Dec. 10, 1968 C. H. HERTZ ETAL 3,416,153

INK JET RECORDER

Filed Oct. 6, 1963 3 Sheets-Sheet 1

FIG. 1

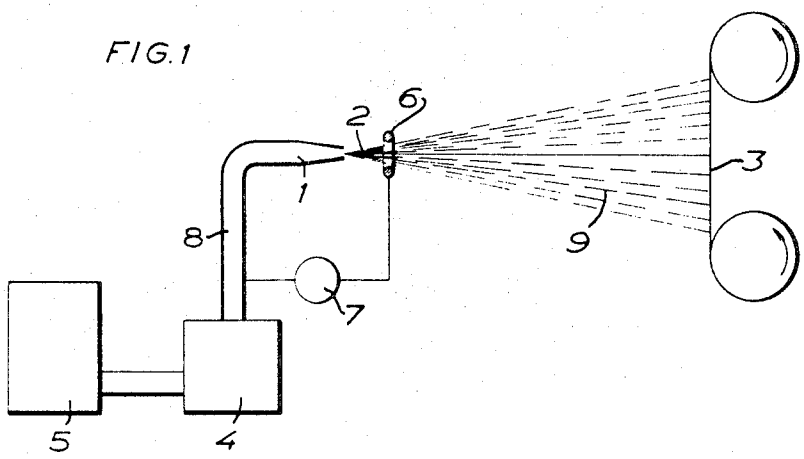


FIG. 2

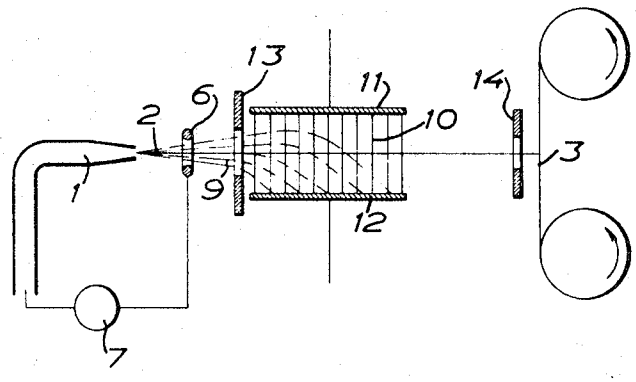
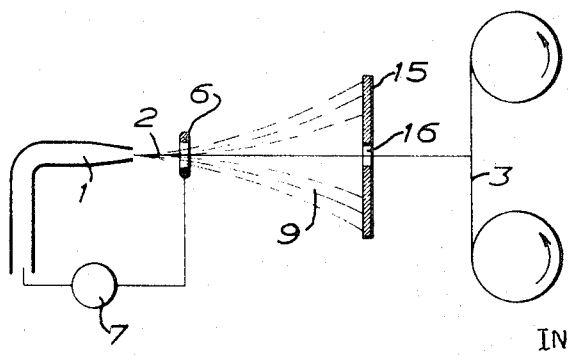


FIG. 3



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INK JET RECORDER

Filed Oct. 6, 1966 3 Sheets-Sheet 2

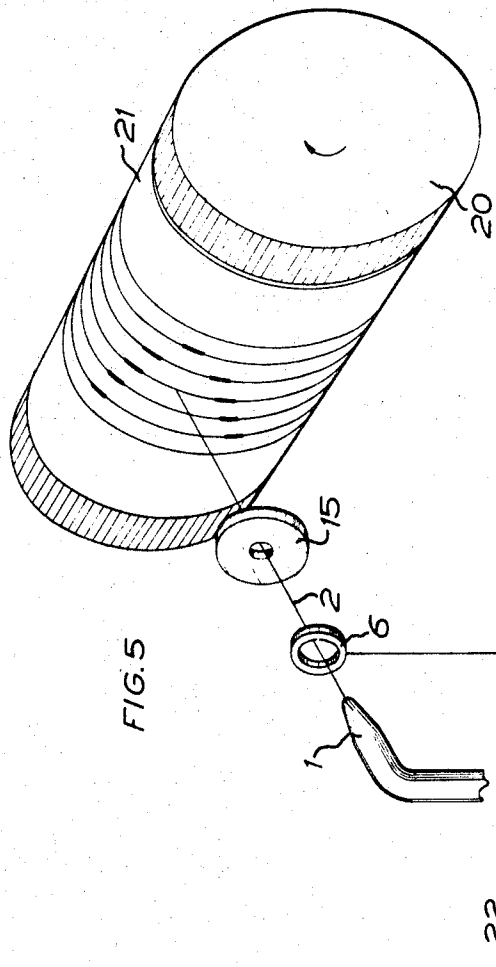

FIG. 5

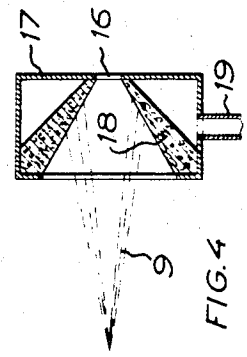

FIG. 4

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INK JET RECORDER

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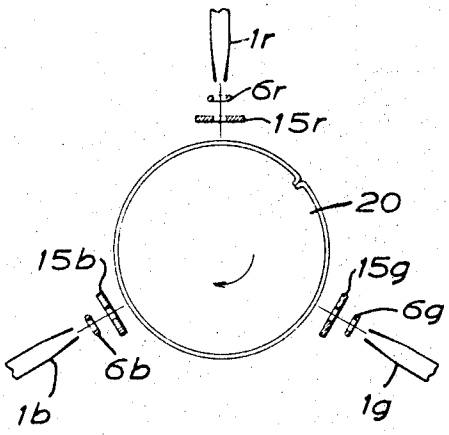

FIG. 6

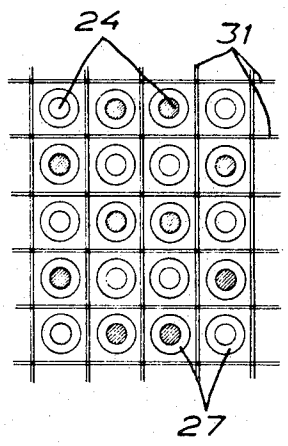

FIG. 7

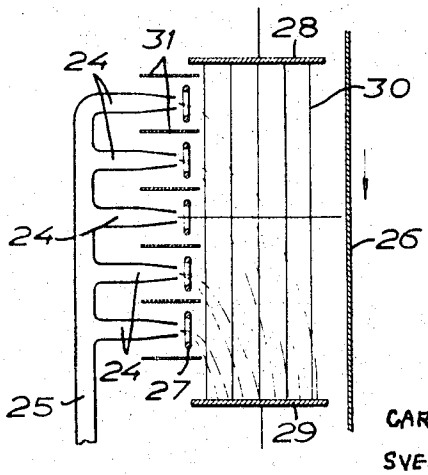

FIG. 8

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3,416,153

INK JET RECORDER

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Filed Oct. 6, 1966, Ser. No. 584,900
Claims priority, application Sweden, Oct. 8, 1965, 13,057/65, 13,058/65
9 Claims. (Cl. 346—75)

ABSTRACT OF THE DISCLOSURE

In a device for converting electric signals from a signal source into markings on a record receiving surface by means of a liquid jet projected along a jet axis from a nozzle against said surface, while relatively moving the nozzle and said surface, the signal source is connected between the nozzle and a control electrode provided laterally of the jet axis between the nozzle and said surface, for generating between the nozzle and the electrode an electric field extending substantially along the jet axis so as to charge the liquid jet according to the electric signals and thereby to diffuse to a greater or lesser extent the liquid jet under the action of said signals into small drops departing from the jet axis.

In many branches of science and engineering different types of recording devices are used to convert electrical signals into characters or curves on a recording paper, i.e. electric typewriters, facsimile devices and recording oscillographs. To this end, different methods are used which have certain inherent drawbacks. Thus the upper frequency limit of such devices as the teleprinter or certain oscillographs is limited by the inertia of their electromechanical system, while the use of light sensitive paper in facsimile devices and other types of oscillographs is inconvenient because of cost and the necessity of processing. Even fine liquid jets have been used as recording means, but even here the inertia of the jet forming nozzle or the liquid itself has proved to limit the maximum frequency of these devices seriously. Furthermore, with the exception of the photographic process, these methods are not able to reproduce a satisfactory gray scale.

The present invention relates to a recording device that allows the recording of electrical signals with frequencies up to 1 Mc./s. on normal paper. Further, the device is able to generate a continuous gray scale from white to nearly total black. The invention, which makes use of a liquid jet, is first described in principle, whereafter various applications are discussed, with reference to the accompanying drawings in which:

FIG. 1 shows a liquid jet **2** emerging from a nozzle **1** and dispersed by the action of an electrode **6**, reaching the recording paper **3** as a spray **9**;

FIG. 2 shows how an electric field **10** and a shield **14** prevents the dispersed liquid jet **9** from reaching the recording paper **3**;

FIG. 3 shows the action of a circular diaphragm **15** in passing only part of the dispersed ink jet **9** to the recording paper **3**;

FIG. 4 shows a cross section of a modified diaphragm for use in the device according to FIG. 3;

FIG. 5 shows the use of the recording device in FIG. 3 for the generation of a picture on the rotating drum **20**;

FIG. 6 shows an end view of an apparatus for the generation of color pictures;

FIGS. 7 and 8 show a front view and a side view, respectively, of an array of nozzles **24** which can generate letters and numbers on the recording paper **26** dependent on the voltages applied to the electrode **27**.

In FIG. 1 an ink jet **2** is ejected from a nozzle **1** by a pump **4** which receives liquid or ink from a reservoir **5** and produces a permanent record in the form of a point or line on the recording paper **3**. However, if an electric voltage **7** is applied between the electrode **6** and the metallic tube leading the liquid from the pump **4** to the nozzle **1**, it is found that the liquid jet is dispersed into a spray of fine droplets **9**. In this case no defined trace is recorded on the paper. Hence, the recording trace on the paper **3** can be interrupted by applying the control voltage **7** to the control electrode **6**, and it can be shown, that this can be done up to 1,000,000 times per second.

The above described phenomenon is due to the well-known property of a jet of liquid to part into droplets soon after leaving the nozzle due to the action of surface tension. Now, if an electrode **6** in the form of a small ring is placed around the jet **2** near the point of drop formation and a voltage **7** is applied between the liquid and the electrode **6**, the drops are electrically charged due to the influence of the electric field on the jet **2**. This electric charge gives rise to an electric force on the drop surface having opposite direction to the drop conserving force of surface tension. If this electric force becomes larger than the force due to surface tension, the drops will explode into smaller drops. Since each of these droplets still are carrying a charge of equal sign, they will repell each other more or less perpendicularly to the original direction of the jet, thus forming the spray **9**.

Using a nozzle with an inner diameter of 0.015 millimeter, made by the firm Elema, Stockholm, Sweden, from which nozzle a jet of liquid is discharged under pressure of about 20 kilograms per square centimeter with a velocity of about 1000 centimeters per second, the point of drop formation is situated about 1 mm. in front of the nozzle. Using an annular electrode with an inner diameter of 2 mm. at this place, any voltage **7** larger than 90 volts will charge the drops sufficiently to cause at least some of the drops to explode. Since the charge generated on the drops depends on the voltage **7** applied to the electrode **6**, the solid angle formed by the spray will increase if the voltage **7** is increased. A voltage range of 100 to 500 volts is normally used in these experiments.

The high upper frequency limit of this device is due to the fact that the center of gravity of the undisturbed jet is not accelerated or decelerated by the influence of the voltage **7**, and, further, that the point of drop formation is reasonable stationary. It has been found that the size of the nozzle **1** and electrode **6** as well as the voltage **7** can be varied within wide margins without impairing the operation of the device.

In the device shown in FIG. 1 the liquid spray **9** still reaches the recording paper **3** which results in a certain colouring of the paper. This can be avoided by a static electric field **10** having a strength of about 5000 volts per centimeter being generated between two electrodes **11** and **12** as shown in FIG. 2. The length of the electrodes **11** and **12** is about 1.5 centimeters and the distance from the nozzle **1** to the recording paper **3** is 4 centimeters. An electrostatic shield **13** held at ground potential is introduced between the electrode **6** and the electric field **10** to prevent the influence of the latter on the electric field close to the nozzle. The colouring of the recording paper by the ink spray can be prevented also by the use of a suitable formed shield **14** which allows the passage of the undisturbed liquid jet only. Both the shield **14** and at least one of the electrodes **11** and **12** should be prepared in such a way that the liquid collected on them is swiftly removed, for example by some sort of suction device or porous material or both.

For the generation of a gray scale of the recording trace use is made of the fact that the solid angle formed

by the spray of droplets from the scattered beam is dependent on the voltage **7** applied to the electrode **6**. In FIG. 3 this spray **9** is intercepted by a diaphragm **15** with a circular aperture **16** the diameter of which is usually 0.2 millimeter. If the diaphragm is mounted 8 millimeters from the electrode **6** perpendicular to the liquid jet and so adjusted that the undisturbed liquid jet passes exactly through the aperture **16**, the amount of liquid reaching the recording paper **3** is entirely dependent on the voltage **7** applied to the electrode **6**. Thus the colour of the recording trace can be varied continuously between black and white. The diaphragm **15** is normally grounded, but can also be connected with electrode **6**. In that case electrode **6** can be omitted entirely.

Since the diaphragm **15** must be able to intercept most of the liquid ejected from the nozzle **1** it is necessary to remove this liquid continuously from the diaphragm. FIG. 4 shows a cross section of a diaphragm which meets this requirement. It consists of a cylindrical housing **17** with a diameter of 12 millimeters, in the center of which the aperture **16** is drilled. A conically shaped porous disk **18** which is placed inside the housing **17**, receives the liquid **9** that does not pass the aperture **16**. To prevent the porous disk **18** from becoming saturated with liquid, a vacuum is continually applied to the suction pipe **19**, whereby the liquid is removed from the disk.

The recording device shown in FIGS. 1, 2 and 3 can be used to advantage in very widely differing fields because of its high upper frequency limit. Thus it is obvious that the electrode system shown in FIG. 2 will lend itself to the on-off intensity modulation of the well-known ink jet oscillograph recorder as described in U.S. Patent 2,566,-443 (1951). In this case the direction of the nozzle **1** is varied in accordance with the signal applied to the oscillograph and the shield **14** has a slit-shaped aperture. Two other forms will be described below in more detail.

In facsimile recording systems, the speed of reproduction is often limited by the slowness of the recording device which plots the electric pulses from the picture transmitter on a recording paper. Further, in many instances the recording paper has to be processed after the recording, which is both tedious and uneconomic.

These difficulties can be avoided by using the recording device shown in FIG. 3. FIG. 5 shows the otherwise well-known construction of a facsimile recorder with such a device in front of the drum **20**, the device being assembled in the usual way from the nozzle **1**, the electrode **6** and the diaphragm **15**. As is well known from conventional facsimile receivers, the drum **20** holding the recording paper **21** is rotated at a certain speed controlled by synchronizing pulses from the transmitter. The recording device itself is mounted on a carriage and moved slowly along the surface of the drum **20** parallel to its axis with a speed determined by the transmitter. In this way the liquid jet **2**, if undisturbed, generates a spiral line on the recording paper when the drum is rotated. If, however, the electrode **6** is connected to the picture transmitter **22** through the amplifier **23**, the picture scannned by the transmitter will be reproduced line after line on the recording paper **21**. Alternatively, the recording paper **21** can be substituted by a liquid receiving surface, which after the recording of the picture can be used to produce one or more prints of the recorded picture by rolling the drum **20** over copy paper.

The reproduction of coloured pictures can be done in a similar way by using three of the recording devices shown in FIG. 3, which are supplied with red, yellow and blue ink or liquid. respectively. According to the cross section shown in FIG. 6 these three recording devices comprise the nozzles **1***r*, **1***y*, **1***b*, the lectrodes **6***r*, **6***y*, **6***b*, and the diaphragms **15***r*, **15***y*, and **15***b* which are mounted around the drum **20** in essentially the same way as the recording device in FIG. 5. The three picture signals for the red, yellow and blue pictures are then applied to the electrodes **6***r*, **6***y* and **6***b*, and red, yellow and blue coloured liquid is suppled to the nozzles **1***r*, **1***y* and **1***b*. Possibly, even a forth recording device using black coloured liquid can be added to improve colour quality.

Another application of the recording device shown in FIG. 2 is found with print-out systems for electronic computers or teleprinters, the computing velocity of which often is decreased by the slowness of the conventional print-out systems. This disadvantage can be circumvented by using an array of nozzles the front view of which is shown in FIG. 7. In this example, twenty nozzles **24** are mounted side by side and supplied with ink or liquid by a common feeder tube **25** as illustrated by the side view in FIG. 8. From each nozzle a liquid jet is ejected against a continually moving recording paper **26**. However, if a suitable voltage is supplied separately to the annular electrodes **27** surrounding each nozzle **24**, none of the liquid jets reaches the recording paper **26** since each jet is dispersed and the resulting spray removed by the static electric field **30** generated between the electrodes **28** and **29** in the same way as in the device shown in FIG. 2. An electrostatic screen **31** prevents the influence of the electrodes **27** on the adjacent nozzles **24**.

If the voltage is removed from certain electrodes **27** for a short moment, the ink jets produced by the corresponding nozzles **24** are not dispersed and reach the recording paper **26**. In this way each jet creates a point on the paper. Thus by selecting appropriate electrodes any kind of numbers or letters can be written on the recording paper **26**, in FIG. 7 this is indicated by cross-hatching those nozzles **24** which would print the number eight. In this way any kind of character can be printed at high speed. Naturally, even simple marks or series of marks can be affixed to recording paper. This can be used instead of the holes in conventional punched cards or punched tapes. Alternatively, only one horizontal row of about 5 nozzles **24** can be used in front of a recording paper moving vertically at constant speed. By applying voltage pulses in a suitable time sequence to each electrode **27**, arbitrary characters can be written even in this way. The recording time for one character is about 5 to 10 times as long in this case as in the arrangement shown in FIG. 7, where the entire character is written at the same moment, but on the other hand the construction is much more simple.

What we claim and desire to secure by Letters Patent is:

1. A device for converting electrical signals from a signal source into markings on a record receiving surface comprising

a source of marking fluid under pressure,

at least one nozzle means connected to said source of fluid under pressure, said nozzle means being spaced from said record receiving surface and adapted to direct a liquid jet along a jet axis against said surface,

driving means to produce relative movement between said nozzle means and the record receiving surface,

signal electrode means between said record receiving surface and said nozzle means and located substantially at the point of drop formation due to surface tension alone,

means applying electrical signals from the source of electrical signals to said nozzle means and said electrode means to establish an electrical field extending between said nozzle means and said electrode means and substantially along the jet axis and varying according to the electric signals whereby said liquid jet is charged according to the electric signals to thereby cause diffusion to a greater or lesser extent the liquid jet under the action of the field produced by said electrical signals into small droplets departing from the jet axis.

2. A device as claimed in claim **1**, including droplet interceptor means between said electrods means and said record receiving surface for intercepting charged droplets which have departed from said jet axis.

3. A device as defined in claim 2, wherein said interceptor means includes a pair of electrodes transversely spaced relative to the jet axis and adapted to have a large unidirectional potential connected thereto to thereby create a static electrical field transverse to the jet axis.

4. A device as defined in claim 3, including shield electrode means between said droplet interceptor means and said signal electrode means for shielding said signal electrode means and said nozzle from the influence of the static electric field between said pair of interceptor electrodes.

5. The device claimed in claim 2, wherein said droplet interceptor includes a baffle plate transverse to said jet axis having an aperture therein aligned with said jet axis.

6. A device as claimed in claim 1, wherein said signal electrode means is in the form of an annular plate having an aperture permitting jet liquid travelling along the jet axis to pass therethrough.

7. A device as claimed in claim 5, wherein said baffle plate is porous.

8. A device as claimed in claim 7, including means to subject the porous baffle plate to suction.

9. A device according to claim 5, in which said control electrode and said baffle means are electrically connected.

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