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Berger

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[54] **FUEL BURNER WITH IMPROVED ULTRASONIC ATOMIZER**

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[52] **U.S. Cl.** **431/1,** 239/102, 310/8.2, 310/8.7, 310/9.1, 431/265, 431/350

[51] **Int. Cl.** **F23c 11/00**

[58] **Field of Search** 431/1, 265, 350; 239/102, 239/4; 310/8.2, 8.3, 8.7, 9.1

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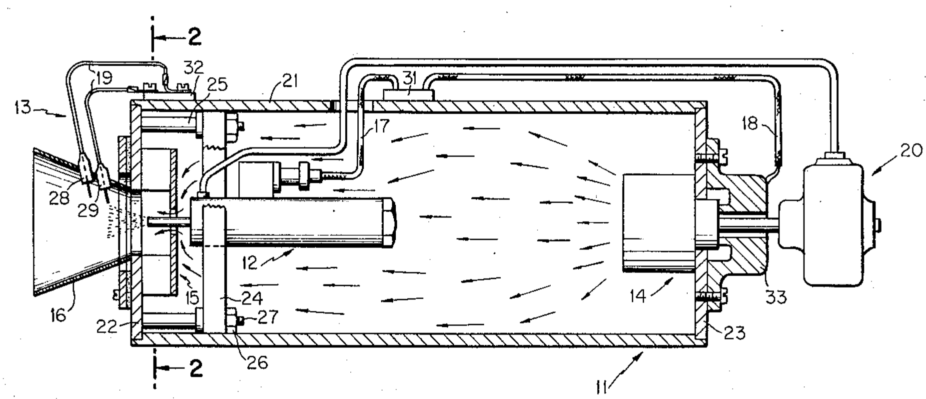
[57] **ABSTRACT**

An apparatus for achieving efficient combustion of fuels employs an improved ultrasonic atomizer. This atomizer includes: an active cylindrical resonator section having an atomizing surface and a passage therethrough for delivering fuel to the atomizing surface; a dummy cylindrical resonator section for providing counteractive forces to the active resonator section and having a flanged portion; a transducer sandwiched therebetween for providing the driving force to the resonator sections including a pair of piezoelectric discs and a high voltage electrode positioned therebetween; clamping means, including internally threaded, electrically conductive cylindrical casing, thrust washer and clamp nut for enclosing the resonator sections and transducer and for holding the resonator sections in compression against the transducer to insure good acoustical coupling while at the same time assuring that losses of acoustical energy are kept to a minimum; an insulating sleeve surrounding the resonator sections and transducer, spacing same from the casing and electrically isolating the transducer from the casing; means mounted on the casing for delivering electrical energy to the transducer from a terminal post; means mounted on the casing for delivering fuel to the fuel passage within the active resonator section; and, sealing means between casing and active resonator section, for protecting the interior portions of the atomizer, especially the transducer, from fuel contamination.

13 Claims, 6 Drawing Figures



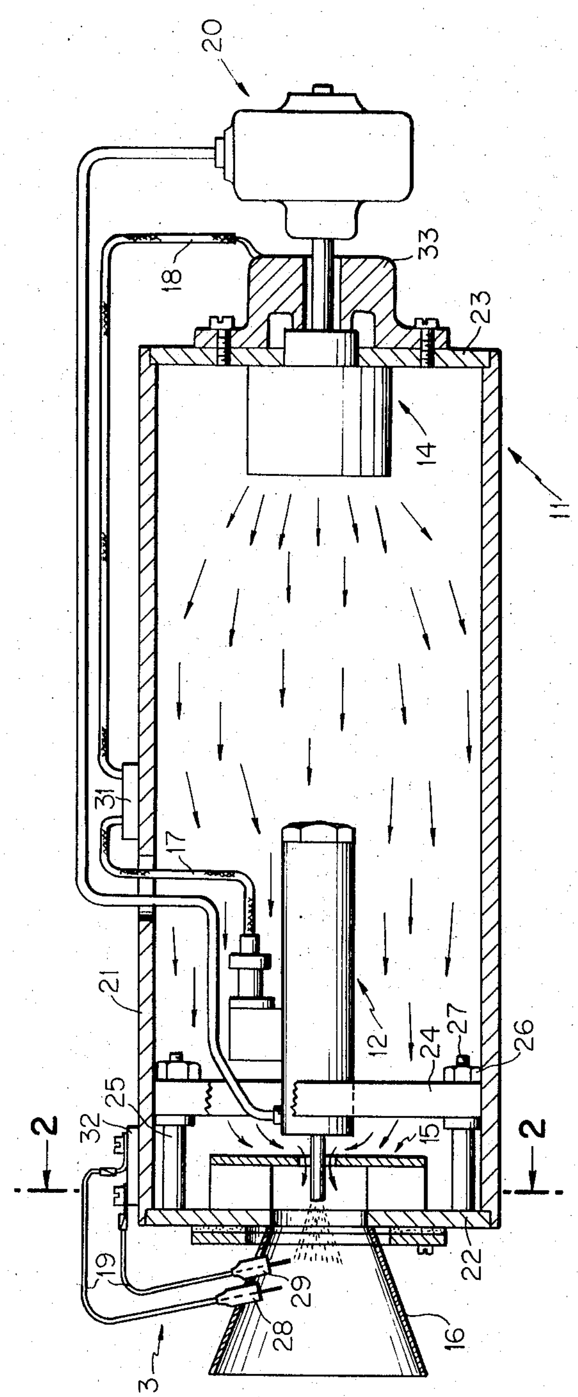

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FIG.1

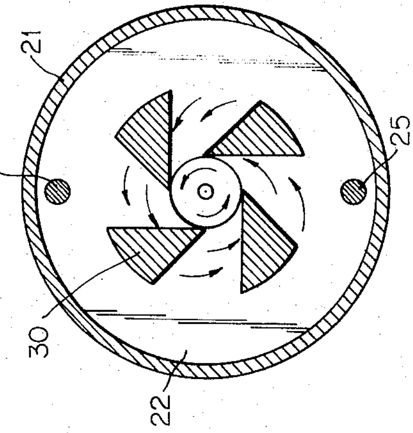
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FIG.2

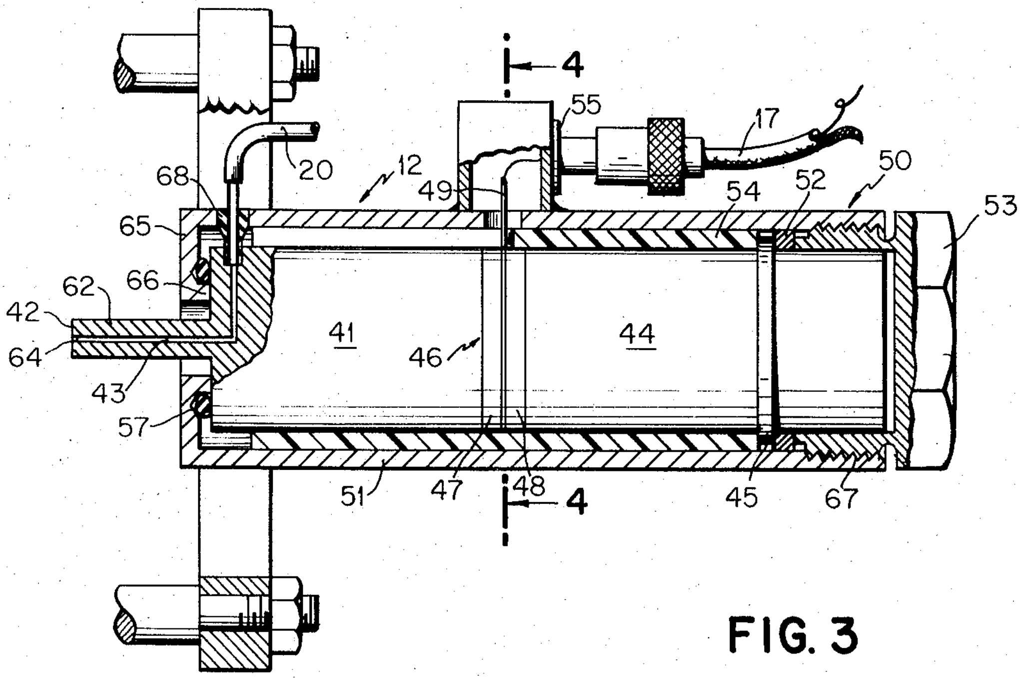

FIG. 3

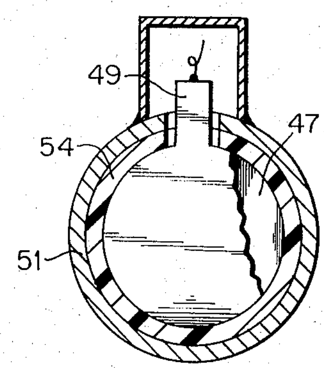

FIG. 4

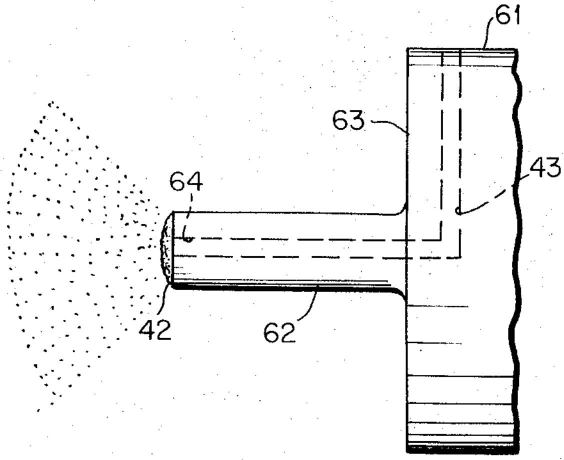

FIG. 5

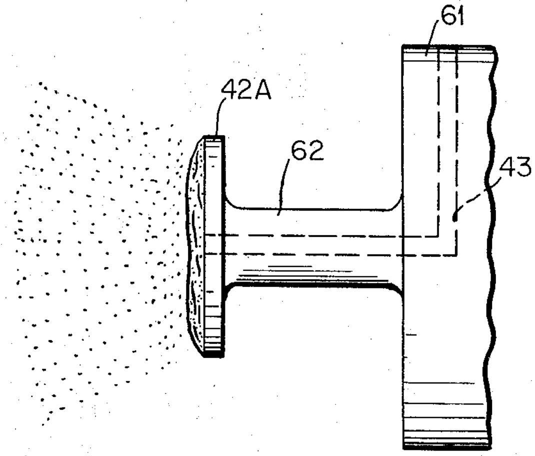

FIG. 6

FUEL BURNER WITH IMPROVED ULTRASONIC ATOMIZER

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to apparatus for achieving complete and efficient combustion of fuels that employs an improved ultrasonic atomizer.

2. Description of the Prior Art

In a conventional fuel atomization device, the fuel (fuel oil, kerosene, gasoline, etc.) is forced at high pressure through a small orifice breaking the stream into droplets. For a conventional fuel nozzle spray at a flow rate of 1 gal./hr. the mean droplet diameter is usually greater than 125 microns.

In a fuel atomization device using ultrasonic energy, a film of the fuel is injected at low pressure onto a plane surface, and vibrated at frequencies in excess of **20** kHz in a direction perpendicular to the surface. The rapid motion of the plane surface sets up capillary waves in the liquid film. When the amplitude of the capillary wave peaks exceeds that required for stability of the system, the liquid at the peak crests breaks away in the form of droplets. For flow rates of approximately 1 gal./hr. the mean droplet diameter is about 15 microns, an order of magnitude less than for conventional fuel atomization devices, thereby increasing approximately tenfold the effective fuelair interface surface area for a given quantity of fuel. Since burning occurs only at the fuel-air interface, the increase in surface area significantly improves burner efficiency.

The typical prior art ultrasonic atomizer includes a transducer sandwiched between and acoustically coupled to a pair of resonator sections. The transducer includes a pair of piezoelectric crystals with a high voltage electrode positioned therebetween for electrically exciting the crystals and thereby providing the driving force for the resonators. A passage extends through one of the resonator sections for delivery of fuel to its tip where atomization takes place. Because the motion developed by the transducer would be, in itself, insufficient to cause atomization without further amplification the resonator section is provided with a large diameter segment and a small diameter segment so as to form a step in the region of their joining. Amplification at the tip is approximately equal to the ratio of the squares of the larger to the smaller diameters.

At the juncture where the small diameter segment joins the large diameter segment the right angle bend and the reduced cross section of material causes extremely large stress concentration. Since stress levels increase with operating frequency, prior art atomizers have been prone to fracture at this juncture when constructed of conventional materials such as aluminum.

Also in the past the resonator sections — transducer structure have been clamped together using individual screw type clamping which leads to non-uniform compression of the piezoelectric discs, possible early fracture of the discs, loosening of the screws due to vibrations and consequent loss in performance thereby suffered. The individual screw type units usually employ a soft material, for example, lead, adjacent to the crystals to compensate for non-uniform compression. This "foreign" material causes degradation in performance. Finally, in the prior art individual screw type arrangement, the crystals are completely exposed to contamination by fuel and other contaminants, leading to degradation in performance.

SUMMARY OF THE INVENTION

Accordingly, an object of the invention is an apparatus for achieving efficient combustion of fuels employing an improved ultrasonic atomizer.

Another object is the provision of such an atomizer that resists premature fracture of its resonator sections.

Still another object is the provision of such an atomizer that elminates early fracture of its piezoelectric crystals and fuel contamination of same.

These and other objects are accomplished in accordance with the teachings of the present invention, one illustrative embodiment of which comprises a fuel burner that employs an ultrasonic atomizer that includes: an active cylindrical resonator section having an atomizing surface and a passage therethrough for delivering fuel to the atomizing surface; a dummy cylindrical resonator section for providing counteractive forces to the active resonator section and having a flanged portion; a transducer sandwiched therebetween for providing the driving force to the resonator sections including a pair of piezoelectric discs and a high voltage electrode positioned therebetween; clamping means, including internally threaded electrically conductive cylindrical casing, thrust washer and clamp nut for enclosing the resonator sections and transducer and holding the resonator sections in compression against the transducer to insure good acoustical coupling while at the same time assuring that losses of acoustical energy are kept to a minimum; an insulating sleeve surrounding the resonator sections and transducer, spacing same from the casing and electrically isolating the transducer from the casing; means mounted on the casing for delivering electrical energy to the transducer from a terminal post; means mounted on the casing for delivering fuel to the fuel passage within the active resonator section; and, sealing means between casing and active resonator section, for protecting the interior portions of the atomizer, especially the transducer, from fuel contamination.

BRIEF DESCRIPTION OF THE DRAWING

The foregoing and other objects, features and advantages of the invention will be apparent from the following more particular description of the preferred embodiments of the invention, as illustrated in the accompanying drawing, wherein:

FIG. **1** is a cross sectional view of a fuel burner employing the novel ultrasonic transducer of the present invention;

FIG. **2** is a sectional view taken along the lines **2—2** of FIG. **1**;

FIG. **3** is an enlarged cross sectional view, partially cut away, showing the novel ultrasonic atomizer constructed in accordance with the teachings of the present invention;

FIG. **4** is a sectional view taken along the lines **4–4** of FIG. **3**;

FIG. **5** is an enlarged cross sectional view, partially broken away depicting the step region and atomizing surface of the ultrasonc transducer of FIG. **4**; and,

FIG. **6** is a view similar to FIG. **5** but of an alternate embodiment depicting a flange type atomizing surface.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawing, apparatus constructed in accordance with the teachings of the present invention will now be described. While not so limited, the invention finds immediate application in achieving complete and efficient combustion of fuels and will be so described in such an environment.

FIG. 1 illustrates a burner **11** suitable for burning fuel oil for heating a home or other building or for hot water heating. Such a burner is designed to achieve atomization of the fuel oil, ignition of same and to provide a controlled flow of air.

The burner **11** is seen as including atomizer **12**, ignition means **13**, blower **14**, air deflection means **15**, flame cone **16**, means **17, 18** and **19** for supplying electric power to atomizer **12**, ignition means **13** and the motor **33** which drives blower **14** and pump means **20** for supplying fuel oil to the atomizer **12**.

Essentially the entire structure is surrounded by and supported on a cylindrical housing **21** with cover plates **22, 23.**

The atomizer **12** is of the ultrasonic variety and is positioned axially of housing **21** via support means **24** affixed to and spaced from cover plate **22** by spacers **25**, nuts **26** and bolts **27.**

Ignition is achieved in the burner **11** through the use of ignition means **13** that includes a pair of ignition electrodes **28, 29** positioned within but electrically isolated from flame cone **16.**

Air is forced by means of a blower **14** mounted on the cover plate **23** through the housing **21** over the atomizer **12** through cover plate **22** past the electrodes **28, 29** in flame cone **16** and thoroughly mixed with the fuel.

Before reaching the atomizing tip of atomizer **12** the air is passed through the deflector means **15** that includes a plurality of deflecting vane segments **30** to impart a swirling motion to a portion of the air just before reaching the atomizing tip to achieve better fuel-air mixing. The deflector means **15** is affixed to and supported on the cover plate **22.** Flame cone **16** provides confinement and shaping means for the resulting flame.

Electric power is fed to the atomizer **12**, ignition means **13** and motor **33** for blower **14**, via the power leads **17, 18, 19** extending from terminal post **31, 32.** Fuel is supplied to the atomizer **12** at low pressure via means **20** that is also driven by the motor **33** for the blower **14.**

Referring in particular to FIG. **3** of the drawing, the atomizer **12** is seen as including: An active cylindrical resonator section **41** having an atomizing surface **42** and a passage **43** therethrough for delivering fuel to the atomizing surface; a dummy cylindrical resonator section **44** for providing counteractive forces to the active resonator section **41** and having a flanged portion **45**; a transducer **46** sandwiched therebetween for providing the driving force to the resonator sections including a pair of piezoelectric discs **47, 48** and a high voltage electrode **49** positioned therebetween; clamping means **50** including internally threaded electrically conductive cylindrical casing **51**, thrust washer **52** and clamp nut **53** for enclosing the resonator sections and transducer and for holding the resonator sections in compression against the transducer to insure good acoustical coupling while at the same time assuring that losses of acoustical energy are kept to a minimum; an insulating sleeve **54** surrounding the resonator sections **41, 44** and transducer **46**, spacing same from the casing **51** and electrically isolating the transducer **46** from the casing **51**; means **55** mounted on the casing **51** for delivering electrical energy to the transducer from the terminal post **31**; means **56** mounted on the casing **51** for delivering fuel to the fuel passage **43** within the active resonator section **41**; and, sealing means **57** between casing **51** and active resonator section **41** for protecting the interior portions of the atomizer **12**, especially the transducer **46**, from fuel contamination.

The active resonator section **41** comprises a large diameter cylindrical segment **61** and a small diameter cylindrical segment **62**, so as to form a step **63** in the region of their joining. The small segment provides an atomizing surface **42** at its terminal end. The fuel to be atomized is fed through the right-angle passage **43** in the active resonator segment terminating at an orifice **64** in the atomizing surface. The cross sectional area of right-angle passage **43** and orifice **64** should be large enough to ensure low pressure flow at the normal fuel delivery rate.

The motion developed by the transducer **46** would be, in itself, insufficient to cause atomization without further amplification of the motion. Amplification is accomplished by the provision of the step **63** at the interface between the large diameter segment **61** and the small diameter segment **62**, with the amplification being approximately equal to the ratio of the squares of the larger to the smaller diameters, with the amplitude of motion being maximum at the atomizing surface **42.** In a typical embodiment the small diameter segment **62** is one quarter wave length long.

In the geometry thus far depicted which is that of a resonant cavity for longitudinal pressure waves, there will be node locations at planes along the structure corresponding to locations of maximum stress and minimum displacement. These nodal planes are designed to be at the step **63** of the interface between the small diameter segment **62** and large diameter segment **61**, at the center of the transducer **46** and at the flange **45** in the dummy resonator section **44.** Deviations of the nodal plane positions from their theoretical locations are commonplace in actual devices because of certain inexactness in the analytic expressions, but this circumstance does not cause appreciable degradation in performance.

At the juncture where the small diameter segment **62** joins the large diameter segment **61** which is a nodal region, the right-angle bend and the reduced cross-section of material causes extremely large stress concentrations. Careful machining of the step is required to avoid machining marks or other imperfections which could cause premature failure. Since stress levels increase with operating frequency, atomizers designed for operation at 100 kHz are prone to fracture at this juncture when constructed of conventional materials such as aluminum.

Titanium is selected as the resonator material since it possesses the required strength to withstand the generated stress. Titanium has the additional desirable feature of having a comparable acoustic impedance to the transducer with the result that transmission of motion from the transducer to the resonator sections is efficiently transferred.

The atomizer further includes a dummy resonator section **44** which serves to provide counteractive forces to the active or atomizing resonator section **41.** In a typical embodiment the total length of the dummy resonator section **44** is one and a half wave lengths long and includes a flanged portion **45** located one quarter of a wave length from the free end.

The transducer **46** comprises a pair of piezoelectric discs **47, 48** and and an electrode **49** positioned therebetween, excited by high frequency electrical energy fed thereto. Multicrystalline piezoelectric materials such as lead zirconate titanate can be employed. The piezoelectric discs **47, 48** are oriented so that the crystal faces in contact with the high voltage electrode **49** are of the same polarity. The high voltage electrode **49** for supplying power to the conductively plated faces of the piezoelectric discs comprises a titanium tab, whose use is dictated by acoustical compatibility requirements with the other elements of the atomizer.

A novel clamping means is provided that includes an electrically conductive cylindrical casing **51,** thrust washer **52** and clamp nut **53** for enclosing the resonator sections and transducer **46** and for holding the resonator sections in compression against the transducers to insure uniform compression and good acoustical coupling. The annular portion **65** of casing **51** has an inwardly extending annular shoulder portion **66** that upon tightening abuts the step **63** of the active resonator section **41.** The opposite end of casing **51** is internally threaded at **67.**

An insulating sleeve **54** of phenolic resin or other suitable material surrounds the resonator sections **41, 44** and transducer **46** spacing same from the casing and electrically isolating the transducer **46** from the casing **51,** as well as providing centering means for the various elements comprising the atomizer along a common axis.

An electrical connector **55** for supplying electrical energy to the titanium electrode **49** is mounted on the casing **51.**

Fuel is supplied through the means **20** to the passage **43** within the active resonator section **41** through a leak proof entry area **68** in the casing **51.**

An O-ring seal **57** of suitable material, including metal, is positioned between the step **63** and the annular top portion **65** to prevent fuel entry.

It is thus seen that the clamping means serves four functions. It provides the means for maintaining tension between the transducer **46** and the resonator sections **41, 44** necessary to create the proper acoustical coupling and to minimize energy losses. Compressive force is applied between two approximate nodal points, the step **63** in the active resonator section **41** and the flanged portion **45** in the dummy resonator section **44** by the casing **51** working in concert with the clamp nut **53** and thrust washer **52** squeezing transducer **46** and resonator sections **41, 44** together. The clamping cylinder **51** also serves as a common electrical path between the two resonator sections **41, 44** which is necessary in this design since both resonator sections operate at the same electric potential. The casing **51** further serves to provide complete protection from fuel or any other foreign matter from reaching the transducer **46.** Finally, the casing **51** acts as a mounting structure.

Since it is tied to two nodal plane, the casing **51** has very little vibratory motion induced and acoustical energy losses are kept to a minimum. Typically, the casing is constructed of a material very different in acoustical properties from the material of the resonator sections in order to further insure a minimum of energy transfer from resonator sections to casing. Stainless steel is one example of preferred material.

In operation, the blower **14** is actuated for circulation of air. Fuel is fed under low pressure from the fuel supply means **20,** leak proof entry area **68,** passage **43** and orifice **64** to the atomizing surface **42.**

High frequency electrical energy is fed to the voltage electrode **49** to actuate transducer **46.** Transducer **46** provides the driving force for the resonator sections **41, 44** such that the fuel oil at the atomizing surface **42** breaks away from same in the form of droplets.

The mean fuel droplet diameter varies approximately inversely with the driving frequency to the two-thirds power. Thus, the greater the ultrasonic driving frequency, the smaller will be the droplets and the greater will be burning efficiency as demonstrable by noting that the available air-fuel interface area increases in approximate proportion to the inverse of the droplet diameter. Operation in a frequency region of between 80–100 kHz for my application is preferred since droplet size is optimum for burning in this frequency range. Specifying the frequency fixes the length of the large diameter segment since this must be a multiple of one-half of the wave length of the sound wave corresponding to the chosen frequency. In a typical embodiment, the large diameter segment is one-half wave length in length.

Important other advantages flow from my novel design. In the past the resonator sections-transducer structure have been clamped together using individual screw type clamping which leads to non-uniform compression of the piezoelectric discs, possible early fractures of the discs, loosening of the screws due to vibrations and consequent loss in performance thereby suffered. The individual screw type units usually employ a soft material, for example, lead, adjacent to the crystals to compensate for non-uniform compression. This "foreign" material causes degradation in performance. Finally, in the prior art individual screw type arrangement, the crystals are completely exposed to contamination by fuel and other ambients leading to degradation in performance.

My cylindrical clamping designs assures the imparting of uniform compression to the crystals, and provides complete protection from fuel or any other foreign matter from reaching the crystals.

The atomizing surface **42** (see FIG. **5**) can be designed for a specified range of fuel deliveries. For lower delivery rates atomizing surface **42** can be used. Enough surface area (equal to the face area less the cross section of orifice **64**) is available for good atomization.

In cases where larger fuel flow rates are required a thin flange **42A** is machined on to the tip of the smaller diameter segment **62** as shown in FIG. **6.**

While the invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and detail may be made without departing from the spirit and scope of the invention.

What is claimed is:

1. In an ultrasonic atomizer that includes a transducer sandwiched between a pair of resonator sections, an atomizing surface at the tip of one of said sections and fuel delivery means to said atomizing surface, the improvement which comprises;

clamping means for holding said resonator sections in compression against said transducer for good acoustical coupling and uniform compression;

said clamping means including a cylindrical casing enclosing said resonator sections and said transducer and engaging said resonator sections at approximate nodal planes; and,

sealing means positioned between said casing and said one of said resonator sections for preventing fuel contamination of said transducer.

2. The invention defined by claim **1** wherein said one of said resonator sections has a large diameter segment and a small diameter segment terminating in said atomizing surface, the interface between said large diameter and small diameter segments constituting a step for amplification of vibratory motion at said atomizing surface, and said resonator sections being of titanium.

3. The invention defined by claim **1** wherein said transducer includes a pair of piezoelectric discs having electrically similar essentially parallel contact faces and a high voltage electrode positioned therebetween, said electrode comprising a titanium tab.

4. The invention defined by claim **1** wherein said casing is of a material having different acoustical properties from the material of said resonator sections.

5. The invention defined by claim **2** wherein the small diameter segment of said one of said resonator sections terminates in a flanged portion acting as said atomizing surface.

6. A fuel burner comprising the combination of:

the ultrasonic fuel atomizer of claim **1**;

means for delivering air for combustion of said fuel;

means for imparting rotary motion to a portion of said combustion air;

means for delivering fuel to said atomizer;

ignition means operable adjacent the atomizing surface of said atomizer; and,

means for confining flame in a cone of proper dimensions.

7. An ultrasonic fuel atomizer comprising: an active resonator section having a large diameter segment, a small diameter segment extending therefrom having an atomizing surface at its terminating end, and a fuel passage therethrough to an orifice in said terminating end for fuel delivery to said atomizing surface, the interface between said large diameter and small diameter segments constituting a step for amplification of vibratory motion at said atomizing surface;

a dummy resonator section for providing counteractive forces to said active resonator section having a flanged portion;

a transducer for delivering mechanical energy to said resonator sections sandwiched between the large diameter end of said active resonator section and said dummy resonator section, said transducer including a pair of piezoelectric discs having electrically similar essentially parallel contact faces and a high voltage electrode positioned therebetween;

clamping means for holding said resonator sections in compression against said transducer for good acoustical coupling and uniform compression of said piezoelectric discs over their entire contact faces;

said clamping means including an electrically conductive cylindrical casing enclosing said resonator sections and said transducer and engaging said resonator sections at approximate nodal planes;

an insulating sleeve surrounding said resonator sections and said transducer, spacing same from said casing and electrically isolating said casing from said piezoelectric discs and centering said transducer and said resonator sections along a common axis;

means mounted on said casing for delivering electrical energy to one of said electrically similar contact faces of said piezoelectric discs through said high voltage electrode and to the other of said faces of said piezoelectric discs through said casing and said resonator sections;

means mounted on said casing for delivering fuel to said fuel passage within said resonator section;

and,

sealing means positioned between said casing and active resonator section for preventing fuel contamination of said transducer.

8. The invention defined by claim **7** wherein said clamping means bears against said active and said dummy resonator section flanged portion.

9. The invention defined by claim **7** wherein said resonator sections are of titanium.

10. The invention defined by claim **7** wherein said high voltage transducer electrode is a titanium tab.

11. The invention defined by claim **7** wherein said casing is of a material having different acoustical properties from the material of said resonator sections.

12. The invention defined by claim **7** hwerein the small diameter segment of said active resonator section cerminates in a flanged portion acting as said atomizing surface.

13. A fuel burner comprising the combination of:

the ultrasonic fuel atomizer of claim **7**;

means for delivering air for combustion of said fuel;

means for imparting rotary motion to a portion of said combustion air;

means for delivering fuel to said atomizer;

ignition means operable adjacent the atomizing surface of said atomizer; and,

means for confining flame in a cone of proper dimensions.

* * * * *