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Oct. 21, 1969 B. BERBERICH 3,473,879

SHOCK WAVE BURNER

Original Filed Sept. 22, 1966 3 Sheets-Sheet 1

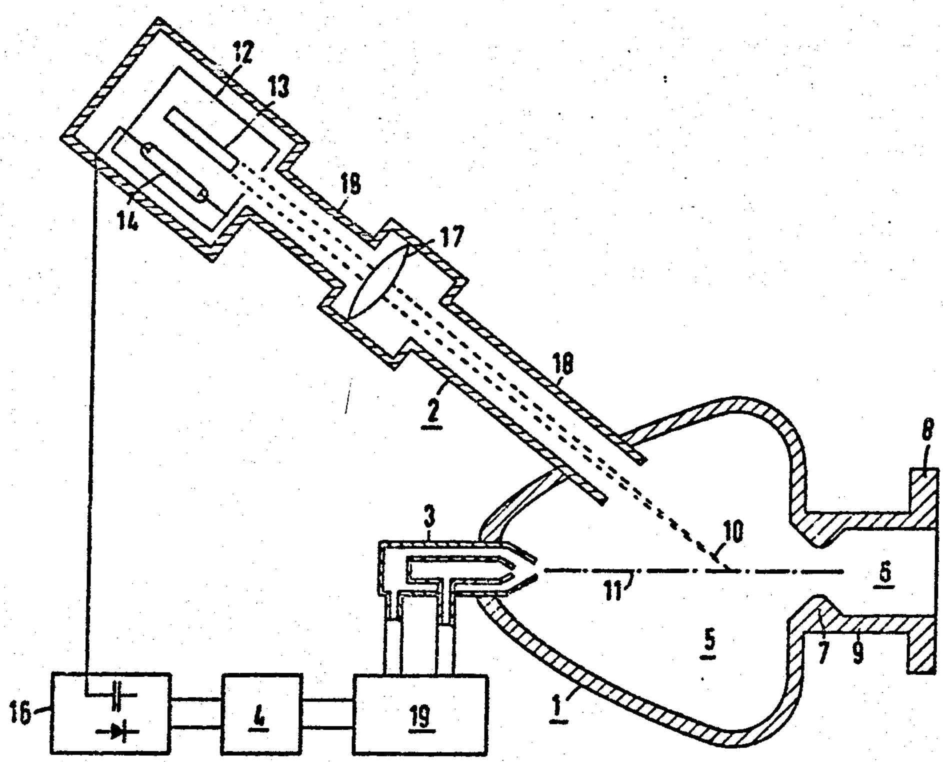

Fig. 1

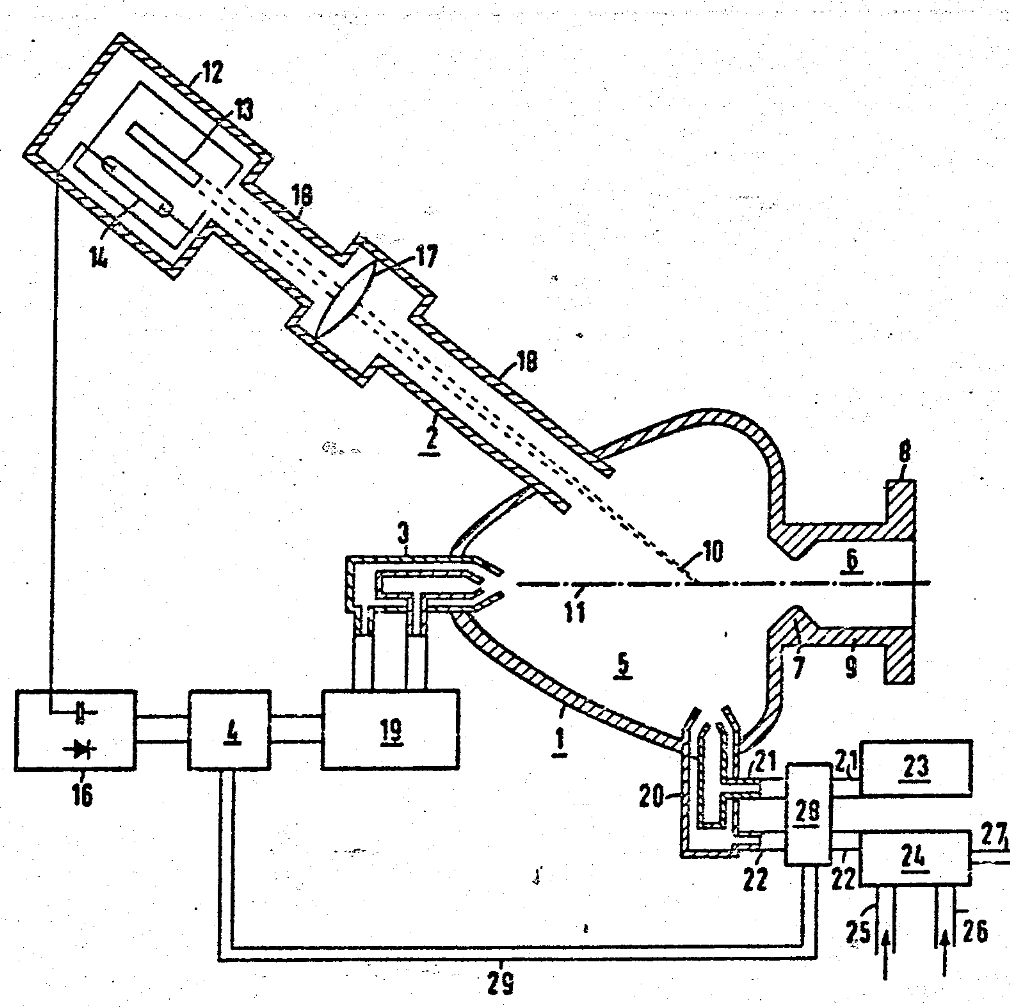
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Fig. 2

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SHOCK WAVE BURNER

Original Filed Sept. 22, 1966 3 Sheets-Sheet 3

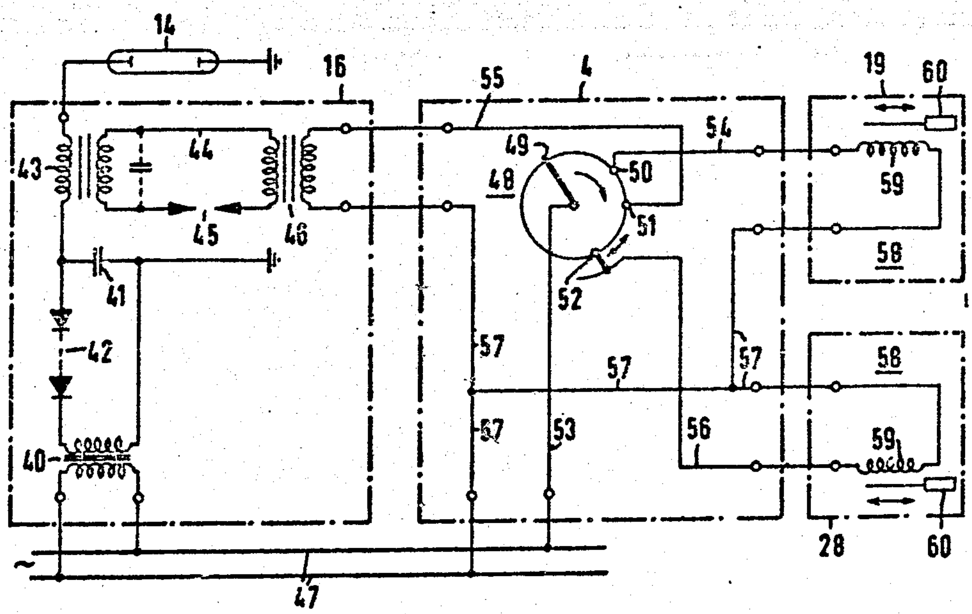

Fig. 3

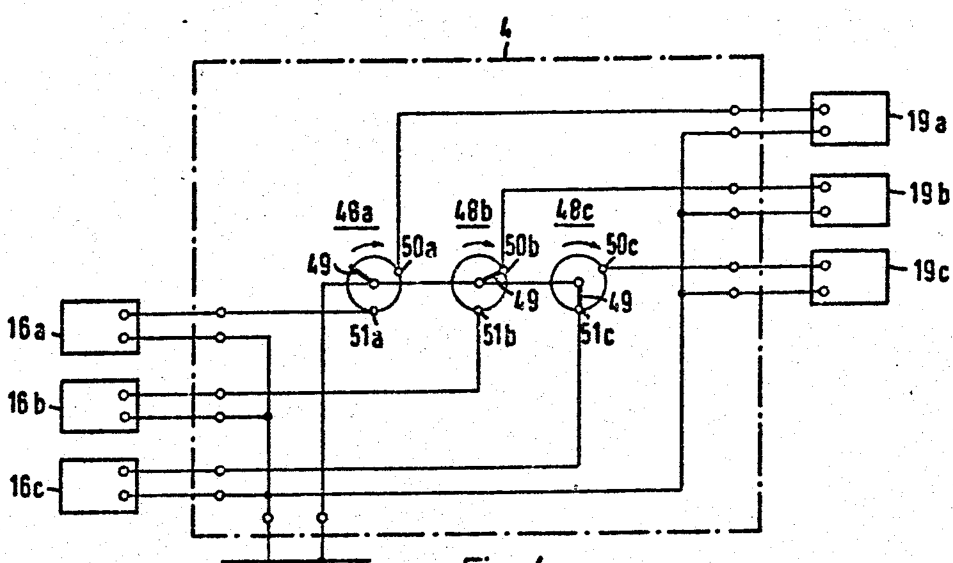

Fig. 4

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3,473,879
SHOCK WAVE BURNER

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Continuation of application Ser. No. 581,284, Sept. 22, 1966. This application Sept. 10, 1968, Ser. No. 768,587
Claims priority, application Germany, Sept. 25, 1965, S 99,662
Int. Cl. F23c 3/02; H01s 3/00
U.S. Cl. 431—1 4 Claims

ABSTRACT OF THE DISCLOSURE

Shock wave burner includes equipment for periodically injecting fuel-oxidant mixture into a constant-volume combustion chamber, a laser pulse device for directing an intermittent beam of laser radiation pulses into the chamber so as to repeatedly ignite fuel-oxidant mixture supplied thereto, and equipment for synchronizing the frequency of injection of the fuel-oxidant mixture into the chamber with the pulse frequency of the laser beam.

This application is a continuation of 581,284, filed Sept. 22, 1966, now abandoned.

My invention relates to shock wave burners. Such burners are of the type undergoing periodically ignited constant-volume combustion. In contrast to conventional firing techniques, wherein constant-pressure combustions occur substantially, a constant-volume combustion entails an explosive combustion with an accompanying pressure wave. A particular advantage of constant-volume combustions is that the pertinent starting components have a stoichiometric relationship and can be virtually completely consumed. Consequently, firing chamber loads above

$$100 \cdot 10_6 \frac{\text{kcal.}}{\text{m.}^3\text{h.}}$$

can be achieved.

Shock wave burners are generally constructed as oscillating burners provided with a burner head and an attached oscillation tube. The periodically ignited combustion occurs in the burner head, which can have the construction of a combustion chamber, and thereafter the hot flaming combustion gases driven by the pressure waves discharge through the oscillation tube. Check valves are provided to permit the negative pressure produced in the burner head after a combustion to suck in new starting components. A pressure wave reflected to the burner head from the end of the oscillation tube then ignites the next combustion. The frequency of ignition is largely determined by the dimensions of the burner head and of the oscillation tube.

Since the details of the kinetic processes of the reaction in vibratory burners are still largely unknown, the ignition sequence cannot be controlled as yet in mass-produced burners of this type. It has therefore been necessary until now to adjust each burner individually. Further details regarding oscillating burners are obtainable for example from the papers published in VDI-Zeitschrift (Journal of the German Engineering Society), vol. 92 (1950), No. 16, pp. 393–399, as well as VDI-Zeitschrift, vol. 94 (1952), No. 31, pp. 1005–1008.

A further disadvantage of oscillating burners is that they can only operate up to pressures that are slightly above atmospheric pressure at the oscillation tube end. They could therefore not be employed heretofore for driving turbines. Furthermore, the constant but unstable firing frequency permits no control of the power.

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It is accordingly an object of my invention to provide a burner of constant-volume construction which can operate also at pressures greater than atmospheric pressure.

It is a further object of my invention to provide such a burner whose power can be easily controlled.

It is yet another object of my invention to provide a burner of this type whose firing frequency can be very accurately adjusted.

It is moreover a general object of my invention to provide a burner for constant-volume combustion which avoids the aforementioned disadvantages of the heretofore known burners of this general type.

With the foregoing and other objects in view, I provide in accordance with my invention a shock have burner having a combustion chamber for constant-volume combustion with a laser ignition device which is adjusted to the injection frequency of a combustible mixture. The shock wave burner of my invention can consequently operate without an oscillatory tube as heretofore required.

More particularly in accordance with my invention I provide a shock wave burner that will permit the periodic constant-volume combustions to occur without a reflecting pressure wave. The starting material components for the combustion are supplied, for example, by injection in premixed condition. Macromixing takes place at the combustion front, whereby the liquid fuel is comminuted into cells that are larger, however, than molecules. The fuel cells are then continuously entrained by the gasified oxidation skins or layers in the vortex of the shock wave, whereby a further combustion and intermixing occurs. This constiutes a micromixing phase, after which molecular digusion occurs. The vortices in the shock wave are produced because of the relative motion between the large masses of the slow moving fuel particles and the more rapidly moving particles of the oxidizing medium.

Ignition by laser beam not only permits dispensing with an oscillation tube but also, in specific applications, with the use of nozzles or tubes outside of the oscillation tube frequency. The frequency of combustions is changeable stepwise to a further range during the operation of the laser by adjusting the pulse frequency of the excitation energy source for the laser material. In addition, with the shock wave burner of my invention, the combustion intensity is capable of being better controlled by suitable selection of the degree of focusing and of the beam intensity. It is consequently possible to construct a suitable burner for a particular use or purpose without being limited by prerequisites. Furthermore, the constancy or steadiness of the combustion frequency permits several burners to be operated flow-wise in parallel. They can be operated in strokes having the same or alternating directions.

In the copending application Ser. No. 562,233, filed July 1, 1966, of B. Andress and L. Kuchelbacher, assigned to the same assignee as the instant application, it has been proposed that oil-fired boilers be ignited by a laser beam, however this copending application relates to a constant-pressure combustion and not to a constant-volume combustion as in the instant application.

But suitable guidance of the laser beam, such as by the structural shape of the combustion chamber, the combustion and explosive wave can be so controlled with the shock wave burner of the instant application that optimum operation thereof is achieved.

Other features which are considered as characteristic for the invention are set forth in the appended claims.

Although the invention is illustrated and described herein as embodied in shock wave burner, it is nevertheless not intended to be limited to the details shown, since various modifications and structural changes may be made therein without departing from the spirit of the invention and within the scope and range of equivalence of the claims.

The construction and method of operation of the invention, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawings, in which:

FIG. 1 is a schematic and partly sectional view of a shock wave burner constructed in accordance with my invention;

FIG. 2 shows the burner of FIG. 1 modified to accommodate auxiliary equipment;

FIG. 3 is a schematic circuit diagram for the burner assembly of FIG. 2; and

FIG. 4 is a schematic circuit diagram corresponding to the diagram of FIG. 3 for a parallel connection of three burner assemblies in accordance with the invention.

Referring now to the drawings and first particularly to FIGS. 1 and 2 thereof, there is shown a pressure wave burner in accordance with my invention having a combustion chamber 1 into which there extends a laser ignition device 2 and an injector device 3 for injecting fuel into the chamber 1, and a control stage 4 connected between the ignition device 2 and the injector device 3. The combustion chamber interior space 5 has the conventional pear shape which has been found to be most suitable heretofore for constant-volume combustions. The inner combustion space 5 can, however, also have a spherical or ellipsoidal form, for example. The combustion chamber 1 is provided with an outlet opening 6 which, as shown, is formed with a nozzle 7 of the Venturi type. Suitable structural components can be connected for any desired purpose to the flange 8 of the outlet tube 9. A laser beam 10 of the ignition device 2 is focused at a location in the vicinity of the center line or center axis 11 of the combustion chamber 1 near the outlet opening 6 whenever high temperatures are to be attained with strong shock waves. If the laser beam 10 is focused more to the center of the combustion chamber space 5, particularly in spherical combustion chamber spaces, more rapid combustions are achieved permitting a greater frequency of combustions.

The combustion chamber space 5 and the outlet opening 6 are of such dimensions that constant-volume combustions are achieved when the throughput through the injection device 3 is so adjusted that the respective hot combustion gases flow out of the combustion space 5 before new fuel is injected into it.

The laser ignition device has the following construction: In a laser head 12 a ruby laser crystal 13 is provided as the laser substance and a flash lamp 14 as excitation energy source. The ignition device for the flash lamp is symbolically shown in FIGS. 1 and 2 by a capacitor and a diode 16. However, the actual circuitry thereof will be described more fully hereinafter with respect to FIG. 3. A lens 17 is disposed in a tube 18 so that the laser beam is focused in a desired manner.

As an operating example, it can be assumed that adjustment is made to a ratio of oil to air of 1:1,000. When the mixture is heated to 80° C. in a hot combustion chamber, a combustible mixture is thus provided which can be ignited by a laser pulse having an energy of substantially 1.5 watt-seconds (w.s.) and a pulse duration of 0.5 milliseconds (m.s.).

When the ruby crystal has an opening angle of about 30 minutes, the laser beam can be focused through a lens 17 having a focal distance of one meter to a region of highest energy density of approximately 2 millimeters (mm.). This region of highest energy can be substantially 2 centimeters (cm.) long. Light pulses of 0.3 to 2 milliseconds (ms.) duration are suitable for exciting the laser crystal. The propagation speed of the combustion operation with the pressure wave is about 1,000 meters per second (m./s.).

The ignition sequence is simply controlled by suitably adjusting the ignition circuit of the flash lamp, as de-

scribed hereinafter in greater detail with regard to FIG. 3. A control device 4 accordingly controls the ignition sequence. The control device 4 simultaneously acts upon the device 19 which controls the fuel supply or the throughput of the combustible fuel to the combustion chamber space 5. The fuel supply control device 19 can be provided with injection pumps of a type known in diesel motors. The starting materials, i.e. the fuel proper and the oxidant therefor, can be supplied in turbulently intermixed form to the combustion space 5 by either being injected separately or through an injector device 3 which is in the form of a ring nozzle. The pulse sequence of the laser beam is synchronized with the injection frequency of the combustible mixture by means of the control device 4.

In FIG. 3 there is again shown the flash lamp 14 which is connected to the ignition device 16, which, with devices 19 and 28, hereinafter more fully described, is in turn connected to the control device 4. Thus FIG. 3 is a schematic circuit diagram of the embodiment shown in FIG. 2. A transformer 40 is located in the device 16 for stepping up the line voltage to approximately 1.5 kilovolts (kv.). A capacitor 41 and rectifier 42 are connected to the secondary winding of the transformer 40. The capacitor 41 is virtually loaded to the peak value of the alternating voltage of the secondary coil. In a narrower sense, the ignition device comprises an ignition coil 43 in which a voltage pulse in the order of magnitude of 10 kilovolts (kv.) is supplied by a spark gap 45 from a circuit 44 which ignites the flash lamp 14. The energy for the flash lamp 14 is supplied by the capacitor 41 from the transformed line voltage. The ignition operation is initiated by a current pulse from the control device 4 to the transformer 46. The assembly 16 and the control device 4 are connected to the alternating current conductors 47 of a power line.

The control device 4 consists primarily of a time-limit switch 48 which, in the interest of simplicity, is shown as a mechanical component. The time-limit switch 48 has a contact arm 49 rotatable in a clockwise direction, which sequentially engages the contacts 50, 51 and 52. The contact 52 is displaceable as shown in FIG. 3. A lead 53 connects one phase of the voltage line 47 with the rotatable switch arm 49. Leads 54, 55 and 56 extend respectively from the contacts 50, 51 and 52 and connect with the terminals of the device 19, the ignition device 16 and the device 28. The branching conductor 57 connects the second pole of the terminals with the return voltage line 47.

The device 19 which controls the throughput of the oxidant, as well as the device 28 which controls the supply of the fuel, which is the reactive partner to the oxidant, can each essentially consist of a magnetic valve 58. If the circuit to the device 19, for example, were closed by the timer 48, current would flow through the coil 59 and would electromagnetically displace an iron core, for example, to actuate the valve member 60. The device 28 can have an analogous construction to that of the device 19 and can also include a coil 59 and a valve member 60. In the simplest case, the valve members 60 can open the pressurized supply conduits by the actuation of the magnetic valves.

By means of the control device 4, the circuit for the device 19 is closed first and thereafter the circuit for the ignition device 16 and finally for the device 28 are closed. Therefore oxidant is initially injected into the combustion space 5, ignition is then effected and reaction material supplied. The time interval between the fuel injection and the injection of the reaction partner therefor, such as the oxidant, can be adjusted by suitably displacing the contact 52.

FIG. 4 shows a circuit for three shock wave burners that are operated in parallel and are alternately ignited. The burner of FIG. 4 has three ignition devices 16a, 16b and 16c, and three devices for controlling the injection of oxidant 19a, 19b and 19c. The control device 4' thus is provided with three time-delay switches 48a, 48b and 48c, each of which is connected to one of the shock wave burners (not shown). If only one ignition device and one device for supplying fuel are to be controlled, the time-delay switches, as shown in FIG. 4, only require two contacts which are engageable by the respective switching arms 49 as they are rotated clockwise. If the respective switching arms 49 of the three time-delay switches 48a, 48b and 48c are rotated with the same rotary speed they can be so adjusted that they are displaced relative to one another at a specific phase angle. The circuits of the components of the shock wave burners which are to be controlled are then closed in a specific sequence. It is understood, of course, that the contacts 50a to 51c can each be of a predetermined width in the rotary direction so as to hold the circuit closed for a specific period of time.

For the shock wave burner constructed in accordance with my invention, a great number of practical applications are available. Thus, it can be utilized in furnace technology and in metallurgical engineering as well as for maintaining turbine installations. In comparison with shock wave burners which operate according to the conventional principle of the oscillating burners, a higher efficiency of combustion is advantageously achieved with the burners of my invention at higher temperatures and especially also at a counter or reactive pressure.

When the shock wave burner of my invention is employed for supplying gas to MHD generators, a particularly favorable effect achieved is that the hot gas zones determine the productive power or output of the generator while the wall material of the flow channel is subjected only to the lower temperature delivered through the hot and cold gas zones.

In chemical processing engineering the materials which are to be reacted can be injected intermittently alone into the combustion chamber or with fuel materials which tend to remain neutral with respect to the materials entering into the reaction and their products. If the combustion frequency is kept very steady or constant, optimum operating conditions are thereby able to be adjusted.

When the shock wave burners constructed in accordance with my invention are to be installed in missiles or space vehicles that operate by jet propulsion or reaction drive, an essential advantage is afforded by my burner over the known oscillating burners, in that the nozzle shape of the burner of my invention can be selected solely according to flight technology aspects. A supersonic or Laval nozzle can accordingly be directly connected to the combustion chamber. With oscillating burners, however, it is very difficult to achieve supersonic flows. The velocity of the reflected wave is namely lower than the flow speed out of the Laval nozzle for supersonic flows. Oscillating burners must rely, however, for ignition on reflecting waves.

I claim:

1. Shock wave burner comprising a combustion chamber for constant-volume combustion, said combustion chamber having a waste gas outlet opening, means for periodically injecting a given quantity of ignitable fuel-oxidant mixture at a given rate into said combustion chamber, ignition means comprising a laser pulse devce for directing an intermittent beam of laser radiation pulses into said combustion chamber so as to repeatedly ignite fuel-oxidant mixture supplied thereto, means for synchronizing the frequency of injection of the fuel-oxidant mixture into said combustion chamber with the pulse frequency of said laser beam and for adjusting the flow rate of said fuel-oxidant mixture through said injecting means so that waste gas from an ignited quantity of fuel-oxidant mixture injected in a previous period discharges through said outlet opening prior to injecting into said combustion chamber fuel-oxidant mixture in said given quantity for the next-succeeding period.

2. Shock wave burner according to claim 1, wherein said mixture injecting means is adapted to intermittently supply fuel and oxidant to said combustion chamber in stoichiometric proportions.

3. Shock wave burner according to claim 1, wherein said mixture injecting means is adapted to intermittently supply fuel and oxidant reactive with each other and at least one other material remaining neutral with respect to the reactive fuel and oxidant and the reaction products thereof.

4. Shock wave burner according to claim 1, wherein said combustion chamber is substantially pear-shaped.

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U.S. Cl. X.R.

60—39.76; 331—94.5