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Kretschmer et al.

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[54] **ON-DEMAND VARIABLE FLOW CLOSED LOOP GAS GENERATOR SYSTEM WITH A VARIABLE AREA INJECTOR**

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[73] Assignee: **The United States of America as represented by the Secretary of the Navy**

[22] Filed: **Aug. 20, 1971**

[21] Appl. No.: **173,510**

[52] **U.S. Cl.** .....**60/39.74 A**, 60/39.82 E, 60/229, 60/258

[51] **Int. Cl.**.....**F02k 9/02**

[58] **Field of Search**.....60/39.74 A, 258, 60/229, 243, 200, 39.48, 39.82 E

[56] **References Cited**

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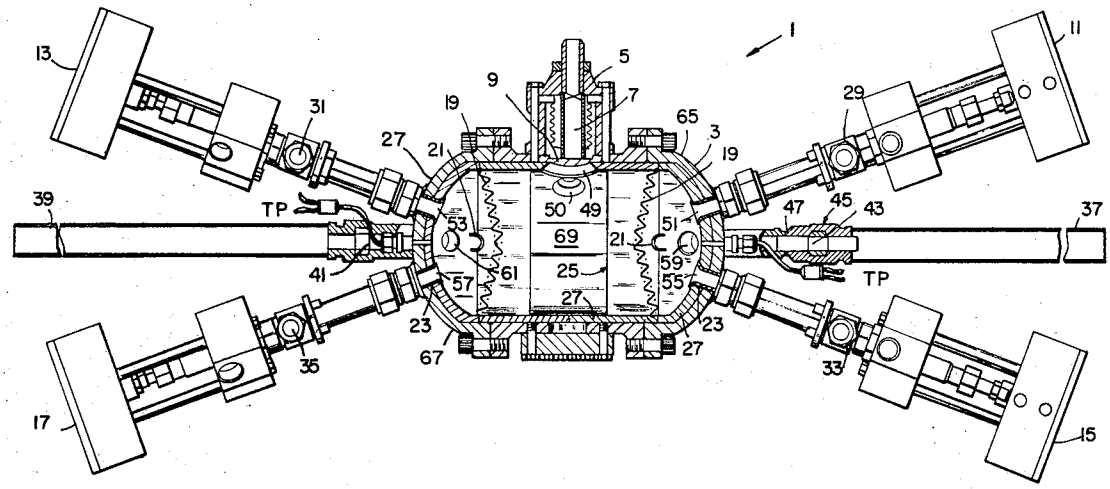
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Primary Examiner—Carlton R. Croyle
Assistant Examiner—Warren Olsen
Attorney—R. S. Sciascia et al.

[57] **ABSTRACT**

A closed loop monopropellant on-demand fuel feeding system for firing a reaction control device. The system includes a single bellows variable area injector having no valves other than an explosive disc in the propellant supply system separating the gas generator from the fuel storage tanks. The injector comprises a stationary pintle with swirl slots and a movable orifice plate attached to the bellows to vary the area of the swirl slots.

10 Claims, 9 Drawing Figures



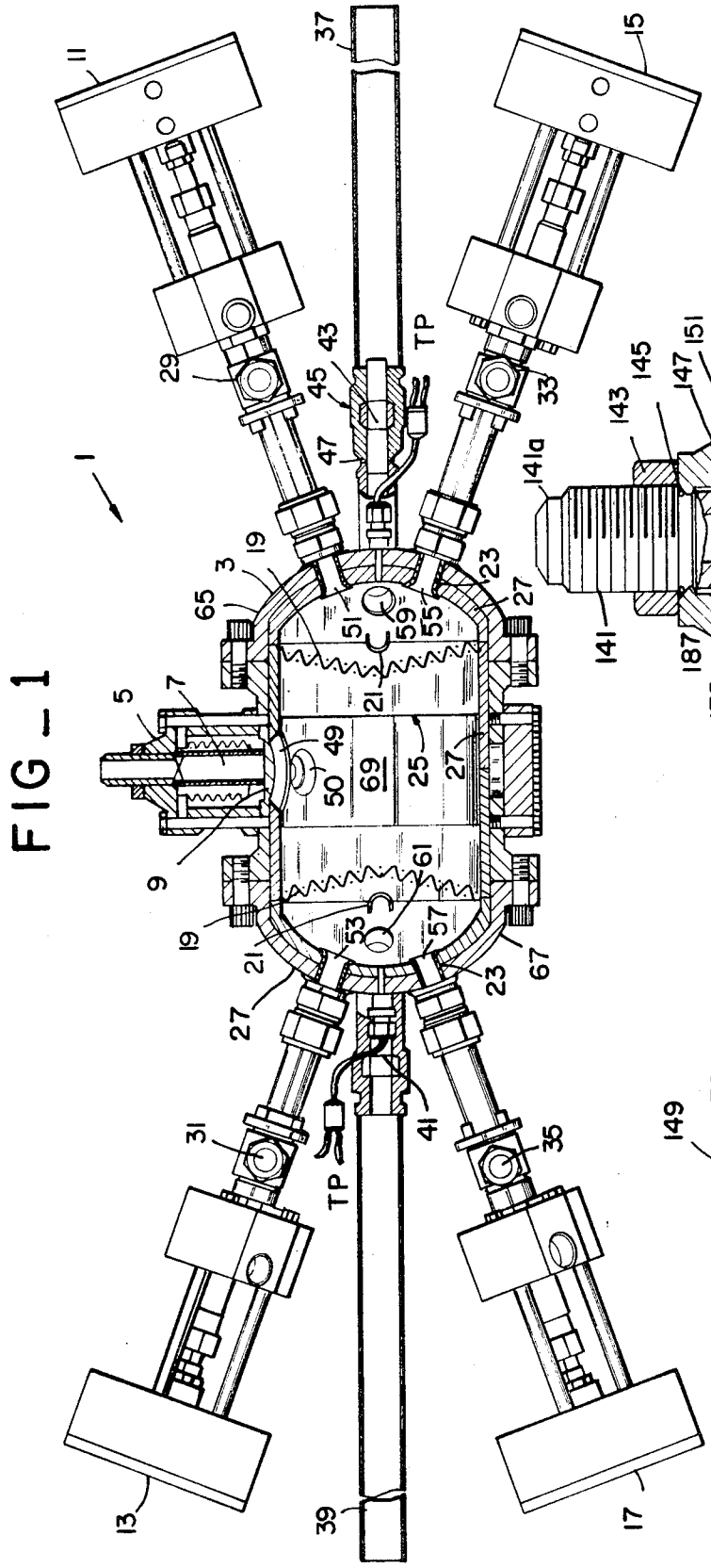


FIG_1

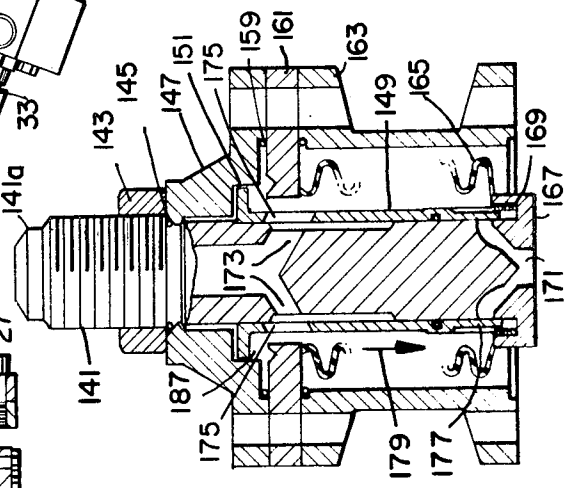


FIG_6

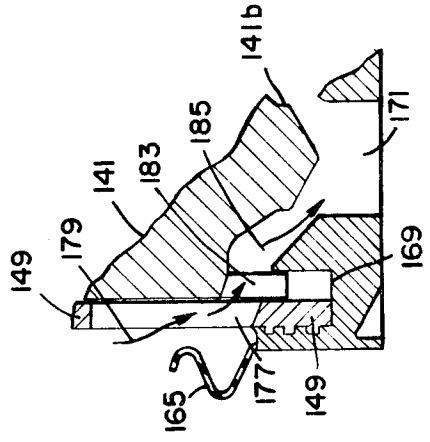


FIG_6A

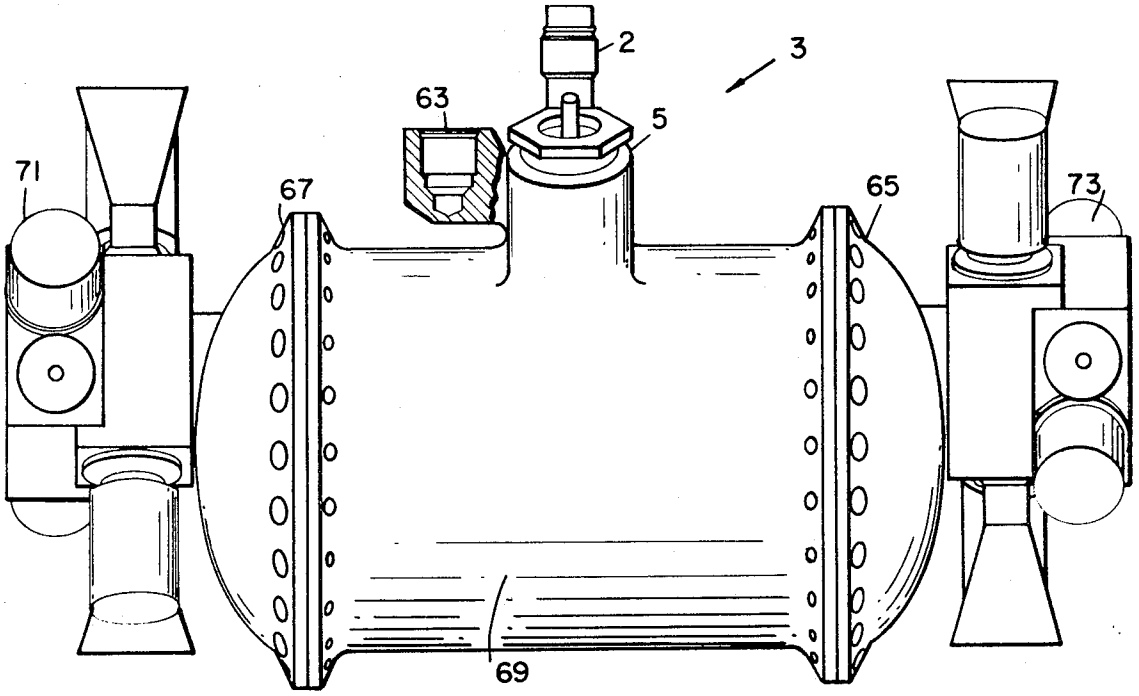


FIG_2

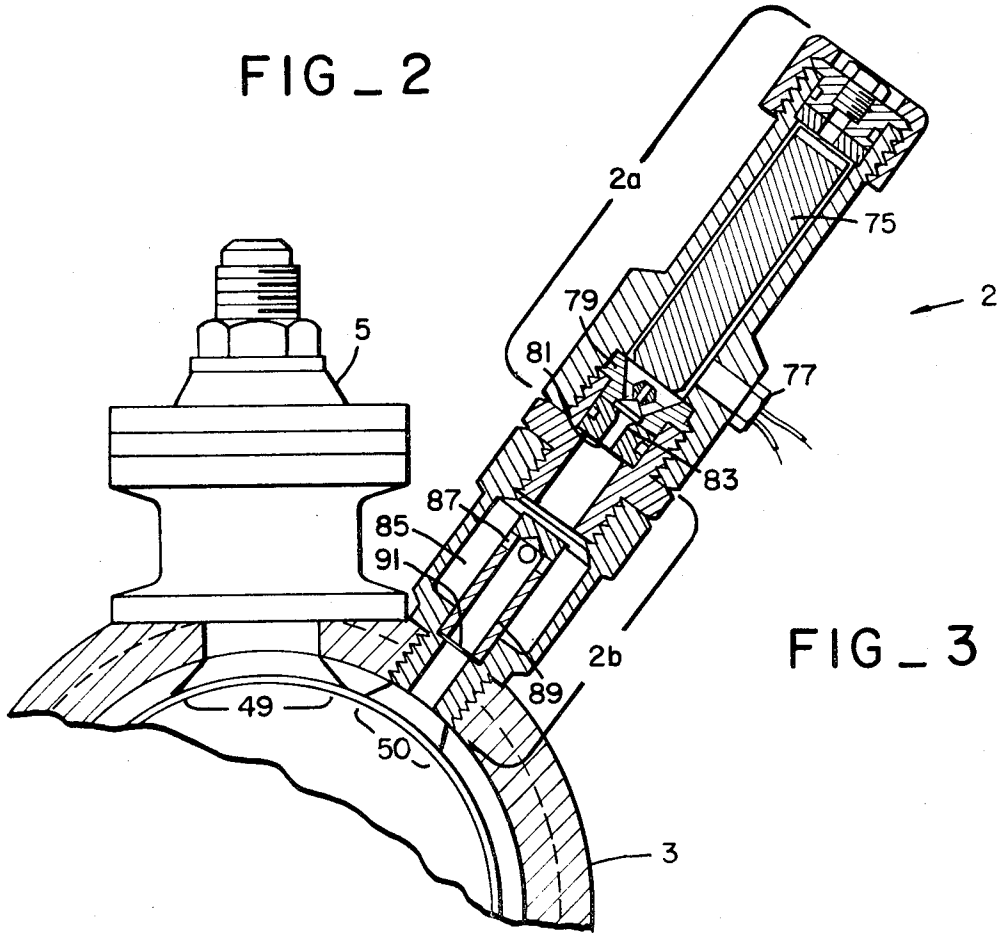
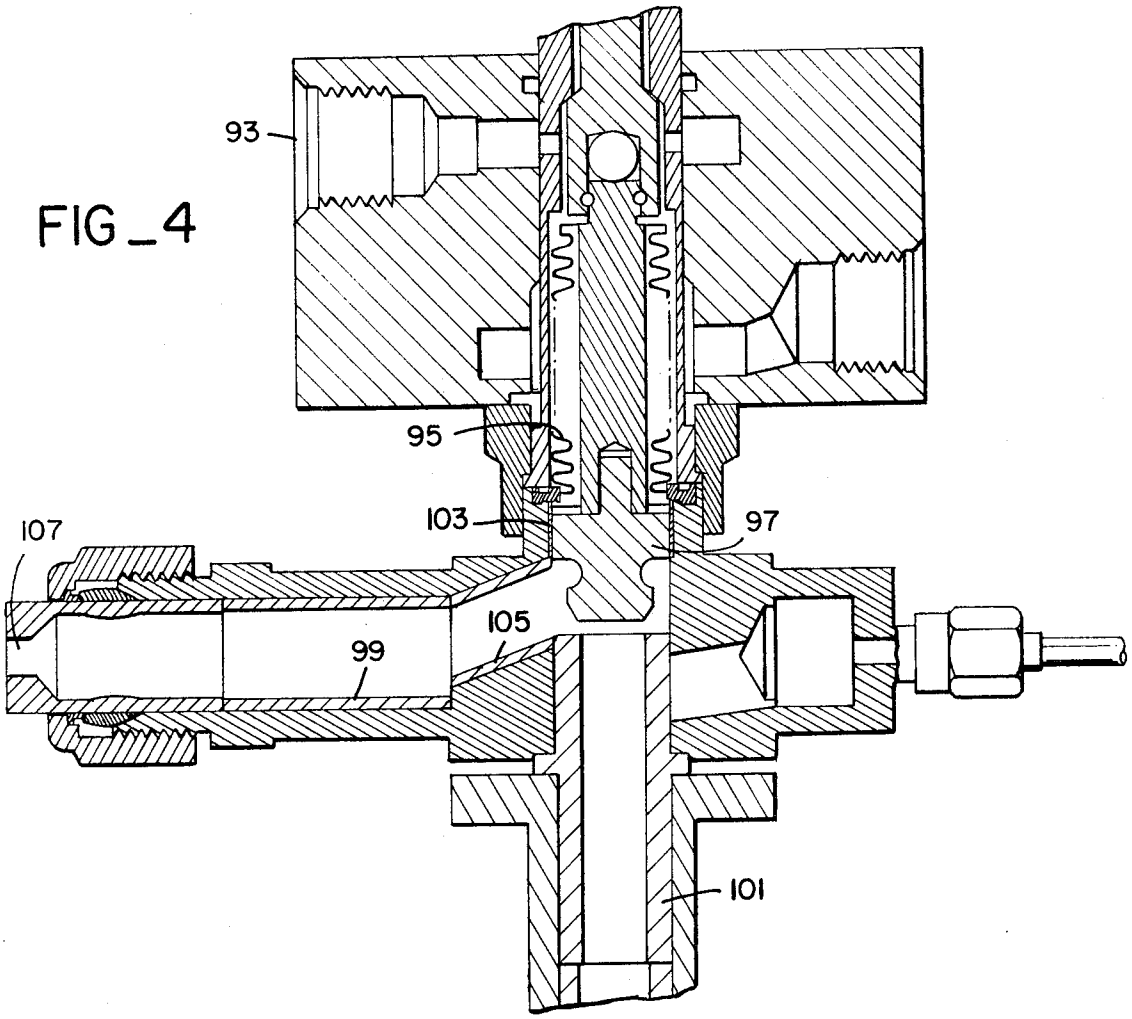


FIG_3

FIG_4


93
95
103
97
107
105
99
101

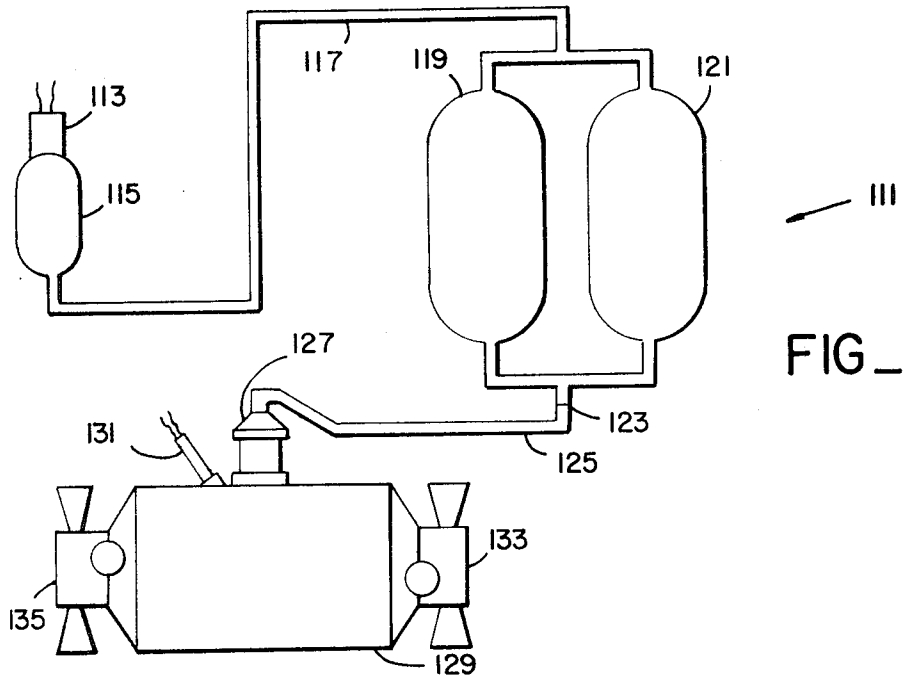

117
119
121
113
115
111
127
123
131
125
133
135
129

FIG_5

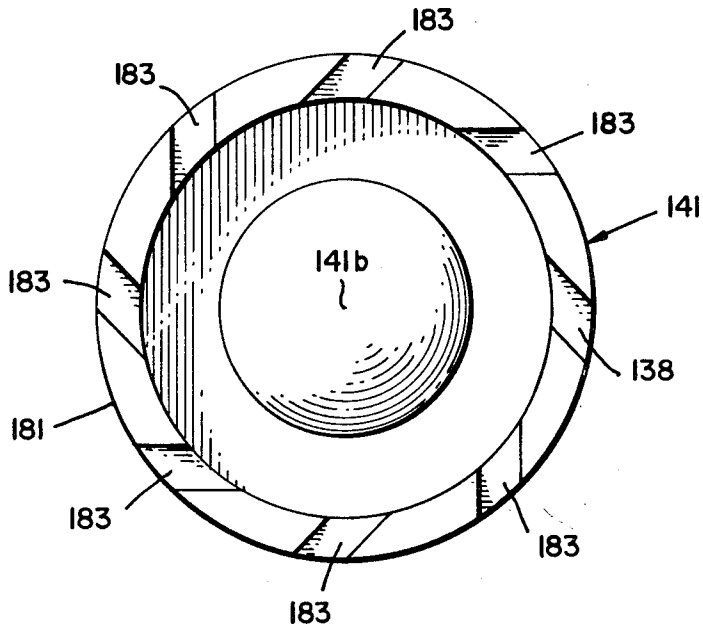

183
183
183
141
141b
183
138
181
183
183
183

FIG_6B

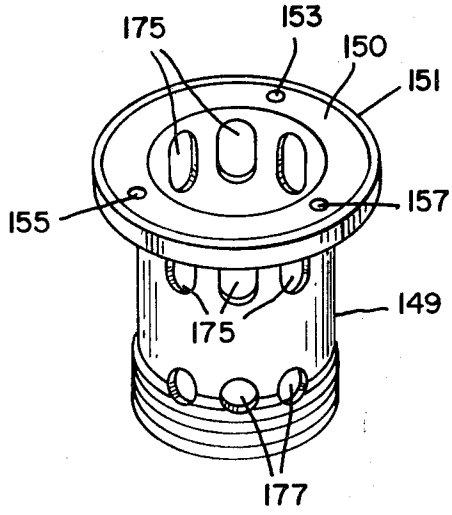

175
153
150
151
155
157
149
175
177

FIG_6C

ON-DEMAND VARIABLE FLOW CLOSED LOOP GAS GENERATOR SYSTEM WITH A VARIABLE AREA INJECTOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates generally to an on-demand variable flow gas generator system and more particularly to a monopropellent on-demand closed loop fuel feeding system with a variable area injector for firing a reactor control system.

2. Description of the Prior Art

The previous systems, to vary the flow, were based on using several injector valves which required a complicated control system. Moreover, the previous systems, to vary the flow, required additional injectors with the capability of switching the injectors on or off in order to maintain enough injector differential pressure (ΔP) for atomization.

SUMMARY OF THE INVENTION

The present invention overcomes the aforementioned problems by reducing the number of valves and injectors while maintaining continuous flow through the injectors. Moreover, the unique system is simple, fully automatic, and can be used in any propulsion device with monopropellent or bipropellent systems. Briefly, the present invention includes a single bellows variable area injector having no valves other than an explosive disc in the propellent supply system separating the gas generator from the fuel storage tanks.

The variable area injector is of the swirl type where the propellant is brought into rotation in orifice plate by slots located in a stationary pintle. The variation in flow is obtained by using the orifice plate to cover and uncover a series of slots in the pintle and thereby change the effective entrance area to the swirl chamber to match the varying exit area of the cone and orifice. Movement of a slotted sleeve, which is joined to the bellows, is initiated by a pressure differential across the bellows and swirl chamber from the decrease or increase in chamber pressure.

An alternative embodiment involves a more complicated open loop system including a two-position fixed area injector which works on the principle that for each thrust step, which is initiated by operating gas valves, a propellent valve is required to match the flow demand to maintain a constant pressure and continuous flow. The subject matter of the aforementioned invention is disclosed in copending U.S. Pat. application Ser. No. 173,508 by W. K. Kretschmer and P. A. Heady, Jr.

STATEMENT OF THE OBJECTS OF THE INVENTION

A primary object of the present invention is to provide a closed loop two-propellent system utilizing a variable area injector which maintains continuous flow.

Another object of the present invention is to provide a simple, fully automatic, closed loop propellent system which is capable of being used with any monopropellent or bipropellent liquid propellent device.

Another object of the present invention is to provide a system with variable fuel propellent flow to a gas generator at a closed loop system which will maintain a constant combustion chamber pressure at flow variations of about ten to one.

Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an assembly drawing of the on-demand gas generator system of the present invention;

FIG. 2 is a drawing of the gas generator of FIG. 1 wherein thruster valves are used in place of the warm gas valves of FIG. 1;

FIG. 3 is an illustration of the unique solid igniter used in the system shown in FIGS. 1 and 2;

FIG. 4 is an illustration of the unique warm gas valve used in the gas generator of FIG. 1;

FIG. 5 is a schematic drawing of the closed loop system of which the gas generators of FIGS. 1 and 2 are a part;

FIG. 6 is an illustration of the unique variable area single bellows injector used in the gas generators shown in FIGS. 1, 2, and 5;

FIG. 6A is an illustration of the unique pintle cone and orifice plate of injector of FIG. 6;

FIG. 6B is an illustration of the swirl slots of the injector of FIG. 6; and

FIG. 6C is an illustration of sleeve dash pot of the injector of FIG. 6.

DESCRIPTION OF THE PREFERRED EMBODIMENT

There are two somewhat similar on-demand gas generators, namely, the closed loop system shown in FIG. 5 and the open loop system, not shown, but disclosed in the aforementioned copending application. Both systems have good response to change in flow demand for simulation of thrust pulses of different duration and energy at relatively constant chamber pressure (P_c). FIG. 1 shows the general scheme of the on-demand gas generator used in the open and closed loop systems. The closed loop system shown in FIG. 5, which is the subject matter of the present invention, is simple and requires few components.

The variable area injector, illustrated in FIG. 6, combines a flow regulation valve and spring-loaded bellows into one integrated unit. Flow changes in the injector are initiated by chamber pressure P_c decrease or increase through changes in gas flow demand by chamber pressure P_c decrease or increase through changes in gas flow demand by switching gas valves on or off. The pressure drop across the injector for different flow rates varies within a relatively narrow band and the P_c pressure changes are equal to this ΔP variation. A more detailed description of the unique closed loop system of FIG. 5 and the injector of FIG. 6 are set forth below.

In contrast, the open loop system with a dual two-position injector, described in the aforementioned copending application, works on the principle that for each thrust step, which is initiated by operating gas valves, a propellent valve is required to match the flow demand to maintain constant P_c pressure. The two-position injectors of the open loop system reduce the number of valves required to three and maintain con-

tinuous flow through the injector at an injector ΔP of about 35 psi, or above, at the orifice for six thrust steps.

Referring to FIG. 1, the on-demand variable flow closed loop gas generator system 1 comprises gas generator 3, injector assembly 5, hot gas valves 11, 13, 15 and 17 and gas nozzles 25, 27, 29 and 31. The closed loop system also includes an igniter 2 which is illustrated in FIG. 2 and described in conjunction with FIG. 3. The volume of the gas generator is a function of the characteristic length of the chamber and the throat or nozzle area. The upper and middle section of chamber 69 contains aperature 49 opening onto orifice plate 9 and pintle 7 of injector assembly 5; aperature 50 is provided to accept igniter 2, shown in FIGS. 2 and 3. Gas tube openings 51, 53, 55 and 57 are provided to accept hot gas valves 11, 13, 15 and 17, respectively. The aforementioned hot gas valves may be replaced by a standard thruster cluster if desired. The igniter 2 and injector 5 are threaded into valve openings 49 and 50, respectively of cylindrical chamber 69. To protect the chamber walls and domes from overheating a silica phenolic insulation or other equivalent material may be used. More specifically, the generator may be lined with a spiral wound 0.2 inch thick silica phenolic liners. This insures gas flow over the liners in the direction of the spiral windings and prevents delamination. The generator shown in FIG. 1 can be provided with gas tube liners 23 to line tube openings 51, 53, 55 and 57. Impingement liners 25 may be used to line cylindrical chamber 69. Chamber liners 27 can be used to line chamber domes 65 and 67 to prevent overheating of the chamber domes. Nicrome screens 19 including screen supports 21 may be installed into gas generator 3 to filter contaminents and to prevent nozzle blockage. The screens are respectively mounted in the ends of domes 65 and 67, adjacent to cylindrical chamber 69 and supported in the axial direction by the semi-tubular shaped screen supports 21. The screen supports 21 are preferably made of columbium or the equivalent. Domes 65 and 67 each contain ports 59 and 61 to function as a gas relief valve or safety valve. Safety disc assembly 41, with extension pipe 39, is attached to port 61 of dome 67. Safety disk 41 can be ruptured at 2,000 psig and acts as an upper limit gas pressure relief valve. Dome idle orifice 45 and extension pipe 37 are attached to port 59 of dome 65. The idle orifice takes the place of an idle gas relief valve. The idle orifice includes the idle flow nozzle 47 and a 750 psi burst disc 43. The burst disc 43 bursts at ignition and provides a bypass flow for exhaust gas at idle flow. Openings are also provided in the extension pipes 37 and 39 for temperature probes TP.

Referring to FIG. 5, the closed loop system 111 comprises squib 113, fuel expulsion gas generator 115, pressurization line 117, Otto Fuel tanks 119 and 121, burst disc 123, fuel feed line 125, gas generator igniter 131, Otto Fuel gas generator 129, thruster valves 133 and 135 and variable flow injector 127. Each of the clusters 133 and 135 contains four thruster valves, or four warm gas valves, as the case may be, at each end of the chamber of gas generator 129, as illustrated in FIG. 1. Flow changes in the injector are initiated by a chamber pressure P_c decrease or increase through changes in gas flow demand by switching gas valves on or off. The pressure drop across the injector for different flow rates varies within a relatively narrow band; a P_c pressure is equal to the differential pressure variation ΔP. An ancillary solenoid switch may also be used.

Referring to FIG. 2, the gas generator 3 comprises cylindrical chamber 69, two dome ends 65 and 67 and thruster cluster 71 and 73. The thruster valve clusters include thruster valves with thruster nozzles which attach directly to the domes, 65 and 67, as illustrated in FIG. 2. A sectional view of gas inlet 63 of injector 5 is also illustrated. The propellent injector 5 is located in the middle of cylindrical chamber 69. It should be noted that the warm gas valves shown in FIG. 1 and 6 are used to simulate the above-mentioned thruster cluster shown in FIG. 2. A description of the warm gas valves shown in FIG. 6 will follow.

The ignition of Otto Fuel can be accomplished by an electric preheater or with solid igniter. The latter device is more desirable because ignition must be instantaneous. In FIG. 3 is illustrated the solid igniter 2 used in the system shown in FIGS. 1 and 2. Solid igniter 2 comprises filter 79, foil discs 81 and 91, nozzle 83, burst disc 87 and stand pipe 89. Propellent grain 75 is located in the inner upper body of igniter 2. Ball powder 85 circumferentially surrounds burst disc 87 and stand pipe 89. To obtain a rapid gas generator pressure rise from solid igniter 2, smokeless powder is used as a booster because it has a high burning rate and is a good gas producer. To maintain the pressure level, the non-perforated external burning cylindrical propellent grain 75 is simultaneously ignited with the powder 85 which continues to burn for about 0.4 seconds. The igniter 2 consists of two chambers 2*a* and 2*b* which are internally separated by foil rupture disc 81. The front chamber 2*a* contains the igniter nozzle 83 with filter 79. Igniter assembly 2 is threaded into aperature 50 of gas generator 3 in the plane of injector 5 and tilted at an angle of 30° to the axis of the injector 5. The rear chamber 2*b* contains a burst disc 87 and a stand pipe 89 which prevents the loss of powder 85 into gas generator 3 before burning and during ignition.

The ignition may be completed by an igniter squib 77 or a similar device. The propellent grain 75 is preferably nonperforated, or holeless grain, to provide a longer burning time. It has been found by experimentation that by eliminating the hole in the grain, the grain burning time increased by 3 ½ times, or from 0.15 to 0.4 seconds, using 20 grams including about 0.5 grams of boron potassium nitrate ($BKNO_3$). A normal charge of ball powder would be between 6 and 12 grams for good results. The rupture disc 87 is set to burst at about 750 psig with a peak pressure in the gas generator of about 770 psig at 0.4 second with a grain burnout at 0.4 second.

To simulate the on-demand condition in the Otto Fuel gas generator, a total of four warm gas valves are required. Referring to FIG. 4, each of the gas valves 11, 13, 15 and 17 comprises a water cooling manifold 93, bellows 95, poppet head 97, seat insert liners 99, 101, 103 and 105, and nozzle 107. Each valve has a sealed pneumatic valve bellows 95 with an operational gas temperature of about 1,500° F at 1,500 psig pressure. The gas valves simulate the function of the aforementioned thruster cluster. However, the warm gas valves may be used as the thruster valves in certain types of vehicles using reaction control devices such as target

drones. All gas passages are lined with columbium material and the valve seat and poppet units are also made of columbium material. A provision for water cooling is desirable in the operative system. Each valve is fitted with a nozzle **107** that is installed downstream of the gas valves. The warm gas valve opening sequence can be calculated and established in a standard manner. The activation may be by gas generator pressure or an ancillary solenoid valve. The discussion of the valves is informational only and not the subject matter of the present invention.

Referring to FIGS. **6**, **6A**, **6B** and **6C**, the unique variable area injector **139** is a swirl type and comprises stationary pintle **141**, attaching nut **143**, O ring seal **145**, top plate **147**, sleeve **149**, dash pot **151**, metal O ring **159**, bellows flange **161**, housing **163**, bellows **165**, orifice plate **167**, swirl slots **183**, and fuel flow paths **179**. The propellant is brought into rotation in orifice plate **167** by means of tangential swirl slots **183** in the stationary pintle **141**. At the exit of the injector **139** a conical sheet of fuel develops having fine atomized droplets. The variation of flow in the design is obtained by moving orifice plate **167** which uncovers a series of swirl slots **183** in pintle **141** and changes the effective exit area of swirl slots **183**. Movement of the orifice plate **167**, which is joined to bellows **165** is initiated by the pressure differential ΔP across the bellows **165**, sleeve **149** and swirl chamber **185**. The flange **150** of injector sleeve **149**, shown in FIG. **6C**, is a piston which is connected to dash pot seal **151**. The flange **150** of sleeve **149**, which is attached to orifice plate **167**, is free to move vertically within the limits of flange limiting area **187**. The pintle **141** includes a downward extending portion **181** and cone **141***b* which forms a swirl chamber **185**. The downward extending portion **181** includes eight swirl slots **183**. Each slot forms a 45° angle to a line tangent to the exterior section. The pintle point, or cone, **141***b* extends, when bellows **165** is in the expanded position, so that the attached orifice **167** and the pintle point **141***b* form a line parallel to the base of the orifice **167** when in the closed position. The top of the pintle **141** has a hollow section **141***a* to allow the fuel to flow when burst disc **123**, shown in FIG. **5**, is fractured. The fuel flows through side ports **173** of pintle lel along a path through sleeve **149** ports **175** and between bellows **165** to the swirl slots **183**. Sleeve **149** includes three small pressure balancing holes **153**, **155** and **157** located on sleeve flange **150**, as shown in FIG. **6C**. The sleeve **149** includes upper ports **175** which align with pintle ports **173** and lower ports **177** which align with swirl slots **183** and to form a continuous fuel flow path direct to swirl chamber **185**. When bellows **165** is extended so that swirl slots **183** are open, the fuel flows through swirl slots **183** to swirl chamber **185** and into the orifice aperature **171** that opens onto gas generator **3**. The inner vertical walls of the bellows **165** and the vertical walls of the sleeve **149** form the flow path for the fuel. The sleeve **149** is also ported at the top and bottom, thus forming a path for fuel flow, as mentioned above. The orifice plate **167** includes a bored orifice section **171** allowing fuel to exit into generator **3**. The orifice plate further includes a circular slotted or recessed portion **169** to accept the downward extending portion **181** of the pintle **141** and to act as a closure means to control the amount of swirled fuel from the swirl slots **183** exiting into the gas generator **3**. The total effective flow area is a function of the slots and orifice plate exit areas. The cone angle of the pintle is designed to bring the pintle diameter and the hole of the swirl plate into an even position, as described above. A small movement of the swirl plate, about 0.007 inch from this point, is enough to develop a cone spray of approximately 54° at the desired low flow of 0.09 lb/sec of Otto Fuel with an injector ΔP of 23 psi. Dash pot seal **151** is incorporated into the design to help eliminate excessive pressure oscillation during idle flow. The seals **151** may be made of Teflon or other similar material. The fixed pintle **141** is fastened to top plate **147** by nut **143**. The injector housing **163** is attached to top plate **147** and is separated slightly by metal O ring **159**. The pintle cone **141***b* and the downward extending section **181**, when openly aligned with sleeve ports **177**, form a flow path **179** to swirl chamber **185**. The pintle **141** is fixed wherein the bellows **165** is operatively coupled to the orifice plate **167**. The sleeve **149** is attached to orifice plate at recess section **169** so that when bellows **165** compresses or expands, the orifice plate **167** and sleeve **149** move correspondingly and in phase with bellows **165**.

The overall system functions in the following manner with approximate timing sequences being determined by experimentation, as illustrated in Table I.

TABLE I

Time (seconds):		
	0	Ignition of solid igniter squib
	0.016	Power to solenoid of propellant value
	0.16	Arrival and ignition of Otto Fuel in gas generator
	0.180	Rupture of burst disc
	0.40	Solid igniter burst

Referring to FIG. **1**, burst disc **123**, located between fuel feed line **125** and Otto Fuel tanks **119** and **121**, bursts at ignition. The idle orifice **45** takes the place of a gas relief valve for idle operation.

Referring to FIG. **6**, the flange of sleeve **149** has three holes **153**, **155**, and **157** drilled to allow for the exchange of Otto Fuel between the upper and lower side of the flange **150**. The holes are each 0.0135 inches in diameter. The system then functions as a dash pot when coupled with a dash pot seal **151** to damp out excessive pressure oscillations during idle flow. Holes **153**, **155** and **157** allow the necessary pressure equalization. The system has stable operation with rapid flow changes up to 7.25/1 and the capability of handling flow variation of 13/1 with changes in the spring constant of the bellows and the injector valve stroke. Moreover, increases to 20/1 for idle periods are possible by adding a fixed flow pilot hole to the injector. The system requires no valves other than an explosively operated burster disc **123** in the propellant supply line **125** to separate the gas generator and the propellant tank during storage. The fuel system is self-regulating and responds almost instantaneously to changes in chamber pressure P_c from idle to demand flow. This type of unique injector can also be used with other monopropellants such as hydrazine and MHF as well as bipropellants. The gas generator may be constructed of titanium or other similar lightweight high temperature material that is well known in the art.

What is claimed is:

1. An on-demand closed loop variable flow gas generator for a reaction control system including a fuel flow means, variable flow injector, igniter and a gas generator with a plurality of thruster means, said injector comprising in combination:

a. a fuel inlet operatively connected to said fuel flow means;

b. fuel discharge ports;

c. a stationary pintle device including said fuel inlet and said discharge port and a cone shaped point attached to a circular shaped downward extending portion, said downward extending portion including a means for swirling fuel and a plurality fuel discharge slots;

d. a vertically extending partially enclosed sleeve with an upper flange portion and a lower flange portion having swirling fuel exit ports said sleeve circularly encompassing said stationary pintle;

e. a bellows portion circularly encompassing said sleeve, said circularly surrounding pintle wherein a space between said bellows and said sleeve forms a fuel flow path for said fuel;

f. an orifice plate operatively attached to said bellows and said sleeve so that when said bellows compresses or expands said sleeve and said plate move in a vertical direction with respect to said bellows;

g. said plate having an orifice opening onto said gas generator; and

h. said sleeve having a recessed portion to accept said downward extending portion of said pintle wherein said recessed portion varies the discharge area of said slots.

2. The device in claim 1 wherein said igniter is operatively attached to an opening into said gas generator at a 30° angle from said injector to allow a convergence between ignited fuel and injector fuel at locus point in said generator.

3. The device recited in claim 1 wherein said igniter is divided into a first section and a second section wherein said first and second section are separated by a foil burst disc, said first section comprising a solid propellent grain and a squib to ignite said propellant and a filter attached to a nozzle, said nozzle discharging said ignited propellant at such a pressure to break said disc, thus allowing propellant to enter said second section, said second section comprising ball powder surrounding a further burst disc and a foil disc which separates said second section from the chamber of said gas generator, said ignited propellant subsequently igniting ball powder and breaking said discs, thus allowing said ignited propellant to enter said gas generator.

4. The device recited in claim 1 wherein said sleeve includes a pressure equalization means.

5. The device recited in claim 4 wherein said equalization means is a flange extending from the upper portion of said sleeve and said flange including three pressure equalization holes wherein said flange is located between a vertical limiting means whereby said vertical movement of said flange bellows and orifice plate are limited by said limiting means.

6. The device recited in claim 5 wherein said equalization means further includes a sealing means coupled to said flange wherein said flange having holes and said sealing means, when located in said limiting means, functions as a dash pot.

7. The device recited in claim 1 wherein said swirl slots are tangentially intermittently located at 45° of the side walls of said downward extending portion of said pintle and in a stationary relationship with respect to said orifice.

8. The device recited in claim 7 wherein the propellant is brought into rotation into said orifice plate by means of said tangential slots of downward section of said stationary pintle in a swirl chamber formed by said orifice and said slots.

9. The device recited in claim 8 wherein said movable orifice includes a slotted portion to accept said downward extending portion with said tangential slots whereby said orifice plate in moving away from said pintle said tangential slots are uncovered thus varying the effective area of said swirl chamber.

10. The device recited in claim 9 wherein said swirl chamber is joined to the bellows wherein said movement is initiated by a pressure differential across the bellows and swirl chamber wherein the resistance to movement by said bellows is further controlled by a pressure equalization means.

* * * * *