United States Patent

Robertson

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[45] **Apr. 11, 1972**

[54] FLUID DROP MARKING APPARATUS

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 96,083, Dec. 8, 1970.

[52] **U.S. Cl.** .....**346/75,** 178/6.6 R

[51] **Int. Cl.** **G01d 15/18**

[58] **Field of Search** .....346/1, 75, 140; 239/15, 3; 209/127 R, 127 C, 3; 178/6.6; 317/3

[56] **References Cited**

UNITED STATES PATENTS

3,373,437	3/1968	Sweet et al.	346/75
3,416,153	12/1968	Hertz et al.	346/75
3,560,641	2/1971	Taylor et al.	346/75 X

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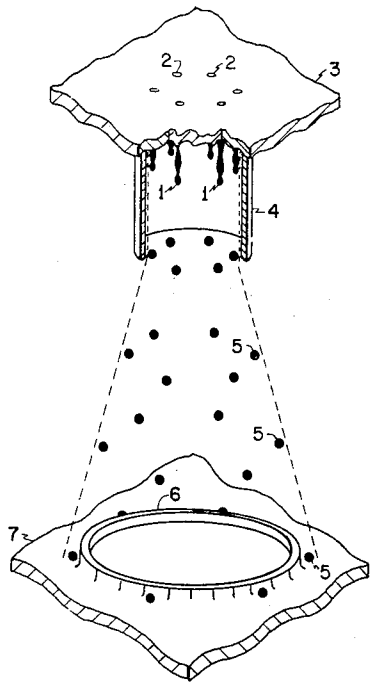
[57] **ABSTRACT**

A fluid drop marking apparatus which generates a plurality of fluid marking streams from a set of orifices spaced apart along a closed contour in an orifice plate. The streams are stimulated to create a corresponding set of drop trains and the drops are selectively charged by application of an electrical signal to a conductive surface surrounding the streams at their breakup points. The conductive surface extends downstream for production of outwardly attractive images of the drop charges; thereby causing the charged drops to be deflected outwardly for selective catching by an apertured catching plate. Halftone representations are created by modulation of the applied electrical signal; the nature of the modulation depending upon the type of catching plate aperture employed.

4 Claims, 5 Drawing Figures



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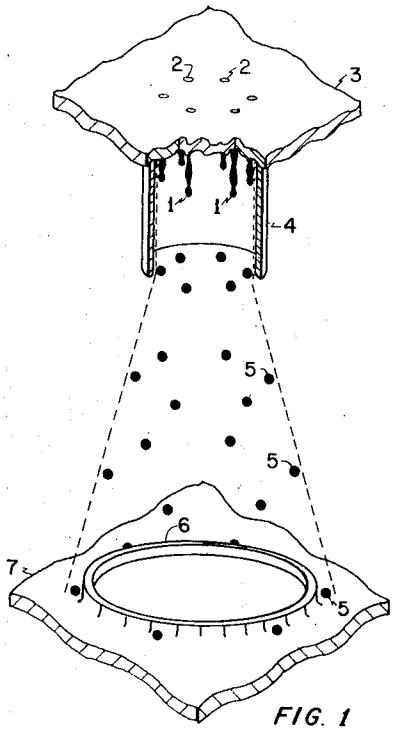

FIG. 1

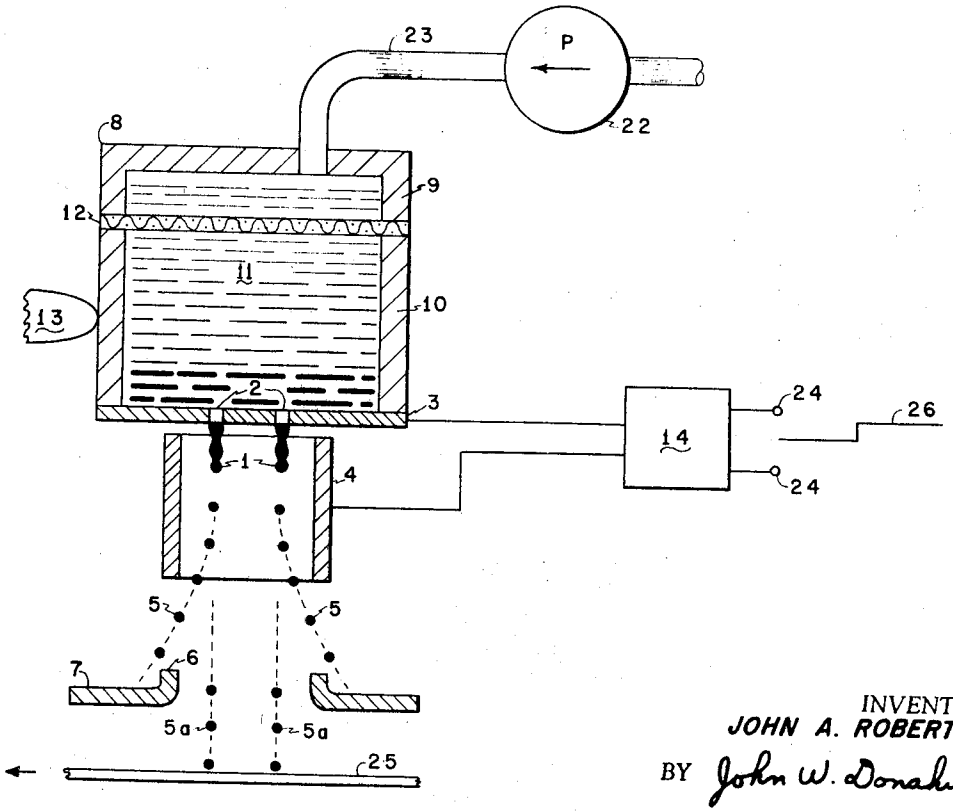

FIG. 2

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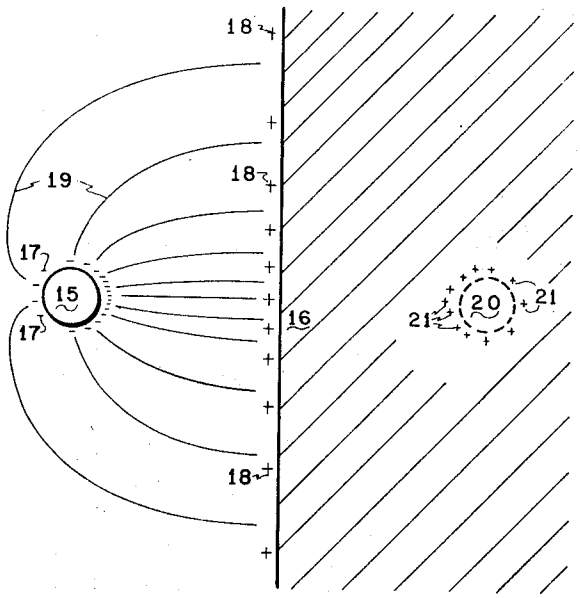

FIG. 3

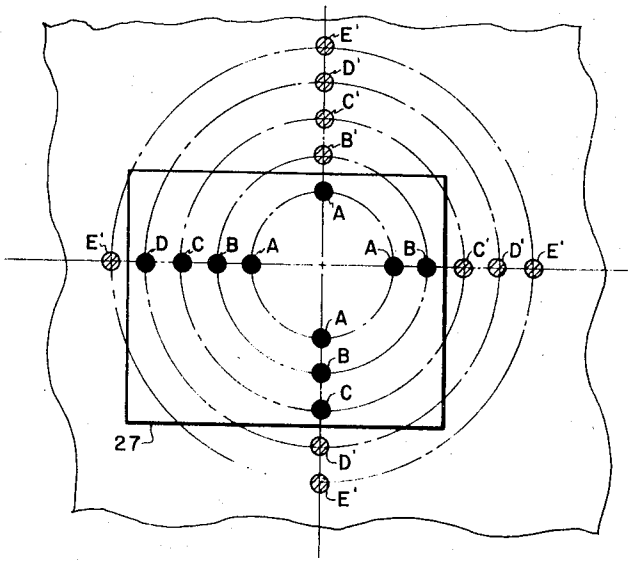

FIG. 4

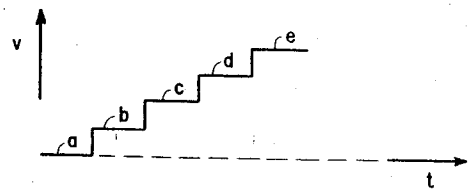

FIG. 4a

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FLUID DROP MARKING APPARATUS

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of U.S. Pat. application Ser. No. 96,083 filed Dec. 8, 1970.

BACKGROUND OF THE INVENTION

This invention relates to the general field of fluid drop marking and more particularly to fluid drop marking apparatus of the type wherein a marking fluid is forced through an orifice under pressure and is stimulated upon exit therefrom to break up into a train of uniformly sized and regularly spaced drops. Typical prior art devices of this type are shown in Lewis et al. U.S. Pat. No. 3,298,030 and in Sweet et al. U. S. Pat. No. 3,373,437. Such devices ordinarily employ a charging electrode for capacitive charging of the drops during formation. Thereafter they variably deflect the drops by subjecting them to the action of a steady state electrical field. Certain of the drops which are charged to deflect more than some predetermined distance are ordinarily caught. The catcher for such a purpose may be a porous block as shown in the mentioned Sweet et al. patent, a simple funnel as shown in the mentioned Lewis et al. patent, or an apertured plate as shown for instance in Hertz et al. U.S. Pat. No. 3,416,153 or Nordin U.S. Pat. No. 3,500,436.

As disclosed in the parent patent application, it is possible to eliminate the requirement for a steady state electrical deflection field by providing a laterally non symmetrical conductive surface to enable drop deflection by a self induced electrical field. In general it is an object of the present invention to provide an apparatus using the principles of the invention of the parent application and which is particularly well adapted for halftone recording of graphic information.

It is another object of the invention to provide a jet drop recording apparatus of reduced complexity.

Another object of the invention is to provide a fluid drop marking apparatus having improved marking accuracy.

Still another object of the invention is to provide apparatus for digital jet drop recording at increased information rates and with relatively small sized drops.

Additional objects and features of the invention will become apparent by reference to the following description together with the accompanying drawings and claims.

SUMMARY OF THE INVENTION

This invention accomplishes the aforementioned objects by creating a plurality of trains of uniformly sized and regularly spaced drops, directing these drops through an aperture in a catching plate, and selectively deflecting drops outwardly beyond the aperture lip by employment of self induced deflection fields. The drops trains are created by forcing a marking fluid through a plate and applying a constant frequency drop stimulating disturbance to the resulting set of issuing fluid streams. As the drops are generated they are selectively charged by controlled application of a capacitive charging voltage between the fluid streams and a surrounding conductive surface. Thereafter the drops are deflected outwardly by the attractive action of self-induced image charges in a downwardly extending portion of the conductive surface. Halftone representations may be created by employing a non coincident catching plate aperture and modulating the amplitude of the drop charging voltage for catching of a predetermined percentage of the drops generated during any given stimulation cycle. Alternatively, halftone representations may be created by employing a coincident catcher together with on/off modulation of the drop charging voltage in accordance with an appropriately timed schedule.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partially cut away representation of a general apparatus arrangement constructed in accordance with this invention.

FIG. 2 is a cut away schematic representation of one species of the invention.

FIG. 3 is a diagrammatic illustration of the distribution of actual and image charges induced in a conductive wall by the presence of a nearby charged drop.

FIG. 4 is an illustration of a catching plate aperture for use in generating halftone representations.

FIG. 4*a* illustrates a charging voltage sequence for use in connection with the catching plate aperture of FIG. 4 to produce 5 halftone densities ranging from black to white.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The preferred arrangement for this invention is shown generally in FIG. 1 wherein are illustrated a set of circularly disposed fluid filaments 1 issuing from a set of orifices 2 in an orifice plate 3 and breaking up into drops 5. Surrounding filaments 1 is a conductive cylindrical tube 4 which is adapted for capacitive charging and self induced outward deflection of drops 5. Drops 5 accordingly (but only if charged) fall beyond the upstanding lip 6 of apertured catching plate 7 and are caught. They are then drawn away by a vacuum (not illustrated).

FIG. 2 illustrates the above mentioned drop marking operation in somewhat more detail for only two streams. As shown in FIG. 2 a fluid supply chamber 8 having upper and lower sections 9 and 10 contains a supply of marking fluid 11. Fluid 11 is supplied to chamber 8 by conduit 23 and is maintained under pressure by any convenient means such as a pump 22. A filter screen 12 removes any large particulate matter from fluid 11 thereby preventing any plugging of orifices 2. A stimulation transducer 13 transmits constant frequency vibrations through the structure of chamber 8 to filaments 1 thereby causing regularly timed formation of uniformly sized drops. The drop stimulation process is well known in the prior art, and a variety of stimulation transducers are available. Accordingly transducer 13 may be magnetostrictively driven or may be replaced by a piezoelectric device which may be bonded directly to chamber 8 or to orifice plate 3. The vibration frequency should be somewhere near the natural frequency of streams 1 which in one successfully operated embodiment is about 175 kHz. Associated with this frequency area fluid pressure of 2.1 kg. per sq. cm. and an orifice diameter of 11.4 microns. The apparatus conveniently employs six orifices on a 204 micron diameter circle. The stimulation frequency should be increased with increasing fluid pressure or with a decreased orifice diameter.

Drops 5 may be selectively charged by applying a charging signal 26 to the input terminals 24 of an amplifier 14. The output terminals of amplifier 14 are connected to orifice plate 3 and to tube 4. This sets up an electrical field between the conductive inner surface of tube 4 and the outer surface of filaments 1. As a result, filaments 1 are capacitively charged and this charge is carried away by drops 5. This technique for drop charging is generally the same as that employed in the prior art as shown for instance in Lewis et al. U.S. Pat. No. 3,298,030. However, in contrast to prior art charging electrodes, conductive tube 4 extends relatively far below the drop breakoff points thereby providing an imaging surface for self induced deflection of the charged drops. For the above mentioned six-orifice configuration, tube 4 may be about 380 microns in dia. and extend about 1,800 microns below the drop formation point. The charging potential may be about 200 volts.

The drop deflection phenomenon may be understood by referring to FIG. 3 wherein a charged drop 15 is shown falling past a conductive wall 16. Drop 15 carries distributed negative charges 17 which induce charges 18 on the surface of wall 16. Charges 18 attract drop 15 toward wall 16 with a cumulative effect equivalent to that of a hypothetical image drop 20 carrying image charges 21. Lines 19 represent the total electrical field between drop 15 and wall 16. The force acting on drop 15 is given approximately by the equation

$$F = \frac{1}{4\pi\epsilon_0}\frac{Q^2}{(2d)^2}$$

where Q is the total charge on drop **15**, ϵ_o is the permittivity of air and d is the distance from drop **15** to the surface of wall **16**.

It should be apparent that a second wall placed opposite wall **16** on the other side of drop **15** would set up attractive forces cancelling the effect of wall **16**. This same cancelling effect is present when a single train of charged drops passes down the axis of a cylindrical conductive surface. Thus, as explained in more detail in the parent application, it is necessary that the conductive surface have a laterally non-symmetrical configuration with respect to the initial drop trajectory. This condition necessarily obtains when the conductive surface is cylindrical and surrounds a plurality of drop trains, all of which are offset from the cylinder axis.

Referring again to FIG. **2**, there are illustrated a set of drops **5***a* which are not caught but have passed through the aperture in catching plate **7** for deposition on the moving recording medium **25**. Drops **5***a* were all formed when signal **26** was at the zero level. These drops received no electrical charge and fell through tube **4** without deflection; the subsequent change in tube potential having no effect upon their trajectories. Drops **5** on the other hand were all formed after signal **26** jumped from a zero to a non zero magnitude and accordingly have been outwardly deflected for catching. Thus the apparatus produces a recorded line which corresponds to on/off states in the input control signal.

It should be appreciated that the above described apparatus will print **6** circularly arranged dots on recording medium **25** during one stimulation period. The individual dots typically will have a diameter of about 40 microns whereas the circle of dot centers will have a diameter of 204 microns. Thus to achieve solid coverage it becomes necessary to adjust the movement speed of recording medium **25** so as to allow time for deposition of several overlapping dot sets while the recording medium moves for a distance of 204 microns. A halftone gray scale may be created by merely charging and catching various ones of these overlapping dot sets. The large 204 micron circle thus may be considered the basic system resolution cell corresponding to one square in a halftone screen. Techniques well known in communication theory may be applied to achieve modulation of the charging voltage signal appropriate for creation of the above described halftones.

Another method of generating halftone representation with the apparatus of this invention makes use of a non coincident catching plate aperture. FIG. **4** illustrates such an aperture which may be used in combination with a set of four drop trains. In general such a non coincident aperture may have a contour which is shaped differently from the contour passing through the centers of the orifice plate orifices, or else it may be similarly shaped and merely laterally offset whereby an equal outward deflection of all drop trains results in catching of the drops in one or more trains with passage through the aperture of the drops in the other trains. For comparison note the coincident circular catcher shown in FIG. **1** in combination with a circular array of orifices. All drops generated by such an arrangement during one stimulation period are similarly charged and deflect outwardly in a conical manner with a cone half-angle dependent upon the level of the charging voltage. Catching plate **7** catches all drops in one six-drop cluster, (i.e., six circularly disposed drops generated from fluid filaments **1** during a single stimulation period) or else it catches none of them. It cannot selectively catch only certain drops within a single cluster.

In contrast thereto, aperture **27** when used non coincidently with **4** equally spaced drop trains as shown in FIG. **4** may print five different density levels ranging from black to white. FIG. **4** illustrates five sequential catching plane positions which the four mentioned drop trains may reach when the four parent field filaments have been sequentially charged by five voltage levels as shown in FIG. **4***a*.

Drop positions A represent the lateral location at the catching plate plane for drops being formed when the charging signal is at level *a*. If level *a* has a magnitude of zero volts, then the spacing between positions A is identical to the spacing of **4** corresponding orifices in the orifice plate.

When the charging signal is raised to lever *b* the drops then being formed are slightly charged and accordingly are deflected outwardly a short distance. Drops from **3** of the drop trains pass through position B and eventually will reach the recording medium. However drops in the fourth train are deflected to position B′ which is beyond the edge of aperture **27** and accordingly are caught. Thus when the charging signal is raised from level *a* to level *b*, the amount of marking fluid reaching the recording medium is decreased by 25 percent. Similarly when the charging signal is raised to level *c* two drop trains are deflected to pass through two non catching positions C while the other two drop trains are deflected to two catching positions C′. This reduces the quantity of deposited marking fluid by a total of 50 percent.

Continuing as above, the charging signal may be raised to levels *d* and *e* for drop deflection to positions D,D′ and E,E′. The drop catching positions are in all cases illustrated in a striped fashion while the passage or non catching positions are solid. It is therefore seen how a non coincident four sided catcher may be used in combination with four drop trains and five charging signal levels to produce five marking intensity levels ranging from black to white. The invention may obviously be extended to produce additional halftone levels by adding additional streams, charging levels and aperture sides.

What is claimed is:

1. Fluid drop marking apparatus comprising:

1. an orifice plate provided with a plurality of orifices spaced apart along a closed contour,
2. a marking fluid supply reservoir communicating with said orifices,
3. means for applying pressure to marking fluid within said reservoir and causing streams of marking fluid to be projected from the orifices,
4. means for stimulating said streams and causing them to break up into trains of uniformly sized and regularly spaced drops,
5. a closed contour electrically conductive surface surrounding the streams at their breakup points and connected to a source of variable electric potential for capacitive inducement of predetermined electrical charges in selected drops; said surface extending downwardly from said breakup points for production of outwardly attractive images of said charges, and
6. an apertured catching plate positioned for passage of said drop trains through the aperture thereof; said aperture being contoured for catching of drops deflected therebeyond by the attractive action of said images.

2. Apparatus according to claim **1** the orifices in said orifice plate being circularly arranged and the aperture in said apertured catching plate being of circular configuration and in line with the circularly arranged orifices for operation as a coincident catcher.

3. Apparatus according to claim **1**, the aperture in said apertured catching plate being non coincident for production of halftone representations.

4. Fluid drop marking apparatus comprising:

1. an orifice plate provided with a plurality of orifices spaced apart along a closed contour,
2. a marking fluid supply reservoir communicating with said orifices,
3. means for applying pressure to marking fluid within said reservoir and causing streams of marking fluid to be projected from the orifices,
4. means for stimulating said streams and causing them to break up into trains of uniformly sized and regularly spaced drops,
5. means for inducing predetermined electrical charges in selected drops and producing outwardly attractive images of said charges, and
6. an apertured catching plate positioned for passage of said drop trains through the aperture thereof; said aperture being non coincident for production of halftone representations by selective catching of drops deflected therebeyond by the attractive action of said images.

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