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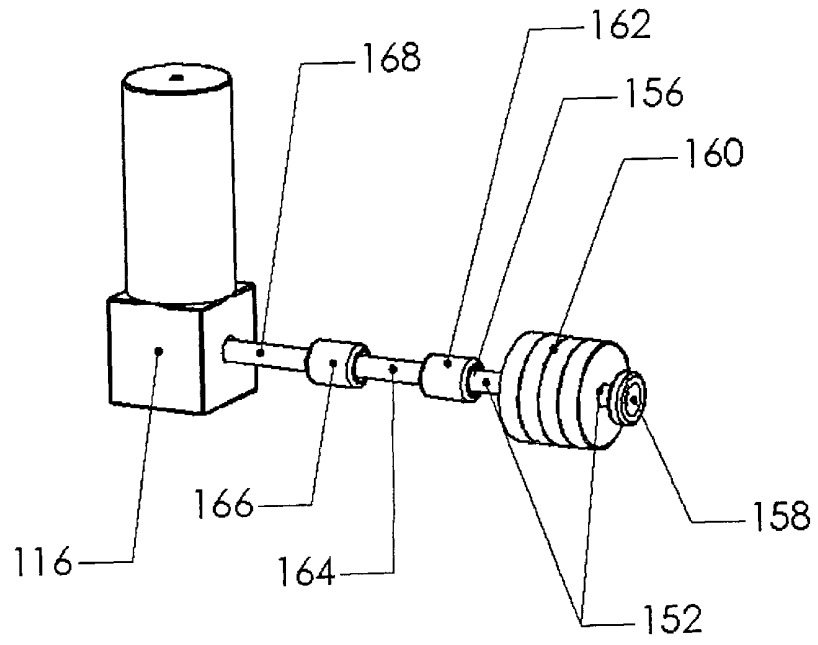

(57) Abstract: An ocular nebulizer that comprises an ultrasonic horn in fluid communication with a first substance source for drawing substance from the source. An ultrasonic oscillator vibrates the horn ultrasonically for nebulizing the substance from the horn exit. An eye cup is configured for placement around an eye, and the horn exit is disposed within the eyecup. The eye cup is configured for directing the nebulized substance towards the eye.

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OCULAR DRUG DELIVERY NEBULIZER

FIELD OF THE INVENTION

The invention relates to a drug delivery device. More particularly, the invention is related to an ultrasonic, piezoelectric, horn nebulizer for delivering an aerosol spray to an ocular region.

BACKGROUND OF THE INVENTION

Eye drops are regularly used by millions of individuals on a daily basis for treatment of a broad spectrum of conditions ranging from dry eye to glaucoma. Eye drops provide a mode of drug delivery that can be made available to a large portion of the population for self-administration, obviating the need for costly medical supervision and/or intervention. Despite the wide-spread acceptance and use of eye drops, the technology for administering the drops is often misused, resulting in sub-optimal treatments. Improper usage typically involves a failure of the user to centrally target the drops in the eye, as well as direct contact between the tip of the dropper and the eye or tear ducts. Various factors lead to such undesirable consequences, including general user difficulty in spatially recognizing the tip of the applicator, an inability to easily squeeze the bottle containing the drops, and hand tremors or shaking during usage. In addition, users typically adopt their own techniques for eye drop administration, including one or more of the following: tilting of the head back or forward, using one or two hands to hold the eye drop device and/or prevent blinking, and displacing the naturally open position of the upper and/or lower eye lid.

In addition to the risks posed by user misuse of standard eye drop devices, the construction of such droppers can lead to substantial variations in performance over the service life of the devices, as well as variations in performance from user to user. In particular, standard liquid-containing bottles with dropper tips can be oriented by different users in a significant range of handling angles. The angulation of the tip with respect to the eye can have a substantial effect on drop size and concomitant volume of medication delivered. Furthermore, the stressing of the device during handling can result in non-uniform delivery volumes with increasing device usage.

To address the inadequacies of eye drop technology, aerosol delivery systems have been developed. For example, U.S. Patent No. 3,170,462 discloses an aerosol ophthalmic device. An aerosol cartridge supplies a mist of medicament that is guided by an

eyecup to an eye. The medicament is discharged from the aerosol cartridge in a single, small burst of mist at a velocity and temperature that will not injure the eye.

Another mist generator is disclosed in U.S. Patent No. 5,346,132. The device includes a spinning rotor within a mist chamber. Liquid is pumped by a finger actuated pump from a cartridge module into the chamber surrounding the rotor, and a spray is created as the liquid exits through a mist port.

Various other types of liquid drug delivery devices are known. For example, as disclosed in U.S. Patent No. 5,630,793, aqueous ophthalmic sprays include a spray nozzle for ejecting a jet of liquid. The nozzle is situated adjacent a piezoelectric or electromagnetic transducer which excites the jet of liquid to form a stream of droplets, which then are directed passed a charging electrode so that each droplet becomes electrically charged as soon as it is formed. The charged droplets then continue toward the eye, and discharge their electric charge at the first earthed surface they encounter, the eyeball tissue. Another dispensing device is disclosed in U.S. Patent No. 6,062,212. The dispensing device defines an outlet through which a metered dose of liquid from a reservoir is dispersed as an atomized spray. A droplet of liquid is metered onto a perforate membrane which is vibrated by way of a piezoelectric transducer such that atomized droplets are dispensed through the holes formed in the membrane.

Due to their ease of use by patients and ability to deliver large doses of drugs, nebulizers have become popular devices for providing a means for creating an aerosol that can be inhaled and thus delivered naturally by the respiratory system. Various types of nebulizers are known for creating such aerosols, which in general are fine droplets suspended in air. Jet nebulizers, for example, employ a high velocity air jet which passes over a liquid feed tube and draws a stored liquid to the jet by the Bernoulli effect. The liquid is then propelled forward toward an impaction plate, where it impacts and bursts into droplets of varying sizes, with the heavier droplets returning to the stored liquid and the lighter droplets forming the aerosol. Baffles may be used to limit the particle size that escapes from the nebulizer.

Ultrasonic nebulizers rely on the transmission of ultrasonic vibrations to a tube in communication with a stored liquid. Ultrasound is the part of the sonic spectrum between 20 kHz to 10 MHz, In one type of device known as a horn nebulizer, the tube is vibrated so that liquid is pumped through it from the stored position at one end of the tube, to a surface at the opposite end of the tube. Vibration is accomplished with a piezoelectric material, which produces a mechanical stress when subjected to an electrical influence. The

piezoelectric material is formed in the shape of a donut that surrounds the tube, and when an electric charge is passed through the material, a mechanical stress is produced along the cylindrical axis of the donut and transferred to the walls of the tube. A thin film is formed on the tube surface, and as the tube is further vibrated, geysering and cavitation cause the film to burst into an aerosol cloud. Typically, the amplitude of vibration on the tube surface must be at least about 1 μm, and the tube diameter is generally limited to one-quarter of the ultrasonic wavelength of the tube material. For example, an aluminum tube may be used due to its strength, rigidity, and acoustic properties, with a 40 kHz aluminum alloy tube having a diameter of about 10 mm. Commercially available horn nebulizers for respiratory treatments, such as those available from the Omron Corporation, operate at an ultrasonic frequency of about 65 KHz, a nebulization rate of about 0.25 ml per minute, and create particle sizes of between 1 and 7 μm.

Another form of ultrasonic nebulizer, generally referred to as a surface acoustic wave nebulizer, is disclosed in U.S. Patent No. 5,996,903. An oscillator formed from lithium niobate is provided with a pair of electrodes on its surface. A high frequency voltage is applied between the electrodes, generating a surface acoustic wave. The wave is received by a liquid surface, and drawn by capillarity and surface tension into a clearance created between the oscillator and a thin plate. A mesh formed in the plate permits the passage of atomized liquid to create a spray. Commercially available surface acoustic wave nebulizers for respiratory treatments, such as those available from the Schill Corporation, operate at an ultrasonic frequency of about 1.7 MHz, a nebulization rate of about 0.75 ml per minute, and create particle sizes less than 4.7μm.

It is known that aerosol droplet size is related to the wavelength of capillary waves in the liquid and is inversely proportional to the ultrasonic frequency. The drop size, D, of the aerosols produced from capillary wave instability can be estimated from the Lang equation:

$$D = 0.34\left(\frac{8\pi\gamma}{\rho F^2}\right)^{1/3}$$

where γ is the liquid surface tension, ρ is the liquid density, and F is the frequency of vibration of the surface acoustic wave substrate. Thus, the frequency at which the oscillator vibrates is a very important factor in the performance of the device.

With regard to efficiency of jet nebulizers and surface acoustic wave nebulizers, the former employ a dry air stream that typically reaches speeds of 60 miles per hour through the nebulizer orifice, so that when the air stream passes over a large liquid surface area, high levels of evaporation occur. In contrast, significantly smaller losses due to evaporation occur with ultrasonic nebulizers, leading to increased efficiency of aerosol output.

Commercially available nebulizers for use in respiratory treatments are typically either (1) so powerful that an aerosol cloud is propelled with a velocity such that it migrates 2 to 3 inches beyond the output point of the devices, or (2) so weak that the aerosol cloud moves at low velocity and cannot leave the output point of the devices without an inhalation force exerted by a patient. A fan is used in some designs to facilitate aerosol travel by forced convection. The devices are in many cases cumbersome in size, complex, and designed for drug delivery over periods on the order of one to thirty minutes.

Despite these developments, there is a need for an ocular drug delivery device for delivering an aerosol to the eye without significant aggravation of the eye itself. Specifically, there is a need for an ocular drug delivery device with improved delivery accuracy, simplicity in design, and ease of use. More specifically, there is a need for an ocular drug delivery device that delivers liquid drug to the eye in droplet sizes no greater than about 100 μm. Further, there is a need for an ultrasonic nebulizer with a timing circuit for controlling the volume of liquid drug delivered to the eye. There is also a need for an ultrasonic nebulizer that delivers a 10-50 μL dose of a drug to the eye in a time period of about one second or less, with stimulation of a blink reflex preferably being avoided. In addition, there is a need for an ocular drug delivery device that has a disposable fluid path so that sterility may be achieved from one drug dispensation to the next dispensation. Also, there is a need for an ocular drug delivery device that provides a means for self-sterilization so that the fluid path need not be changed from one dispensation to the next dispensation.

SUMMARY OF THE INVENTION

The present invention relates to an ocular nebulizer. The preferred embodiment has an ultrasonic horn in fluid communication with a first substance source for drawing substance from the source. In one embodiment, the substance has a therapeutic effect when administered to an eye, and circuitry in the nebulizer is associated with an oscillator for nebulizing and delivering a therapeutically effective amount of the substance to an eye. The horn has a discharge exit. An ultrasonic oscillator is associated with the

ultrasonic horn for vibrating the horn ultrasonically for nebulizing the substance from the horn exit. An eye cup is configured for placement around an eye, with the horn exit disposed within the eyecup, and the eye cup configured for directing the nebulized substance towards the eye.

In the preferred nebulizer, the ultrasonic oscillator comprises a piezoelectric element. Circuitry of the nebulizer is connected for controlling the piezoelectric element for controlling the dispensation of the substance. Additionally, a valve is associated with the horn for opening and closing the fluid communication with the substance source, wherein the circuitry controls the valve. The valve is in fluid communication with a second substance source and has a configuration for fluidly communicating the second source with the horn for feeding a second substance to the horn from the second source. Preferably, the first source comprises a medicament, and the second source comprises a sterilizing fluid.

A manually operable dosage control is preferably in operative association with the circuitry for selecting an amount of substance to be nebulized. The ultrasonic oscillator and horn are preferably configured for nebulizing a dose of about between 10 μL and about 100 μL of the substance in a single actuation of the oscillator. The ultrasonic oscillator and the horn also preferably produce ultrasonic vibrations sufficient for drawing the substance from the source into the horn. The oscillator vibrates the horn preferably at an ultrasonic frequency of about between 20 kHz and about 100 kHz.

The horn in the preferred embodiment is friction fit into the oscillator to permit removal and replacement of the horn therein. A coupling connects first and second portions of the horn such that at least one of the portions is removable from the body of the nebulizer, which houses the oscillator and horn.

In the preferred method according to the invention, an eye condition is treated by administering a therapeutically effective amount of the fluid substance to an eye by placing an ultrasonic nebulizer adjacent an eye, ultrasonically vibrating a horn of the nebulizer to draw the substance from a source and to nebulize the substance, and delivering the nebulized substance to the eye. In one embodiment of the method, a portion of the horn is reconnectably removed from the body for sterilizing the portion.

The method can include coupling an ultrasonic oscillator to a fluid communication channel having a horn; disposing the oscillator in close proximity to an eye cup surrounding an eye; providing power to a power supply circuit; activating a timing circuit; activating an ultrasonic vibration circuit; opening a fluid flow valve to permit a preselected amount of a medicament fluid to pass from a stored location to the fluid

communication channel; energizing the ultrasonic oscillator; vibrating the medicament fluid for no more than about 1.5 seconds in the fluid communication channel to produce fluid droplets proximate the horn and having droplet sizes no greater than about 100 μm; delivering the droplets to the eye cup; closing the fluid flow valve; and ceasing power to the power supply circuit.

The method may further include opening a fluid flow valve to permit a preselected amount of sterilizing fluid to pass from a stored location to the fluid communication channel, replacing at least a portion of the fluid communication channel, and selecting the preselected amount. The ultrasonic oscillator of one embodiment is a piezoelectric component, that may be energized to vibrate at an ultrasonic frequency of between about 20 kHz and about 100 kHz, and the preselected amount of liquid is between about 10 μL and about 100 μL.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred features of the present invention are disclosed in the accompanying drawings, wherein similar reference characters denote similar elements throughout the several views, and wherein:

Fig. 1 is a perspective view of a preferred embodiment of an ocular drug delivery device according to the present invention;

Fig. 2 is a partial cross section of an actuable medication source disposed in a recessed portion of a nebulizer body;

Fig. 3 is a perspective view of a horn nebulizer that forms part of the present invention;

Fig. 3A is a perspective view of a horn nebulizer that forms part of the present invention with a disposable pipe;

Fig. 3B is a perspective view of a horn nebulizer that forms part of the present invention with a sterilizing fluid reservoir;

Fig. 4 is a block diagram of the operation of the preferred embodiment of the present invention;

Fig. 5 is a perspective view of another embodiment of the invention with an elongated eye cup; and

Fig. 6 is a perspective back view of another embodiment of the invention with a back-loading medication source.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Any of a wide variety of ocular substance delivery devices can be prepared according to the teachings of the present invention. Referring to Fig. 1, in a preferred embodiment, device 100 includes a nebulizer body 102, an activation button 103, and a substance source, such as a medicament cartridge or other source 104. The preferred embodiment also has an eye cup 106, although this is not present in an alternative embodiment. Preferably, medication source 104 is in the form of a medicament housing that may be detachably connected to nebulizer body 102. Eye cup 106 is configured to rest lightly upon the face and surround a user's eye, aligning the aerosol spray from the device with the eye ball. In addition, eye cup 106 may be rotatable to facilitate comfortable use with both the left and right eyes. Nebulizer body 102 is ergonomically configured for gripping by a user in a comfortable and sturdy fashion.

In one embodiment, as shown in Fig. 2, medication source 104 is resiliently seated in a recessed region 108 in nebulizer body 102, and retained therein with a upper ledge 109 that receives stepped portion 105 of medication source 104. Thus, medication source 104 is coupled to nebulizer body 102 by a snap fit between ledge 109 and stepped portion 105. A needle 120 protrudes from surface 114 and opposes lower surface 112 of medication source 104. As will be described, activation of the device by the user permits medication to be drawn from the stored location in medication source 104,through needle 120, for delivery to the eye. Notably, due to the sizing of needle 120, particularly the fluid delivery channel formed therein, fluid does not readily flow until suitable external force is applied such as suction. In addition, to assist in assuring sterility, a valve 116, such as a solenoid valve with a plunger 117, is disposed between the medication source 104 and the nebulizer, as will be described.

Referring to Fig. 3, a piezoelectric horn nebulizer 150 preferably is employed. Nebulizer 150 includes a horn, which preferably comprises a pipe 152. Pipe 152 in communication with a reservoir 154 that stores a desired amount of liquid for release in nebulized form. Liquid enters end 156 of pipe 152, and exits at cylindrical horn end 158, which in the preferred embodiment is flared with increasing radius in a forward direction towards the eye. Other embodiments has a non-tapered end or a tapered end that decreases in radius, depending on the desired nebulization effect and the energy transfer desired at the horn end to the substance being nebulized. In the preferred embodiment, a piezoelectric element, preferably a piezoelectric ceramic 160 surrounds pipe 152 intermediate ends 156, 158. When energized, piezoelectric ceramic transducer 160 exerts a vibratory force on pipe

152, drawings liquid into pipe 152 and spraying nebulized fluid droplets through end 158. The preferred piezoelectric element comprises a plurality of piezoelectric ceramic disks separated by conductors. The pipe 152 preferably is received within the piezoelectric ceramic 160 in friction fit association, so that the vibration of the piezoelectric ceramic 160 are efficiently transferred to the horn, or pipe 152.

In one preferred embodiment, at least a portion of the drug deliver path is disposable so that a higher level of device sterility can be achieved. As shown in Fig. 3A, a coupling 162 is disposed between end 156 of pipe 152 and a removable pipe 164. Body 102 may be provided with an access so that pipe 164 may be removed and replaced. Preferably, another coupling 166 connects pipe 164 to another pipe 168 leading to medication source 104, through a valve 116 for controlling fluid flow therein, or more preferably, coupling 166 is directly connected to valve 116. In one embodiment, valve 116 is a two-way valve.

In another embodiment, shown in Fig. 3B, a coupling 162 is disposed between end 156 of pipe 152 and an end 169a of a fixed pipe 169. A valve 170 is connected to the opposite end 169b of fixed pipe 169, and is coupled to a secondary, sterilizing fluid reservoir 174 through pipe 172, as well as a pipe 176 leading to medication source 104. Preferably, sterilizing fluid reservoir 174 includes an access port 178 so that it may be refilled. A variety of sterilizing fluids may be employed, and preferably deionized water is used. The dispensation of medicament through pipe 176, or the sterilization of the medicament delivery path of pipe 169, may be controlled using valve 170 which is switchable between open and closed positions between pipes 169, 172, 176, and which in turn may be controlled by a user of the device by activating a switch such as with button 103, or instead may be controlled by a timing circuit as will be described.

It should be noted that although the term misting is often used to refer to the production of fine drops that are 10-100 μm in size, and the term nebulizing typically refers to the production of very fine drops under 10 μm in size, the terms aerosolizing, nebulizing, and derivatives thereof are used herein interchangeably to generally refer to the production of drops 100 μm or smaller in size.

A block diagram of the piezoelectric horn nebulizer device 100 is shown in Fig. 4. A battery 210 is provided as a power source for operation of the circuitry and associated components. Preferably, to meet size considerations, a photo battery such as an Energizer® A544 photo battery is employed, providing six volts. Battery 210 is operatively

associated with power supply circuit 212 by a switch 214. Closing switch 214 permits a closed circuit to be established between battery 210 and circuit 212.

Once power is provided to timing circuit 216, an ultrasonic vibration circuit 218 is activated such that ultrasonic oscillator 220 is set into vibration. Timing circuit 216 also permits fluid flow valve 222 to be momentarily opened, allowing liquid to flow from liquid chamber 224 to ultrasonic oscillator 220. Preferably, a horn nebulizer 150 with pipe 152 is used, and as liquid passes through pipe 152, the pipe is vibrated by ultrasonic oscillator 220 and released in the general vicinity of atomized liquid cup 226 as an aerosol. Preferably, horn nebulizer 150 is configured and dimensioned to deliver liquid drug to the eye in droplet sizes no greater than about 100 μm.

Timing circuit 216 permits the release of a preset amount of liquid, preferably in the range of about 10 μL to about 50 μL. Furthermore, timing circuit 216 governs the activation and deactivation of ultrasonic vibration circuit 218, with delivery of the preset amount of liquid occurring over a time period of about one second or less. Advantageously, such a delivery volume and time may avoid and reduces the likelihood of the stimulation of a blink reflex. Passage of fluid from liquid chamber 224 to release in horn nebulizer 150 typically occurs with a delay as great as 0.5 seconds following excitation of the piezoelectric ceramic to initiate vibration. Thus, delivery of the preset amount of liquid may require a total of 1.5 seconds, accounting for this delay. Preferably, the oscillator is energized to vibrate at an ultrasonic frequency of between about 20 kHz and about 100 kHz. In one embodiment, liquid chamber 224 stores medicament. In another embodiment, two liquid chambers 224 are provided for separate storage of medicament and sterilizing fluid.

In alternate embodiments of the present invention, ultrasonic oscillator 220 is formed as a surface acoustic wave device. Typically, such a device is selected with frequencies from 10-2000 MHz, bandwidths from 0.1-500 MHz, and impulse response lengths as high as 100 μs, Preferably, ultrasonic oscillator 220 and the horn, including the tube and any other parts of the horn, are configured to deliver liquid drug to the eye in droplet sizes no greater than about 100 μm, and thus the proper frequency and the material, shape, and dimensions of the horn are especially chosen for this desired output. In some embodiments, the horn is tapered, either becoming larger or smaller along its length to achieve the desired energy transfer between the piezoelectric element and the substance to be nebulized by controlling the amplitude of the vibrations and the resonance of the horn. Also, suitable baffling may be provided between cylindrical horn end 158 of pipe 152 and

atomized liquid eye cup 226 to remove large particles that exceed the maximum droplet size requirements. Preferably, the dose of medicament is selectable between about 10 μL and about 100 μL. In one embodiment, timing circuit 216 may be set to deliver either 25 μm, 50 μm, or 75 μm doses.

In some embodiments, device 100 may be fully disposable, reusable or partially reusable. Preferably, device 100 is operable by a user with only one hand, although loading of a medication source 104 in recessed region 108 in nebulizer body 102 may require as many as two hands.

Preferably, a therapeutically effective amount of an ophthalmic solution is delivered by device 100 to an eye ball. The solution is typically an aqueous-based solution, and surfactants may be included with the solution if the medical compositions to be delivered have low solubility in water. Thickening agents may also be included to increase viscosity of the solution to facilitate distribution of the solution in the eye. The solution optionally may include one or more of an agent for adjusting the pH of the solution, an antioxidant, an isotonic agent, a buffer, and a preservative. In one embodiment, the solution has a viscosity of between about 4,000 centipoise and about 40,000 centipoise at 25°C .

Due to handling of device 100 by individuals with a variety of medical conditions and allergies that may be unrelated to the eyes, medically sterile plastic is preferably used for forming the non-metallic components of device 100.

Referring to Fig. 5, the embodiment shown has a body 228 with a medication source 230 and an activation button 232. The eye cup 233 of this embodiment is elongated laterally, and has curved upper and lower walls 234,236 that curve downwards towards lateral edges 238, which are of a small, sharp radius, as opposed to the large, smooth radii of the lateral sides of the eye cup 106 of the embodiment of Fig. 1. The curvature of the eye cup walls 234,236 is selected to generally follow the contour of the human face around the eye to better position the nebulization. Preferably, the front edges 240 of the walls have a concave bend to follow the shape of the face around the eye, such that the central portion of the edges 240 are positioned axially behind the lateral portion thereof.

The embodiment of Fig. 6, has a rounded body 242 configured to receive a medicament source 244 at the axial rear of the device in a medicament source loading portion 243. Activation button 246 is disposed atop the device, and an eye cup 248 is disposed substantially at the opposite axial end from the medicament source loading portion. A manually operable dosage control 250 is connected to the circuitry that controls

the piezoelectric element and any valves connected to the horn to control the amount of the substance to be nebulized.

While various descriptions of the present invention are described above, it should be understood that the various features can be used singly or in any combination thereof. Further, it should be understood that variations and modifications within the spirit and scope of the invention may occur to those skilled in the art to which the invention pertains. For example, the drops formed by device 100 additionally may be electrically charged. Additionally, substances other than medicaments can be nebulized with the present device, such as eye moisturizers and saline solutions. Accordingly, all expedient modifications readily attainable by one versed in the art from the disclosure set forth herein are within the scope and spirit of the present invention and are to be included as further embodiments. The scope of the present invention is accordingly defined as set forth in the appended claims.

THE CLAIMS

What is claimed is:

1. An ocular nebulizer, comprising:

an ultrasonic horn in fluid communication with a first substance source for drawing substance from the source, the horn having an exit;

an ultrasonic oscillator associated with the ultrasonic horn for vibrating the horn ultrasonically for nebulizing the substance from the horn exit;

an eye cup configured for placement around an eye, the horn exit disposed within the eyecup, wherein the eye cup is configured for directing the nebulized substance towards the eye.

2. The nebulizer of claim 1, wherein the ultrasonic oscillator comprises a piezoelectric element, and the nebulizer further comprises circuitry connected for controlling the piezoelectric element for controlling the dispensation of the substance.

3. The nebulizer of claim 2, further comprising a valve associated with the horn for opening and closing the fluid communication with the substance source, wherein the circuitry is operatively associated with the valve to control the valve.

4. The nebulizer of claim 2, wherein the valve is in fluid communication with a second substance source and has a configuration for fluidly communicating the second source with the horn for feeding a second substance to the horn from the second source.

5. The nebulizer of claim 4, further comprising the first and second sources, wherein the first source contains a medicament, and the second source contains a sterilizing fluid.

6. The nebulizer of claim 1, further comprising a manually operable dosage control in operative association with the circuitry for selecting an amount of substance to be nebulized.

7. The nebulizer of claim 1, wherein the ultrasonic oscillator and horn are configured for nebulizing a dose of about between 10 μL and about 100 μL of the substance in a single actuation of the oscillator.

8. The nebulizer of claim 1, wherein the ultrasonic oscillator and the horn are configured for producing ultrasonic vibrations sufficient for drawing the substance from the source into the horn.

9. The nebulizer of claim 1, wherein the horn is friction fit into the oscillator to permit removal and replacement of the horn therein.

10. The nebulizer claim 1, wherein the oscillator is configured for vibrating the horn at an ultrasonic frequency of about between 20 kHz and about 100 kHz.

11. The nebulizer of claim 1, further comprising:

a body housing the oscillator and horn; and

a coupling connecting first and second portions of the horn such that at least one of the portions is removable from the body.

12. An ocular nebulizer, comprising:

a substance source containing a substance that has a therapeutic effect when administered to an eye;

an ultrasonic horn in fluid communication with the substance source for drawing substance from the source, the horn having an exit;

an ultrasonic oscillator associated with the ultrasonic horn for vibrating the horn ultrasonically for nebulizing the substance from the horn exit; and

circuitry associated with the oscillator for nebulizing and delivering a therapeutically effective amount of the substance to an eye.

13. A method of delivering a therapeutically effective amount of a fluid substance to an eye comprising:

placing an ultrasonic nebulizer adjacent an eye;

ultrasonically vibrating a horn of the nebulizer to draw a first the substance from a first substance source and to nebulize the substance; and

delivering the nebulized substance to the eye.

14. The method of claim 13, wherein the substance comprises a medicament, and the ultrasonic oscillator is activated for a duration sufficient to administer a therapeutically effective dose of the medicament to the eye.

15. The method of claim 13, wherein the oscillator is energized to vibrate at an ultrasonic frequency of between about 20 kHz and about 100 kHz.

16. The method of claim 13, further comprising reconnectably removing a portion of the horn from a body of the nebulizer for sterilizing the portion.

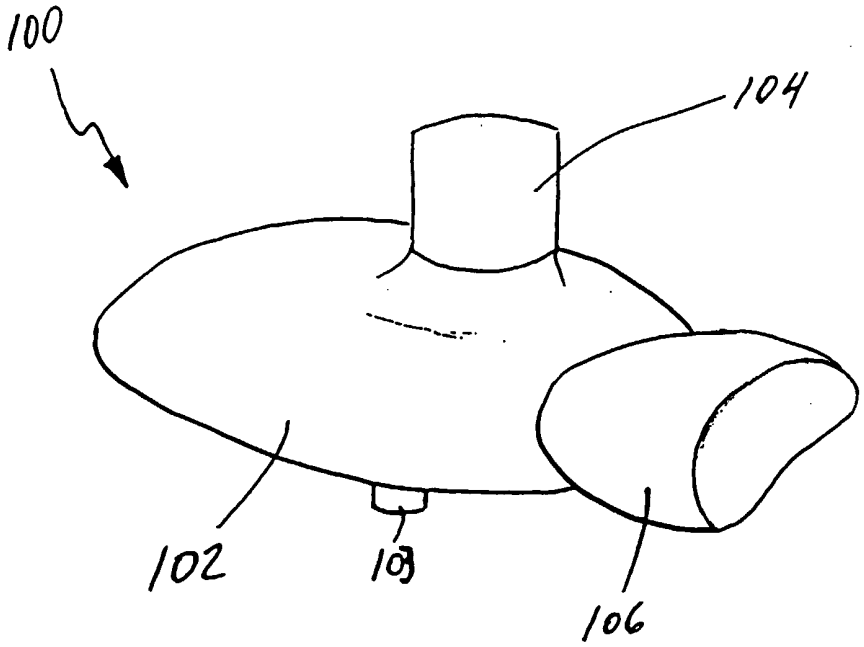

FIG. 1

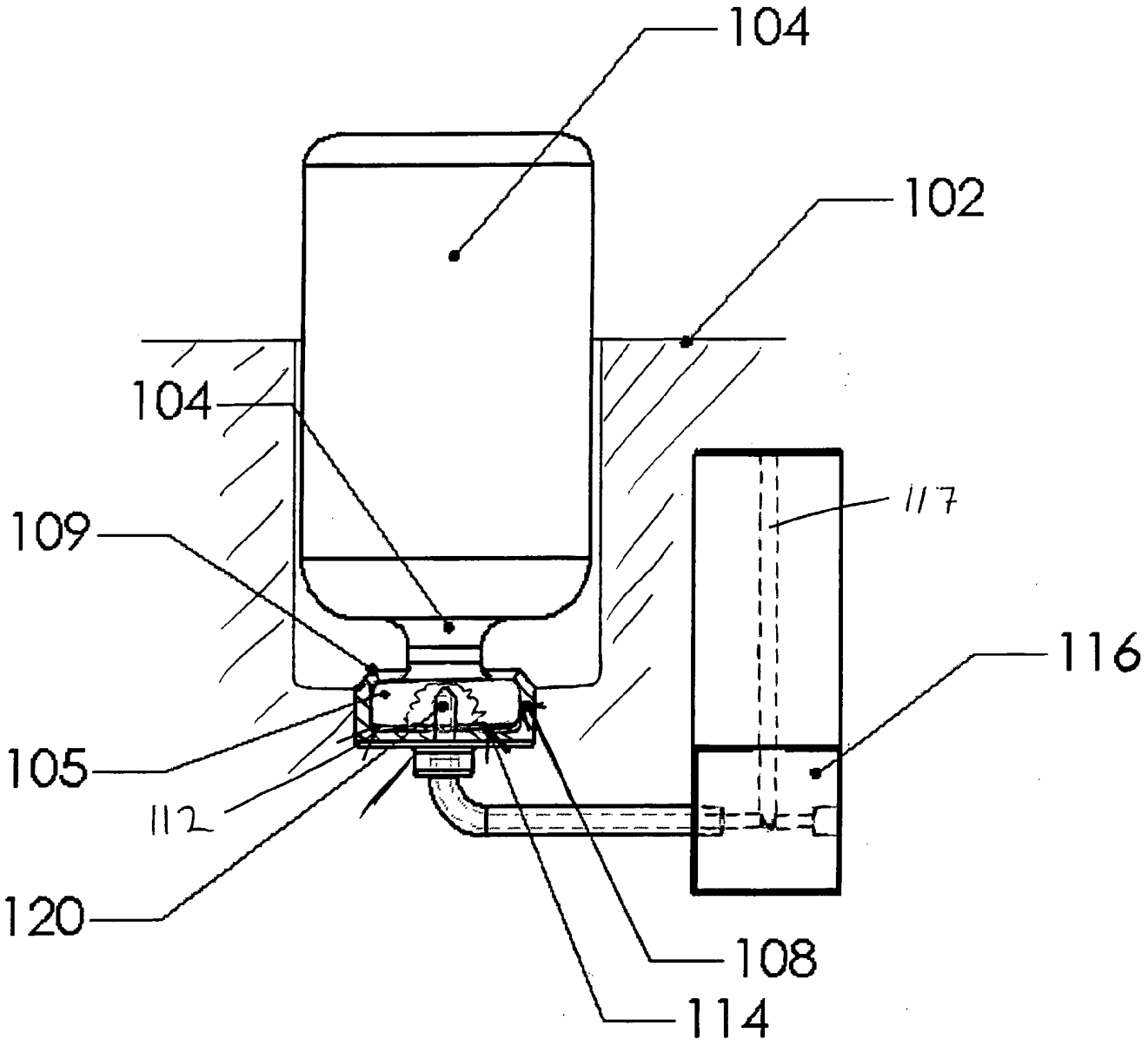

FIG. 2

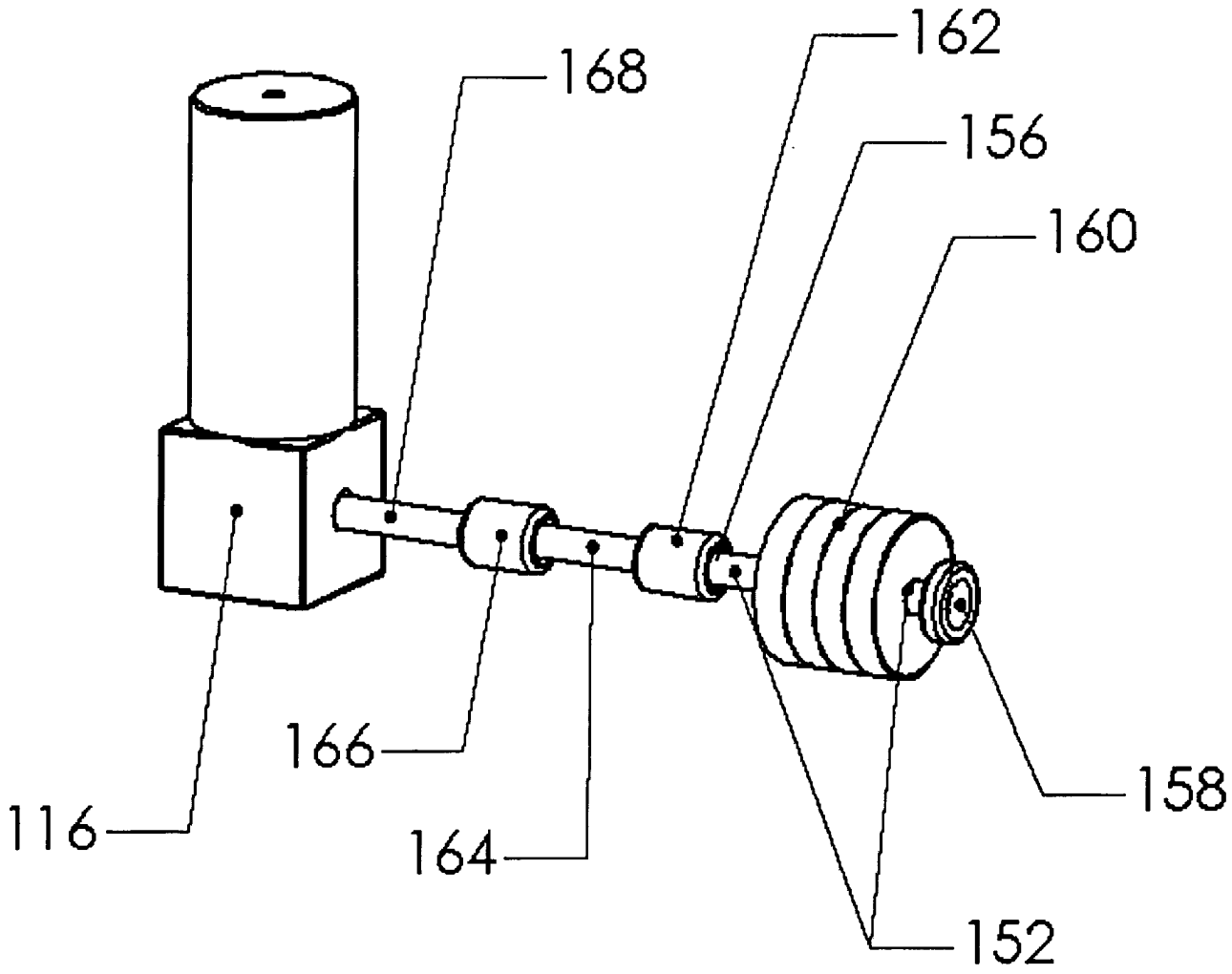

FIG. 3A

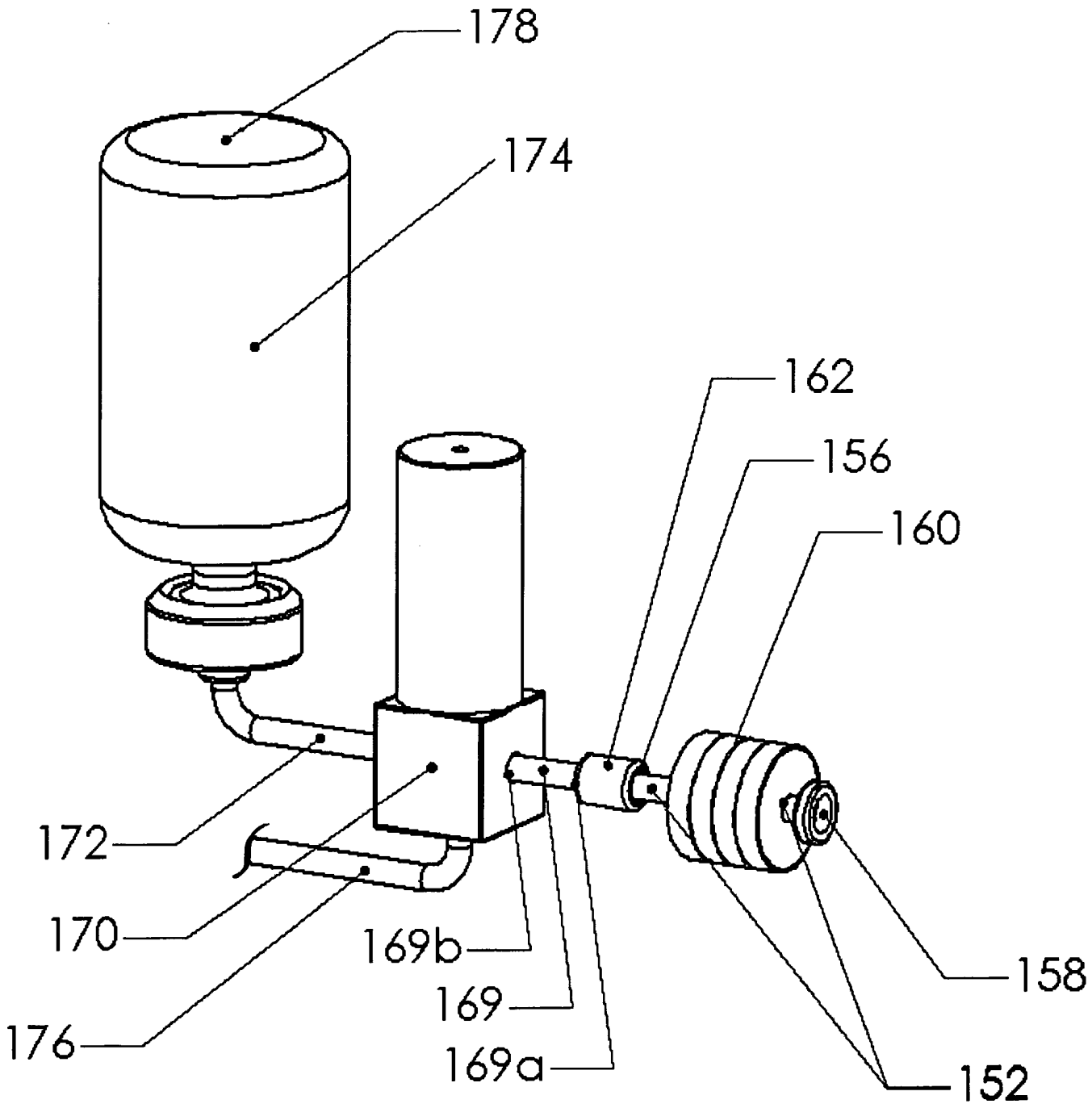

FIG. 3B

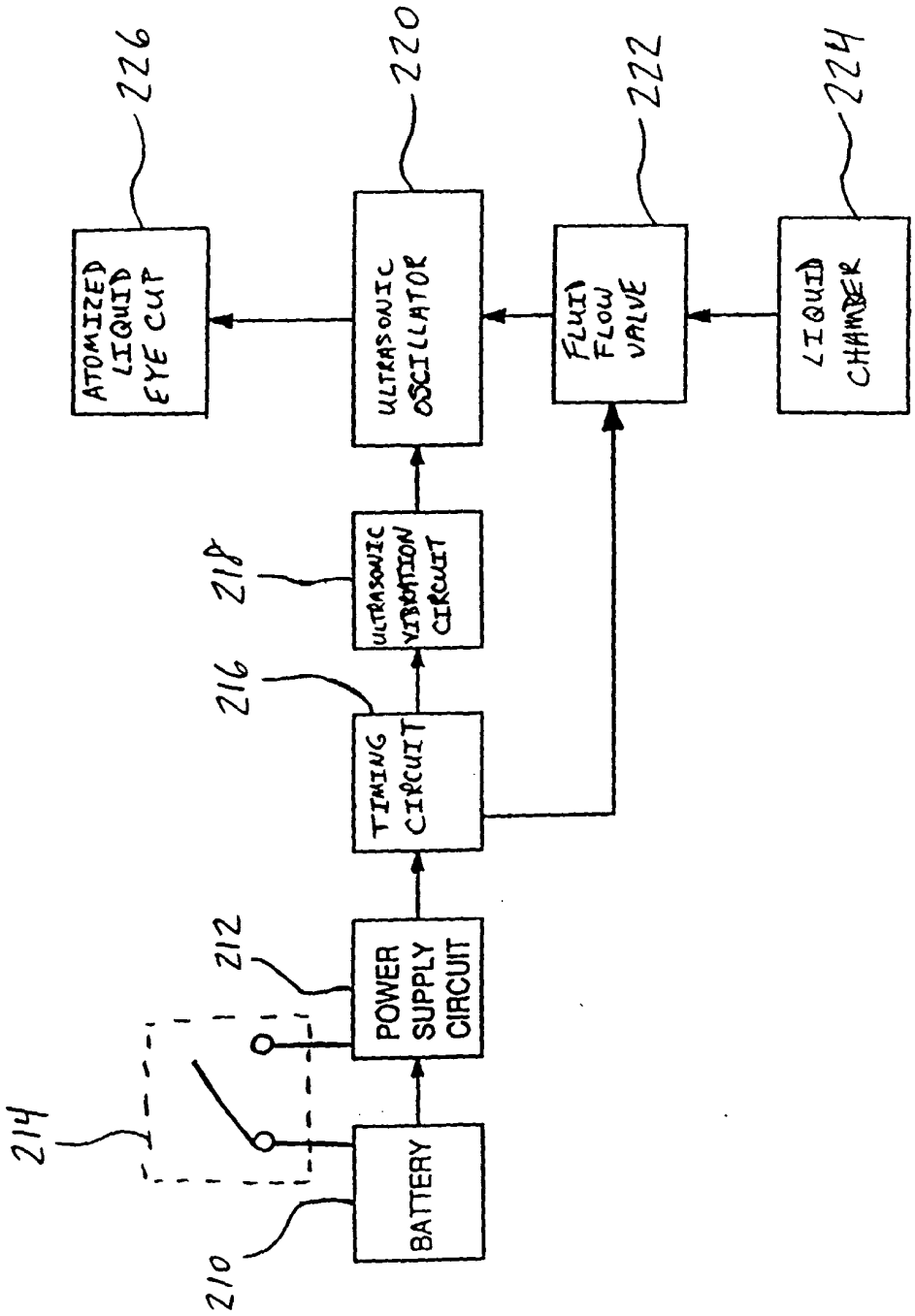
226
220
222
224
ATOMIZED LIQUID EYE CUP
ULTRASONIC OSCILLATOR
FLUID FLOW VALVE
LIQUID CHAMBER
218
ULTRASONIC VIBRATION CIRCUIT
216
TIMING CIRCUIT
212
POWER SUPPLY CIRCUIT
214
210
BATTERY

FIG. 4

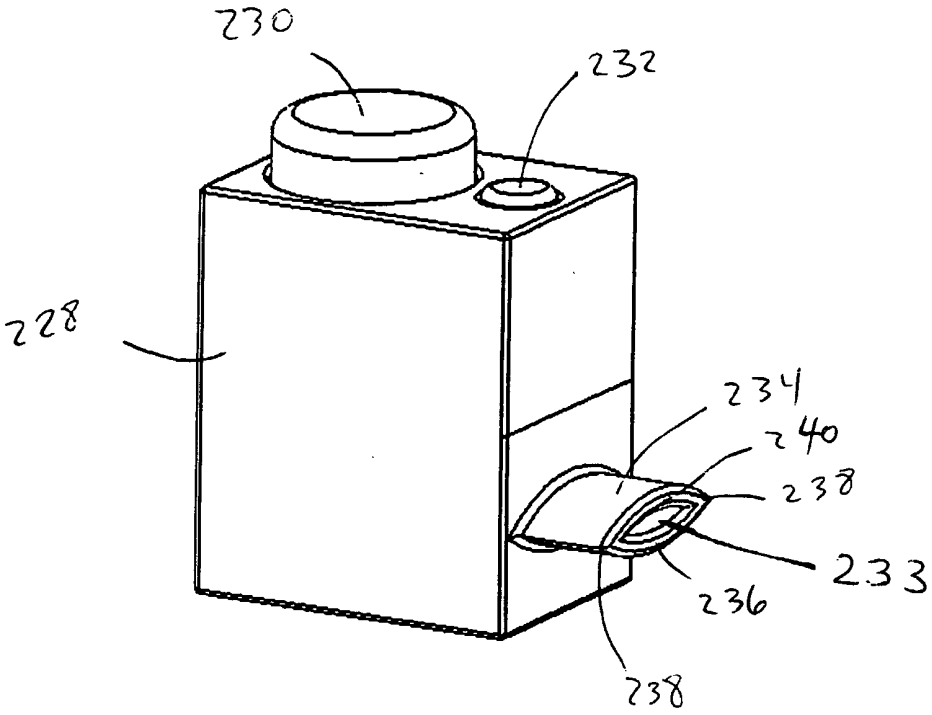

Fig. 5

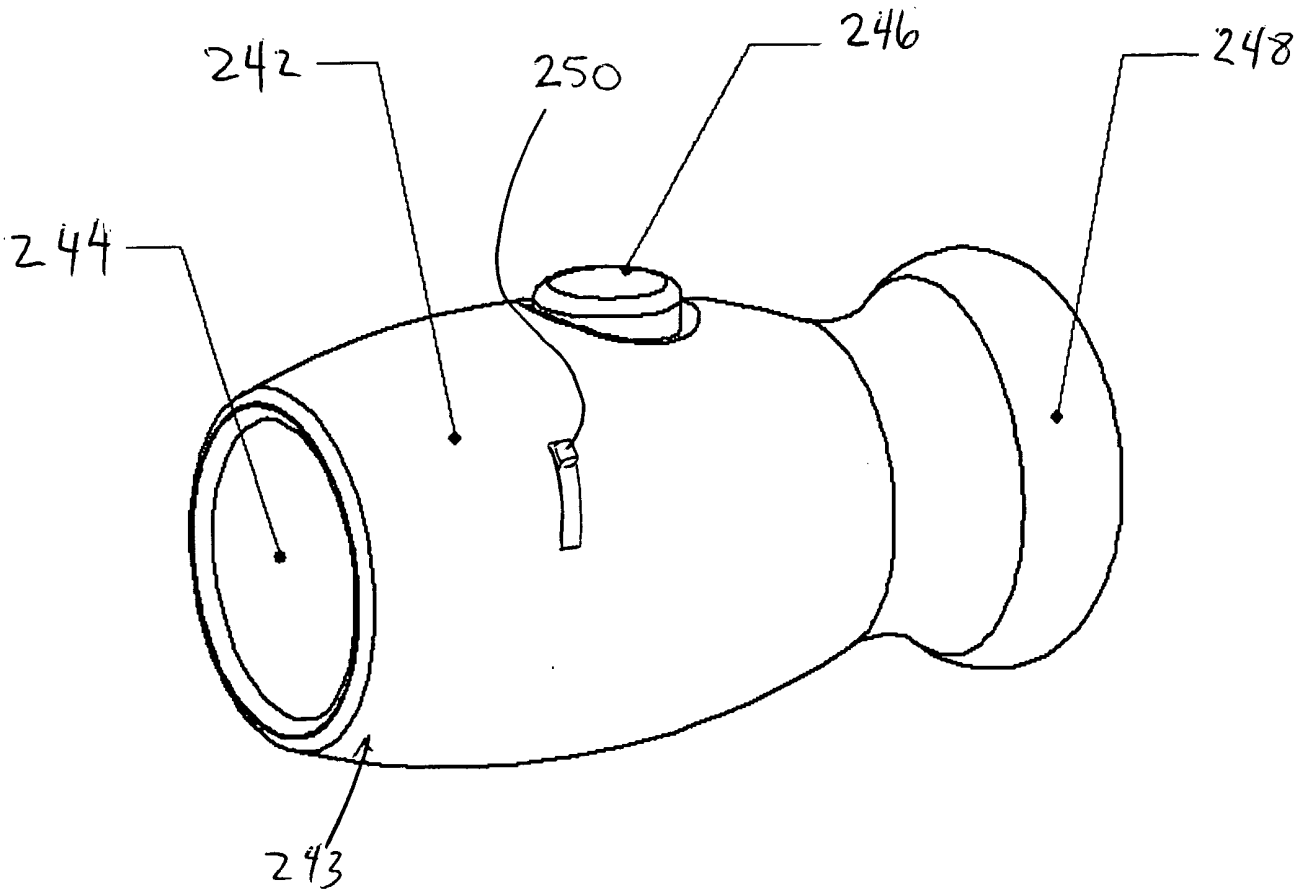

FIG. 6