stoichiometric amount in order to contain and to have
25 surface contact with the exploded metal. This results in
26 vaporization of the excess water that mixes with the
27 hydrogen product gas to increase its weight.
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1 (1) applying a high powder pulse of electrical current
2 to a thin metal wire conductor which passes through a
3 mixture of (a) titanium fuel which is (i) titanium powder
4 or (ii) a mixture of titanium and boron powders and (b)
5 water causing the thin wire conductor to explode forming
6 hot spots of molten metal through the titanium fuel/water
7 mixture which initiates chemical reactions between the
8 titanium powder and water and boron powder and water which
9 generate hydrogen gas at high pressure in a chamber;

10 (2) continuing to apply electrical energy to the
11 reaction mixture to promote the reactions;

12 (3) allowing the hydrogen gas pressure build to a
13 preselected level; and then

14 (4) using the hydrogen gas to push the projectile from
15 the device.

16 BRIEF DESCRIPTION OF THE DRAWINGS

17 A more complete application of this invention, and
18 many of the attendant advantages thereof, will become
19 readily apparent as the same becomes better understood by
20 reference to the following detailed description when
21 considered in conjunction with the accompanying drawings,
22 wherein:

23 FIG. 1 is a schematic drawing of the test apparatus
24 used to demonstrate the invention;

25 FIG. 2 presents graphs representing the hydrogen gas
26 pressures versus time for an aluminum powder/water system
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1 as measured at two pressure gages (transducers) in the
2 barrel of the test apparatus; and

3 FIG. 3 presents graphs representing the hydrogen gas
4 pressures versus time at the same pressure gages
5 (transducers) but for a titanium powder/boron powder/water
6 system.

7 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

8 This invention rapidly generates hydrogen gas in purer
9 form with higher energy efficiency than prior systems. It
10 does this by applying pulse power techniques to a system of
11 a trigger (conductor) wire or wires and a titanium fuel
12 powder/oxidizer mixture and then using the hydrogen gas to
13 launch projectiles. The titanium fuels used in this
14 invention are titanium powder or mixtures of titanium and
15 boron powders. The most preferred oxidizer is water. The
16 electrical energy in the pulsed form first explodes the
17 trigger wire which initiates the chemical reaction between
18 titanium fuel powder and water oxidizer. The remaining
19 electrical energy is discharged through the reacting medium
20 to sustain the reaction. The trigger wire can be any
21 conducting metal wire. The titanium fuel in each system
22 undergoes a complete combustion reaction with the oxidizer
23 (water) and high temperature, high pressure hydrogen gas is
24 produced. When such a metallic system is subject to a high
25 power electrical pulse, the complete combustion reaction of
26 the titanium fuel with water is ensured. Additionally, the
27 energy content of the systems is greatly reinforced by the
28

1 electrical energy. Such enhancement in energy can raise
2 the temperature and pressure of the hydrogen gas to much
3 high value than a chemical reaction alone can provide.

4 Electrically activated combustion of metallic materials
5 also displays some advantageous features such as increase
6 in the reaction rate and controllability of the rate.

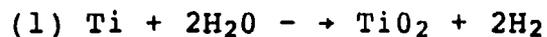
7 A titanium-boron/water system delivers chemical energy
8 about 30% higher per unit volume than the energy of a
9 comparable aluminum/water system. Therefore a titanium-
10 boron/water system is more energy efficient in generating
11 hydrogen gas than an aluminum/water system.

12 The titanium fuel components are finely powdered
13 titanium metal and finely powdered boron. The titanium and
14 boron powders have particles which are preferably 100
15 micron or less, more preferably 50 microns or less, and
16 still more preferably 20 microns or less in size. Small
17 particle size results in a greater surface area at which
18 the reaction between fuel and oxidizer occurs.

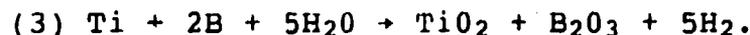
19 Titanium powder alone may be used as the fuel. ~~2~~
20 However, a mixture of boron powder and titanium powder is
21 preferably used as the titanium fuel. The powder mixture
22 preferably contains from more than zero to about 3, more
23 preferably from 1 to 2.5, and still more preferably from
24 1.9 to 2.1 moles of boron for each mole of titanium in the
25 mixture. The preferred embodiment will contain about 2
26 moles of boron per mole of titanium. In other words, ~~2~~ the
27 molar ratio of boron powder to titanium powder in the
28

1 mixture is preferably from more than 0:1 to about 3:1, more
2 preferably from 1:1 to 2.5:1, still more preferably from
3 1.9:1 to 2.1:1, and most preferably about 2:1.

4 The most preferred oxidizer is water. Water is
5 nontoxic, noncaustic, nonexplosive, and thermally stable.
6 Moreover, water is stoichiometrically efficient. The oxygen
7 is used up in the oxidation of the titanium and boron
8 powders and the hydrogen forms low molecular weight
9 propellant gas. The stoichiometric amount of water needed
10 is calculated from the following equations,



13 For the most preferred embodiment the reaction equation is



15 As demonstrated by example 2, less than 100 percent of the
16 equivalent amount of water will produce a working process.
17 However, it is more preferred that at least 100 percent of
18 the equivalent amount of water is used. Preferably from 50
19 to 1000, more preferably from 100 to 500, and still more
20 preferably from 150 to 300 percent of the equivalent amount
21 of water is used. As a practical matter, more than 100
22 percent of the equivalent amount of water is needed to
23 insure that the titanium fuel particles are in contact with
24 oxidizer during the very fast reaction. However, a large
25 excess of water is undesirable when it adds weight to the
26 device without improving the performance.

1 For greater energy efficiency it is critical that the
2 titanium fuel powder is uniformly distributed throughout
3 the water. This can be conveniently done by adding an
4 absorbent ceramic material such as bundles of fine ceramic
5 fibers or ceramic sponges which prevent the separation of
6 the titanium fuel powder and water. The ceramic materials
7 are light weight, electrically nonconductive, and inert.
8 In other words, they add little weight, do not change the
9 resistance properties, and do not interfere with the
10 chemical reactions of the titanium fuel powder/water
11 mixture. The ceramic materials also have very high melting
12 points and boiling points. Therefore the ceramic materials
13 will not melt or vaporize during the high temperature
14 reactions. Of the ceramic materials, alumina (mp 2015°C;
15 bp 2980°C) is most preferred. An example of these ceramic
16 materials are the fine alumina fiber bundles which are
17 available in sheets or mats under the tradename SAFFIL
18 (alumina fibre mat), manufactured by Imperial Chemical
19 Industries, Ltd., Mond Division, Runcorn, Cheshire, WA74QS,
20 United Kingdom. The fine ceramic fibers or ceramic sponges
21 are thoroughly and uniformly mixed into a slurry of the
22 titanium fuel powder and water components. The fine
23 ceramic fiber bundles or ceramic sponges absorb the water
24 and titanium fuel powder particles by capillary action.
25 The fine ceramic fiber bundles (or ceramic sponges) create
26 small spaces in which the titanium fuel powder and water
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1 are held. This prevents the titanium fuel powder from
2 settling out of the water.

3 Using the absorbent ceramic material (e.g., fine fiber
4 bundles or sponges) to take up and hold the water and
5 titanium fuel powder mixture is like using Kleenex facial
6 tissue to remove water from a bowl. The tissue absorbs and
7 becomes saturated with the water. When the tissue is
8 removed it takes the water with it. If not enough tissue
9 is used, water remains in the bowl. In the present case,
10 the ideal situation is when all of the titanium fuel
11 powder/water slurry is absorbed and all of the absorbent
12 ceramic material is saturated. The process, however, will
13 still be operative when more or less than the idea amount
14 of absorbent ceramic material is used. The fine ceramic
15 fibers or ceramic sponges are added in an amount of
16 preferably from about 0.5 to about 3.0, more preferably
17 from 0.5 to 2.0, still more preferably from 0.8 to 1.5
18 weight percent based on the weight of the dry titanium fuel
19 powder. Fine fibers are the more preferred form of the
20 ceramic materials. The fibers will preferably have a
21 diameter of less than 20 microns. The length of the fibers
22 is not critical although longer fibers (e.g., 0.25 inches
23 to several inches) are preferred. Other forms of the
24 ceramic material should be of comparable dimensions.

25 The reactions of titanium and boron with water are
26 initiated and sustained by an electrical discharge through
27 the titanium fuel (titanium or titanium and boron
28

1 powders)/water mixture. This is preferably done by placing
2 the titanium fuel/water mixture in a sealed reaction
3 chamber between two electrodes and passing the current
4 between the electrodes through the mixture. This is
5 facilitated by connecting the electrodes with a conductor
6 wire which passes through the titanium fuel water mixture.
7 The conductor wire can be made of any electrically
8 conductive material. Preferably a metal such as, gold,
9 silver, iron, nickel, tungsten, steel, magnesium, brass,
10 copper, aluminum or aluminum-lithium alloys may be used.
11 Conductor wires made of an alloy containing from more than
12 zero to 3 weight percent of lithium with the remainder of
13 the alloy being aluminum are more preferred. The weight of
14 the conducting wire is preferably less than 5 percent of
15 the weight of the titanium fuel. Preferably a number of
16 fine conductor wires are used instead of a single large
17 conductor wire. This permits a more uniform placement of
18 conductor wire material throughout the mixture of metal
19 fuel/water. The total weight of these fine conductor wires
20 is preferably less than 5 percent of the weight of the
21 titanium fuel.

22 The electrical discharge explodes the conductor
23 wire(s) which in turn provides hot spots of molten material
24 through out the premixed titanium fuel/water mixture. Note
25 that the use of a number of fine conductor wires provides a
26 more uniform distribution of these hot spots throughout the
27 titanium fuel/water mixture. The chemical reaction between
28

1 the titanium fuel (titanium powder or titanium and boron
2 powders) and water is first triggered at the hot spots and
3 propagates to the surrounding materials because the
4 reaction is highly exothermic. Therefore most of the
5 titanium fuel is activated by chemical means rather than
6 electrical means. Nonetheless, the provision of the hot
7 spots by the exploding conductor does not necessarily
8 sustain the titanium fuel/water reaction. The sustaining
9 requires a prolonged discharge of the electrical energy
10 through the medium even after the reaction is triggered.
11 The shape of the electrical pulse applied to the medium is
12 not a critical factor for the completion of the reaction as
13 long as it delivers sufficient electrical energy without
14 forming an arcing channel cross the medium.

15 The electrical discharge parameters are as follows.

16 The total energy of the electrical discharge will
17 preferably be from 0.5 to 15.0 more preferably from 1.0 to
18 5.0 and still more preferably from 1.8 to 2.2, and most
19 preferably about 2 kilojoules (kJ) per gram (g) of titanium
20 fuel. Too little electrical energy may result in an
21 incomplete reaction whereas a large excess of energy
22 requires heavier equipment without substantially improving
23 the performance. The length of the electrical discharge is
24 preferably from 10 to 1000, more preferably from 20 to 600,
25 and still more preferably from 40 to 400 microseconds. Too
26 slow a discharge (long discharge time) will result in
27 slower operation of the device and lower pressures and
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1 propellant gas velocities. Too fast an electrical
2 discharge (short discharge time) will result in an
3 incomplete chemical reaction between the titanium fuel
4 powder and water. The apparatus is designed so that
5 preferably from 10 to 30, more preferably from 15 to 25,
6 still more preferably from 18 to 22, and most preferably
7 about 20 percent of the electrical energy is used to
8 explode the conductor wire(s). The remainder the
9 electrical energy is discharged into the reaction mixture
10 to sustain the chemical reaction between the titanium fuel
11 and water after the conductor wire(s) has exploded.
12 Finally, care must be taken to avoid arcing between the
13 electrodes. Arcing is prevented by keeping the voltage
14 drop across the reaction medium under 2 kilvolts per
15 centimeter of distance between the electrodes. For higher
16 voltage drops the electrodes must be farther apart.

17 The chemical interaction between the titanium fuel
18 (titanium powder or titanium and boron powders) and the
19 water it is mixed with depends on the electrical energy
20 discharge through the titanium fuel/water mixture. After
21 the conductor has exploded to initiate the reaction, the
22 voltage drop between the electrodes rapidly rises. An
23 inductive energy store provides an ideal power source for
24 such discharge since its discharge is not limited by the
25 voltage rise across the titanium fuel/water mixture after
26 the conductor has exploded. For example, a capacitor bank
27 discharge may not discharge all of its stored charge
28

1 through the metal fuel/water mixture because the voltage
2 rise across the mixture without the conductor wire(s) could
3 exceed the bank voltage thereby terminating the discharge.
4 In addition to the voltage aspect, the power source should
5 also allow a very high current to pass through the
6 conductor wire(s) at the moment of its explosion to deliver
7 a high electrical energy to the metal conductor wire(s) in
8 a very short time.

9 Discharge of an inductive energy store can fulfill the
10 two conditions mentioned above. The essence of this type
11 of discharge is to transform an electrical energy stored in
12 a battery, electrical rotating (homopolar) generator,
13 capacitor bank, or other primary electrical power source to
14 an energy stored in an inductor and to utilize the
15 inductive energy at the moment of the explosion. For
16 experimental simplicity, a capacitor bank is often used.
17 When a capacitor bank whose energy is $1/2 CV^2$ is discharged
18 through a RCL circuit, the primary bank energy is
19 transformed into an inductive energy described by $1/2 LI_p^2$
20 at the time of the peak current. At the peak current time
21 the capacitor bank voltage becomes zero and the current
22 (neglecting energy losses) is given by $I_p = V_c \sqrt{C/L}$. Once
23 the electrical energy is transformed to an inductive
24 energy, the discharge of the inductive energy is not
25 subject to the rise of voltage between the electrodes
26 across the titanium fuel/water mixture. =

1 FIG. 1 is a schematic drawing representing typical
2 equipment used to demonstrate the present invention. The
3 electric circuit which provides the high energy electrical
4 pulse comprises a capacitor bank 20, a induction coil²⁸, a
5 metal conductor (wire) 22, and a fast switch 24, all of
6 which are connected in series by electric cables 50, 52,
7 56, and 58. The metal conductor 22 is placed in the
8 titanium fuel (Ti or Ti+B powders)/water mixture 30 and
9 both are enclosed in the interior 42 of a cylindrical
10 reaction cartridge 32. The cylindrical reaction cartridge
11 32 is made of an electrical insulator such as polyethylene.
12 The reaction cartridge 32 is enclosed in a stainless steel
13 chamber 34. A barrel 44 is connected to the top of the
14 steel chamber 34 and completes the enclosure of the
15 reaction cartridge 32. A brass electrode 36 is threaded
16 into the bottom and a second brass electrode 38 is threaded
17 into the top of the reaction cartridge 32. In the center
18 of the top brass electrode 38 is a breakable membrane 40
19 which separates the interior 42 of the reaction cartridge
20 32 from the barrel 44. After the reaction has been
21 initiated and a preselected pressure of hydrogen gas has
22 been reached in the reaction cartridge 32 the membrane 40
23 breaks and the hydrogen gas escapes from the interior 42 of
24 the reaction cartridge 32 into the barrel 44 where it is
25 used to drive a projectile from the barrel 44. For
26 laboratory testing (examples 1 and 2) pressure gages =
27 (transducers) 46 and 48 were mounted in the barrel 44 in
28

1 place of a projectile. FIGS. 2 and 3 present pressure
2 readings from these gages (transducers) in examples 1 and
3 2, respectively.

4 The series electrical circuit as shown in FIG. 1 can
5 be summarized as follows. The capacitor bank 20 is
6 connected by electric cable 50 to the inductor 28 which is
7 connected by an electrical cable 52 to a high current
8 connection 54 on the brass electrode 36 at the bottom of
9 the reaction cartridge 32. The brass electrode 36 is
10 connected to the other brass electrode 38 at the top of the
11 cartridge 32 by means of the metal conductor 22 which
12 passes through the center of the metal fuel/water mixture
13 30. The brass electrode 38 at the top of the cartridge 32
14 is in electrical contact with the stainless steel chamber
15 housing 34 which provides an electrical return path to
16 electrical cable 56 which is connected to one terminal of
17 fast switch 24. The other terminal of the fast switch 24
18 is connected by electric cable 58 to the capacitor bank 20
19 thus completing the series circuit.

20 To more clearly illustrate this invention, the
21 following examples are presented. It should be understood,
22 however, that these examples are presented merely as a
23 means of illustration and are not intended to limit the
24 scope of this invention in anyway.

1
2 Example 1

3 Aluminum fuel/water

4 The oxidation reaction of aluminum powder (48 micron
5 diameter) with water was triggered by allowing an
6 electrical current pulse to pass through an aluminum wire
7 embedded in the mixture of the metal powder and water. The
8 wire was 6 cm long, 0.84 mm in diameter, and weighed 0.09
9 gm. The weight of the aluminum powder and water were 1.6
10 gm and 1.8 gm, respectively. The wire 22 and the mixture
11 30 were placed in a circuit arrangement as shown in FIG. 1.
12 The capacitor bank 20 had a total capacitance of 6×10^{-4}
13 farads and was charged up to 4 kV. Approximately 30% of
14 the stored energy was transformed into inductive energy
15 that was used to explode the wire. The remaining stored
16 energy was dissipated in capacitive discharge mode.

17 The cartridge 32 was made by drilling a 0.6 cm
18 diameter bore into a polyethylene cylinder of 2.5 cm
19 diameter and 7.5 cm long. The threaded ends of the
20 cartridge were plugged by brass electrodes 36 and 38. The
21 electrode 38 located near the barrel 44 has around the
22 center a thin spot of 0.1 mm thick and 0.4 mm diameter,
23 which functions as a breakable membrane 40 as the pressure
24 inside the cartridge rises.

25 The cartridge was installed in the steel chamber 34
26 with the bottom brass electrode 36 in electrical contact to
27 the high current feed through 54 and the other electrode 38
28 with the breakable membrane 40 connected to inside of the

1 chamber 34 at the point where the barrel 44 is installed.
2 When the predetermined hydrogen pressure is obtained from
3 the reaction the thin breakable membrane 40 in the upper
4 brass electrode 38 breaks providing a path for the hydrogen
5 produced by the reaction to pass from the interior 42 of
6 the reaction cartridge 32 to the barrel 44. Pressure
7 gauges (transducers) 46 and 48 monitored the hydrogen gas
8 pressure along the barrel 44. The hydrogen gas pressure
9 monitored by them is shown in FIG. 2. The hydrogen gas
10 pushing the air column in the barrel attained a velocity of
11 approximately 1 km/sec.

12 Example 2

13 Titanium-boron/water

14 The procedure of example 1 was repeated using a
15 mixture of titanium powder (48 microns), boron powder (100-
16 150 microns), and water. The weights of the reactants were
17 titanium powder, 1.5 g; boron powder, 0.7 g; and water,
18 1.8 g. The hydrogen gas pressure monitored by the pressure
19 gauges (transducers) 46 and 48 is shown in FIG. 3. The
20 generated hydrogen gas pushing the air column in the barrel
21 attained a velocity of approximately 2 km/sec. The
22 pressure rise time shown in FIG. 3 is more than six times
23 faster than the rise time shown in FIG. 2, indicating that
24 the burning rate of Ti/B/Water is much faster than that of
25 Al/Water.

26 Obviously, numerous modifications and variations of
27 the present invention are possible in light of the above
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teachings. It is therefore to be understood that within the scope of the appended claims the invention maybe practiced otherwise than as specifically described herein.

1 Navy Case No. 72,461

2 METHOD FOR LAUNCHING PROJECTILES WITH HYDROGEN GAS

3 ABSTRACT OF THE DISCLOSURE

4 A method of propelling a projectile from a device by
5 applying a high power pulse of electrical current to a thin
6 metal conductor wire causing the wire to explode and
7 disperse hot spots of molten metal throughout an titanium
8 fuel powder/water mixture which reacts to generate hydrogen
9 gas at high pressure in a chamber. The hydrogen gas is
10 used to push the projectile from the device.
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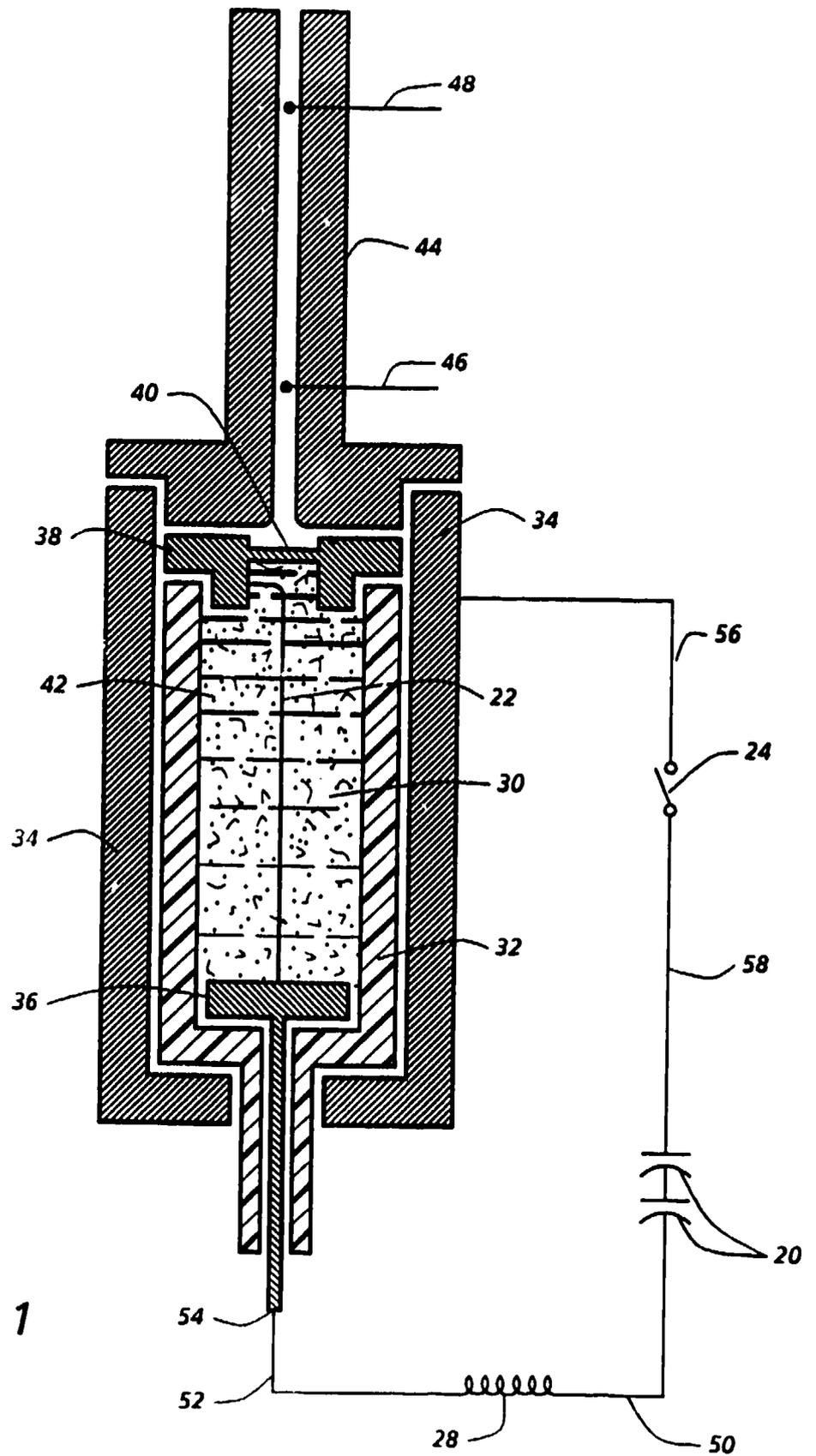


FIG. 1

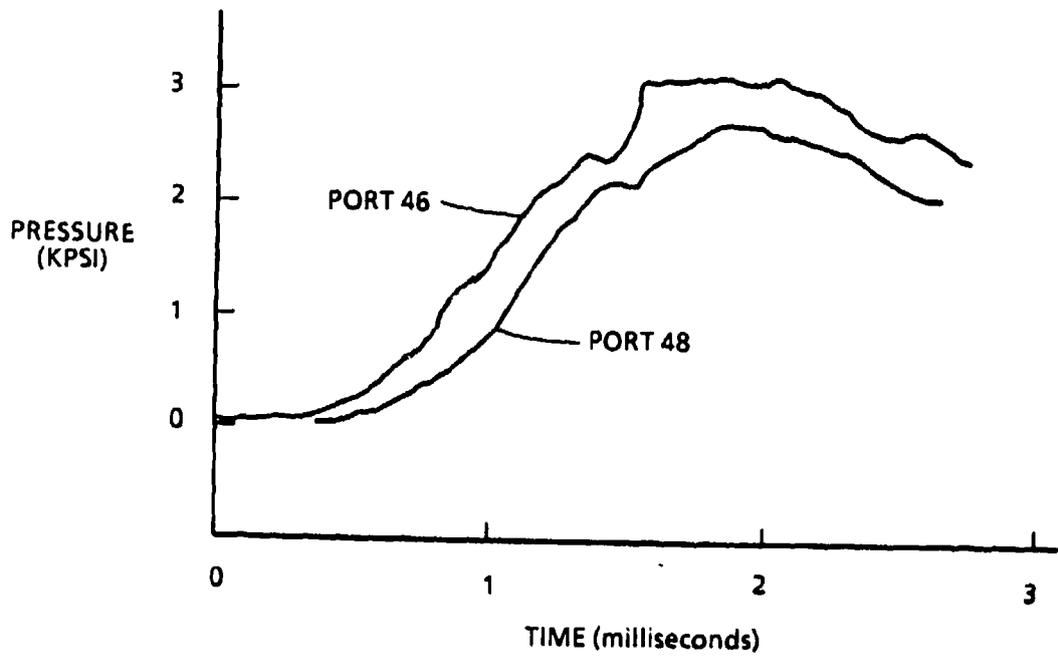


FIG. 2

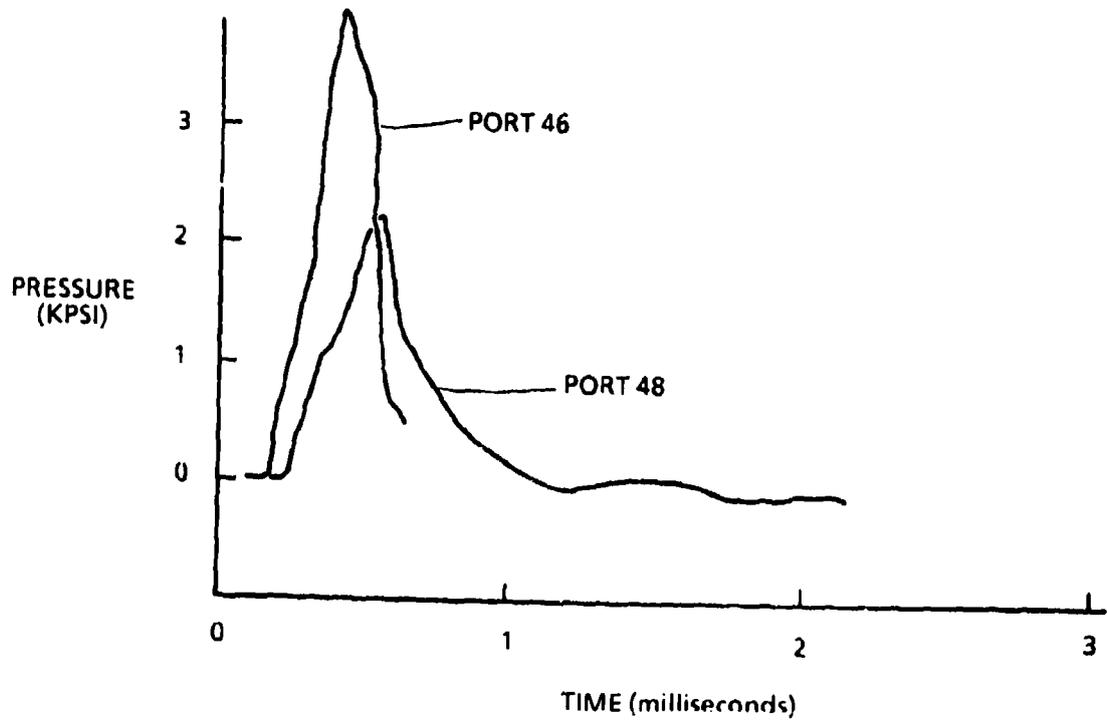


FIG. 3