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JET SPRAYER ACTUATED BY SUPERSONIC WAVES

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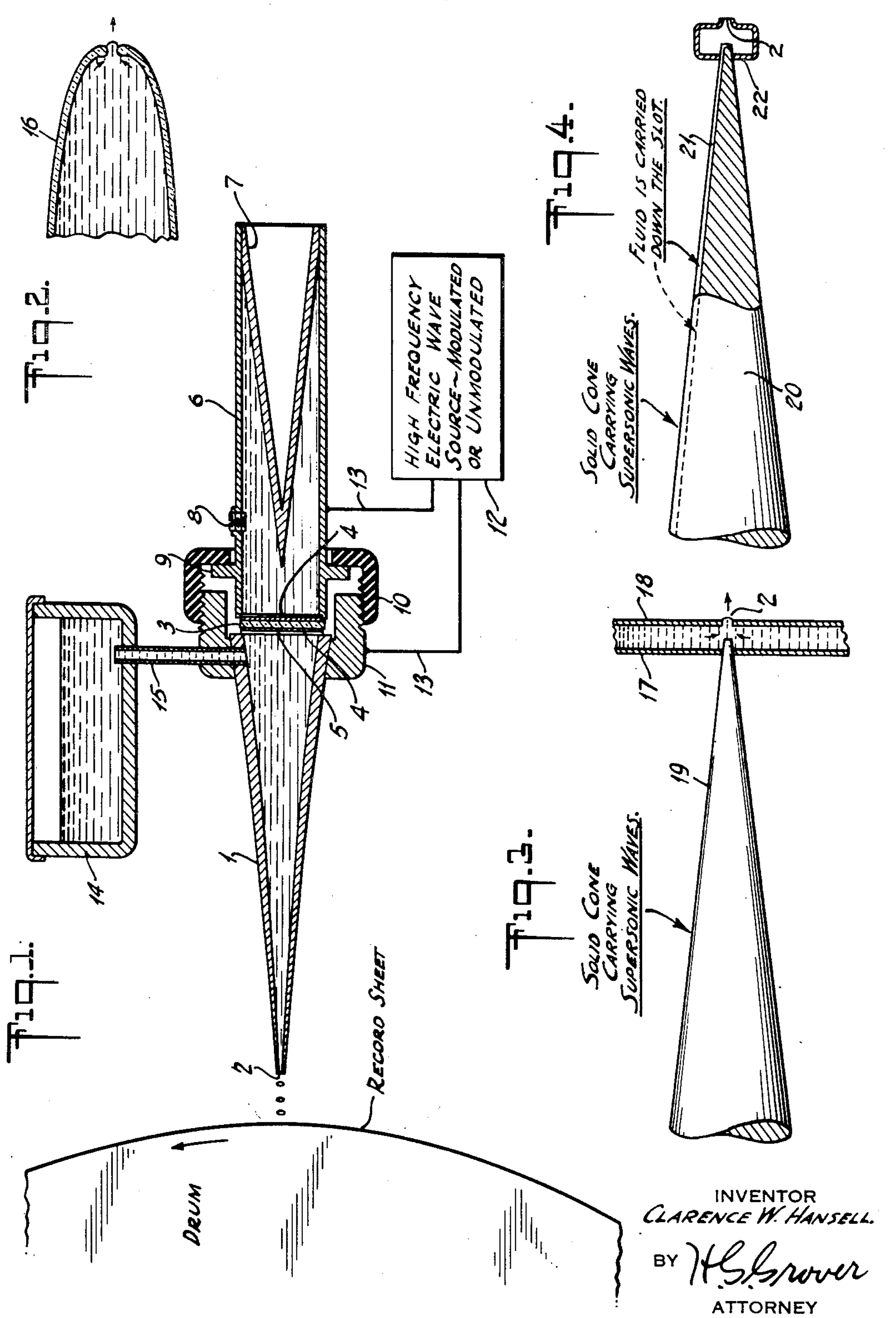

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JET SPRAYER ACTUATED BY SUPERSONIC WAVES

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13 Claims. (Cl. 91—18)

1

This invention relates to means for spraying liquids in fine jets by making use of the phenomenon which takes place when supersonic vibrational waves strike an exposed surface of the liquid.

The sprayer is applicable to facsimile recording and to various painting and spraying operations, and is particularly suited to performing the same operations as the device called an air brush, which is now used by many commercial artists. It is suitable for performing many striping and finishing operations in industry, and, in general, it may be used to control the flow of liquids in many advantageous ways.

It has been demonstrated by R. W. Wood and A. L. Loomis that waves from a piezo-electric quartz crystal exert a unidirectional pressure when they arrive at the surface of a liquid. In one experiment in which a crystal was vibrated in oil they reported that a mound was raised on the surface of the oil up to a height of 7 centimeters (see The Encyclopaedia Britannica, 14th edition, vol. 21, page 12, and the additional reference cited there).

To explain how supersonic waves exert such a large radiation pressure when they strike the surface of a liquid it may be noted that, generally, liquids will stand any reasonable amount of pressure but they cannot take any substantial tension because they vaporize to form voids which relieve the tension. Since the supersonic waves in a uniform liquid cause equal increase and decrease in pressure at time periods a half cycle apart in time, or a half wave different in position, in the direction of travel of the waves, it follows that the liquid must be under a steady state pressure about equal to, or greater than, the amount of peak decrease in pressure due to the waves if voids are not to be formed in the liquid.

Under conditions such that the waves are directed toward an exposed surface of the liquid the region in the liquid at and near the surface may not be under sufficient pressure to equal the decrease in pressure at the peak of the negative cycles of the supersonic waves. As a consequence the push of the positive halves of the waves toward the surface cannot be balanced by any corresponding counter pressure on the negative halves of the waves. The only restoring force to balance the positive half cycles of pressure is that exerted by the air less the vapor pressure of the liquid in the inevitable voids formed in the liquid on the negative half cycles of pressure. This restoring force is relatively small and may

2

be far below the positive forward force of the waves.

The overall result of this phenomenon is that strong supersonic motions or waves in a liquid, as the waves arrive at an exposed surface, are rectified or converted into unidirectional motions up out of the main body of the liquid. Thus supersonic waves may be used to cause unidirectional flow of liquids and, by modulating the strength of the waves we may modulate the unidirectional flow.

The experiment of Wood and Loomis, in which supersonic waves raised a mound 7 centimeters high on the surface of a liquid was done with the concentration of vibrational waves which exist in a free liquid at a little distance from the surface of a strongly oscillating crystal. If the liquid, instead of being in an open vessel is confined in a tapered container or nozzle having the vibrating crystal at the large end and being open to the air at the small end, then the intensity of the waves at the open tip of the nozzle may be made much greater than the intensity of the waves at the crystal. Thus, by means of a tapered column of liquid carrying supersonic waves from the large to the small end it is possible to provide for very intense waves at the small end, which are capable of causing very large unidirectional velocities of liquid thrown out of the small end. For this intensity of ultrasonic radiation Ludwig Bergmann, on page 45 of his book Ultrasonics (Wiley), gives calculations showing that when wave velocities in the liquid are 1484 meters per second, the wave causes plus and minus alternations in pressure having a peak value of $5.4\times(10)^6$ dynes per square centimeter (about 80 pounds per square inch) and plus and minus peak velocities of the liquid of 36.7 centimeters per second. The accelerations in the liquid due to the waves are 100,000 times greater than the acceleration due to gravity.

If the tapered liquid column varies in cross sectional area by something greater than 100 to 1, so as to result in a 100 to 1 increase in power intensity of the waves in spite of power losses, then the above figures for peak vibrational pressure, velocity and acceleration will all be increased by 10 to 1. Therefore, if the liquid could remain free from voids, portions of the surface of the liquid would experience accelerations 1,000,000 times the acceleration due to gravity.

In practice voids will develop for some distance, extending through the surface, but the liquid will be propelled at high velocity out of the tip of the nozzle. It may then be allowed to impinge upon a surface which is moving with respect to the nozzle tip, to form a coating on the surface, the density of which may be modulated by modulating the intensity of the supersonic waves.

The nozzle may be manipulated by an artist, similar to the manner of using the artist's air brush, or the relative motion may be performed in a facsimile recorder, or some form of painting machine.

As to the rate at which the sprayer may be modulated, it may be noted that in a paper appearing in Proc. I. R. E. for August 1939, J. Seiger describes the Scophony system of television reception in which supersonic waves in a liquid are used to operate a light valve. Seiger reported that, by using supersonic waves in water, at 18 megacycles, and by using selective side band methods, it was possible to modulate the waves fast enough for television.

The foregoing paragraphs deal largely with the background of art to which my invention relates. As to the invention itself, the principal objects are as follows:

a. To provide novel apparatus for the spraying of liquids in a fine jet, or train of globules in response to the force of ejection from a nozzle which is produced by supersonic vibrational waves striking an exposed surface of the liquid.

b. To provide means for the spraying of ink upon a recording surface in accordance with the modulation of signals of the vibratory characteristics of a piezo-electric crystal, where pressure is exerted upon a surface of the ink by a compressional wave which the crystal emits.

c. To provide paint spraying equipment of the type which utilizes the force of supersonic waves for producing a jet.

d. To provide means acting upon a liquid to produce supersonic compressional waves therein, whereby the liquid may be forced through an orifice and come out as a jet or spray in consequence of the inherent characteristic of the compressional wave phenomenon to cause unidirectional flow of the liquid.

The foregoing and other objects and advantages of my invention will best be understood by the following detailed description taken in view of the accompanying drawings, wherein:

Fig. 1 shows, more or less diagrammatically, an arrangement of a liquid container having one portion thereof conically walled and having an orifice at the apex of the cone for the emission of a liquid jet or train of globules as produced by a supersonic compressional wave applied to a surface of the liquid;

Fig. 2 shows a modified shape for the walls of the liquid container;

Fig. 3 shows a liquid container of still different shape and having in association therewith a solid cone which is capable of transmitting a supersonic wave to the liquid at a focal point opposite an orifice in the liquid container so as to cause expulsion at right angles to the plane of feed of the liquid; and

Fig. 4 shows still another modification characterized by the use of a solid cone having a channel on its top side, down which the fluid may be fed to the apex of the cone, this apex being axially disposed with respect to a nozzle, so as to cause a jet to be thrown out in response to supersonic waves transmitted within the body of the cone.

Referring first to Fig. 1, I show therein a container 1 having conical walls and an orifice 2 from which a jet or train of globules may be ejected. At the base of the cone, I provide a piezo-electric crystal device composed of a crystal element 3, electrodes 4 for exciting the crystal and two mechanical vibration transmitting media 5 which may be in the form of layers of suitable material to offer impedance matching for oscillations, such as to provide a broad band of frequency response.

On the opposite side of the crystal 3 with respect to the conical liquid container, I preferably dispose a second container 6 which is used to enclose a liquid preferably of the same characteristics as the liquid to be used in the jet. Within the container 6, I also provide a conical member 7 which acts as a supersonic wave reflecting and absorbing cone and assists in matching the impedances to which the piezo-electric device is subjected, thereby providing a broad band of frequency response.

The container 6 has a filler hole which may be closed by means of a screw plug 8. The container 6 also is formed with a flange 9 by means of which it can be held tightly against the piezo-electric device 3, using a screw cap 10 of insulating material which is screwed on to a threaded end of a metal ring 11. The container 6 and the ring 11 are electrically connected respectively to one and the other of two electrodes 4 which are disposed on opposite faces of the crystal. A source of high frequency energy 12 is coupled or connected to the electrodes 4 through conductors 13 for activating the crystal. If desired, this source may be modulated by signals thereby to produce variations in the amplitude of the mechanical vibrations set up in the crystal. These vibrations are mechanically transmitted to the liquids within the two containers 1 and 6.

The liquid in the container 1 may be replenished by means of a reservoir 14 containing as much liquid as may be needed for operation of the device during a predetermined period of time. The reservoir 14 communicates with the container 1 by means of a tube 15.

In the design of apparatus according to the foregoing description of Fig. 1, I have taken advantage of the teachings set forth in British Patent 466,212 filed by Scophony Ltd. and J. H. Jeffree wherein the following is stated:

"It is known to generate supersonic waves in liquids by means of piezo electrically produced vibrations of crystal plates in contact with the liquids. To obtain maximum efficiency it is known to work at a resonance frequency of the crystal, such that the thickness of the crystal is equal to half the wave length of the waves of said frequency in the crystal substance, or an odd multiple of half the wave length."

This British patent does not, however, disclose the specific means which I have found to be advantageous for matching the impedances of the vibratory media on the two sides of the crystal. By virtue of these improvements of design the device is rendered operative at much high modulation frequencies than was heretofore found possible. In fact the apparatus of my invention may be used for responding to modulated supersonic waves and for recording conventional television signals on a record sheet. My invention is, however, not limited to such use, but may be employed in facsimile recording at any desired speed and for other commercial purposes as well.

Considering the requirements for television image recording, however, it may be seen that if the velocity of the waves in the liquid is 148,400 centimeters per second (as has been found to be normal by previous experimenters) and if the frequency of the waves is chosen to be 14,840,000 cycles per second then the length of the waves will be 0.01 centimeter (0.00394 inch) and this should be the approximate diameter of droplets as they are ejected from the nozzle. The rate of ejection would then be 14,840,000 droplets per second.

Assuming that each droplet, after it has left the nozzle, is the equivalent of a sphere 0.01 centimeter diameter its volume will be

$$\frac{\pi}{6}(.01)^3=\frac{.52}{(10)^6}\text{ cubic centimeter}$$

and the total flow should be at the rate of

$$\frac{.52\times 14.84\times (10)^6}{(10)^6}=$$

7.77 cubic centimeters per second

At this rate the device would consume liquid at the rate of

$$\frac{7.77\times 3600}{1000}=27.97\text{ liters}$$

or 7.4 gallons per hour. At television speeds, recording 7.5 x 10 inch images, this amount of liquid would be spread over 56,250 sq. feet. This corresponds to 7600 square feet per gallon. That much paint when evenly spread over that many square feet would be approximately .0002" thick. A monochrome picture would, however, require a smaller consumption of liquid, considering that the white areas would remain unpainted.

For slower speed facsimile recording my invention provides for constant-frequency-variable-length-pulse-transmission of signals for producing pulses of supersonic waves which are repeated at a constant rate but which are varied in amplitude and cause a varying amount of liquid to be ejected by each pulse.

It is further contemplated that in carrying out my invention I may use a modulation frequency as high as 9 megacycles per second even though the constant frequency of the piezo-electric excitation means (the carrier frequency) is only 18 megacycles. In order to accomplish this result, however, I intend to use all the available expedients which are known for improving the response.

Assuming that the shortest pulses are allowed a squareness corresponding to the third harmonic, then we may say that the shortest pulses will be $^1/_{3000000}$ second in length. For 100 lines

$$\frac{1}{3000000}$$

per inch detail, in 7.5 x 10 inch images, we need 750,000 impulses per image and for one image per minute we then need a pulse rate of

$$\frac{750{,}000}{60}=12{,}500$$

per second. The shortest pulses would then be

$$\frac{12{,}500}{3{,}000{,}000}=\frac{1}{240}$$

or .416% of the longest pulses and the modulation of liquid applied to the image would then extend over a range of 240 to 1. This should be adequate, particularly if it is found in practice that the last bit of suppression of fluid flow can be obtained by the effect of decreasing the amplitude of response.

My invention is in no way limited to the use of any specific liquids. Inks of any suitable color may be employed. The device may also be used for paint and enamel spraying. Pictures and transparencies which are translated into signals may be reproduced on a record medium which travels with sufficient speed past the jet so as to form enlargements in black and white or any other colors. A combination of colors may also be used by repeated scannings of the recording medium, a different color being used with each scanning. In this way it is possible to obtain copies of paintings with any degree of change in the dimensions, and to print wall paper, canvas, or to apply an image directly to a wall for decorative purposes. The invention may also be used for spraying acids and chemicals for the etching of printing plates and for putting decorative designs on articles of manufacture.

Still another application of my invention is contemplated, as for example, in the automatic control of small amounts of liquids where such control is required in certain chemical processes. For example, the invention may be used to control the addition of fluorine and iodine solutions to the water supply of public water systems. The output of chemicals from the jet may be made to respond to the rate of flow of water at some point in the system, by means of suitable electrical measuring and electrical control systems.

As a matter of engineering design it is contemplated that an optimum diameter of the orifice 2 will be chosen so as to obtain the necessary capillary effects which will prevent the bleeding of the container in the absence of propulsion by the supersonic waves. This, however, is a matter of engineering design and the merits of the invention in no way depend upon such design other than to meet the requirements for operability.

If desired the entire recording system may be enclosed in a larger container so as to be operated under greater than atmospheric pressure. For example, if the overall pressure is raised to five atmospheres then the supersonic waves can create a maximum difference in pressure of five atmospheres, between the ink source and the inside of the nozzle tip where cavitation of the ink due to the supersonic waves reaches its maximum amount. In other words, the maximum force available to replace the ink ejected from the nozzle tips is always equal to the absolute pressure of the air in which the system is immersed, less the vapor pressure of the ink in the cavities created by the supersonic waves in the nozzle tip.

In some cases I expect to add liquids of relatively high vapor pressure to the fluids used in the jet, for the purpose of increasing the pressure in the cavities produced by the half cycles of tension in the liquid, to thereby obtain an increased unidirectional pumping effect due to cavitation.

I have found that very fine droplets of liquid are slowed down from very high to low velocities, due to friction, in a short distance in air. To reduce this effect I may employ a very rapidly moving stream of air, passing over and past the end of the nozzle and flowing in the direction in which it is desired that the droplets should go. By this means a greater spacing between the end of the nozzle and the record surface may be made possible.

Referring now to Fig. 2, I show therein a modification in which the nozzle or orifice for the liquid container is surrounded by a container wall 16 which is of a blunt nose formation. This shape is intended to aid in replacing the liquid thrown out by the supersonic waves. Advantage is taken of the principle of the Venturi tube, a characteristic of which is to produce a vacuum which aids in replacing liquid thrown out through the jet.

The walls of the container 6 may be of glass or other material having a glazed inner surface for reducing friction. The walls may also be waxed outside to inhibit wetting or they may be made hydrophobic by treatment with vapor of methyl chlorosilicones in the presence of adsorbed water, as described by F. J. Norton in his paper Organo-Silicon Films, General Electric Review, August 1944. The inside walls may, however, be etched, if desired, to aid in wetting, for the purpose of reducing wave reflections at the interface between the liquid and its container.

The modification shown in Fig. 3 includes a liquid container having walls 17 and 18 between which the liquid flows inward radially toward the orifice 2. The expulsion of the liquid as a jet is produced by supersonic waves which are carried in a solid cone 19, the apex of which is disposed in back of the orifice 2. The supersonic waves are applied to the cone 19 in the same manner as is described above with respect to the liquid in the container 1 (Fig. 1). The compressional waves in the solid material of the cone 19 are greatly increased in relative intensity at the apex of the cone and thus the expulsion of the liquid is produced with increased force.

The modification shown in Fig. 4 is one in which a solid cone 20 is slotted or channeled on the top side, the channel being indicated at 21. In this arrangement the fluid flows down the channel and is ejected at the apex of the cone. The cone itself carries the supersonic waves and, due to the cavitation and the rectification effect herein above mentioned, the forward propulsion of the liquid greatly exceeds the force of the negative half cycles of the compressional waves.

I claim:

1. Apparatus for the spraying of a liquid in a fine jet, or train of globules, comprising a liquid container having an intake orifice and a spray nozzle, piezo-electric means for applying compressional waves to a surface of said liquid within said container, and means for focussing the effects of said compressional waves on that part of the liquid which faces said orifice.

2. Apparatus according to claim 1 including means for modulating the output of liquid from said nozzle, said means comprising a source of signals and a device responsive to said signals for varying the amplitude of vibration of said piezo-electric means.

3. Liquid spraying apparatus comprising a reservoir for the liquid to be sprayed, a nozzle disposed at the apex of a conically-walled portion of said reservoir, and means for producing supersonic compressional waves on a surface of said liquid, said waves having a front which is caused to travel along the axis of said nozzle and which in turn causes ejection of the liquid from said nozzle.

4. Apparatus in accordance with claim 3 wherein said compressional wave producing means comprises a piezo-electric device which is activated by an alternating current, and said means includes a member for mechanically conducting the vibrations of said device to a surface of the liquid in said reservoir.

5. In a liquid jet producing device, a container for the liquid, said container having an intake opening and a tapered end which is orificed at its apex to provide an outlet having capillary characteristics, piezo-electric means for producing vibrations on a surface of said liquid, said vibrations having a compressional wave front which is directed toward said apex and which causes the liquid to be ejected from said orifice.

6. A device according to claim 5 characterized by a blunt-nosed formation of said apex.

7. A device according to claim 5 having the inner walls of said container composed of a material the surface of which is subject to "wetting" by said liquid.

8. A liquid jet producing device comprising a liquid container opposite walls of which are suitably orificed to provide an entrance and an exit respectively, the orifices being mutually opposed, a solid cone of material having a modulus of elasticity which is favorable for the transmission of supersonic waves therein, said cone having its apex inserted in said entrance orifice, means for producing mechanical vibrations of supersonic frequency in said cone and in a direction such that a compressional wave travels along the axis of said cone toward its apex, and a liquid filling said container and in contact with said apex, said liquid being subject to expulsion through said exit orifice.

9. A device according to claim 8 including a piezo-electric element mechanically coupled to said cone and means for causing said piezo-electric element to translate electrical energy into mechanical energy.

10. A device according to claim 8 further characterized in that said cone is channeled to provide a canal for the flow of liquid down its top side when its conical axis lies horizontally, said channel entering the container.

11. In a liquid jet producing device, a shell for the liquid, said shell having a nozzle portion at one end thereof and a cylindrical portion at the other end thereof, a re-entrant conically shaped member attached to the outer extremity of said cylindrical portion and cooperating therewith for confining a quantity of liquid, a piezo-electric device constituting a partition wall between the nozzle portion and the cylindrical portion of said shell, electrical means for vibrating said piezo-electric device, and means for continuously replenishing the liquid which is ejected from the nozzle portion of said shell, this means being operative in such manner that the inertias of the liquids on opposite sides of said piezo-electric device are maintained in balanced relation.

12. In a liquid jet producing device, a shell for confining the liquid, said shell having a nozzle portion at the end of a front chamber and a liquid-confining portion constituting a rear chamber, a piezo-electric device forming a partition wall between the two chambers, electrical means for exciting the piezo-electric device thereby to set up compressional waves in the liquids within the two chambers, thereby to cause jet-expulsion of liquid through the nozzle portion of said shell, and means for continuously replenishing the liquid in the front chamber, this means being effective to maintain a mechanical impedance match with respect to the transmission of compressional waves through the liquids confined by the two chambers.

13. Apparatus for spraying a liquid in a fine jet comprising a movable member for retaining a removable record sheet, a liquid container having an intake orifice and a spray nozzle positioned adjacent said movable member, an electrically excited piezo-electric device for causing the transmission of compressional waves through the liquid contained in said container to spray the

surface of said record sheet, and pressure chamber means for confining said apparatus and said surface in a compressed atmosphere.

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