Nov. 22, 1966 B. KAZAN 3,287,734

MAGNETIC INK RECORDING

Filed Nov. 26, 1965 2 Sheets-Sheet 1

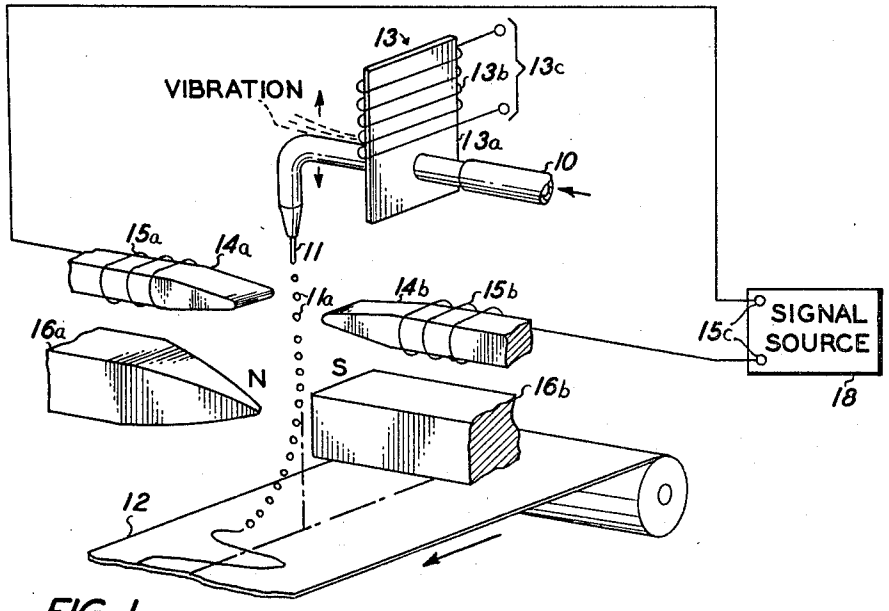

FIG. 1

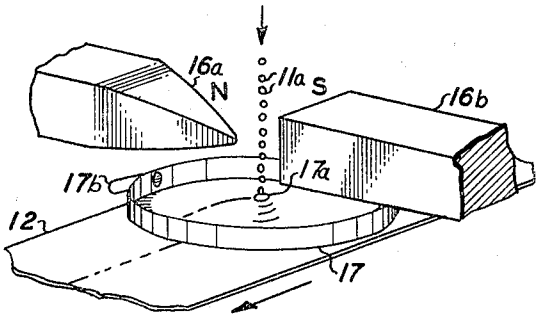

FIG. 2

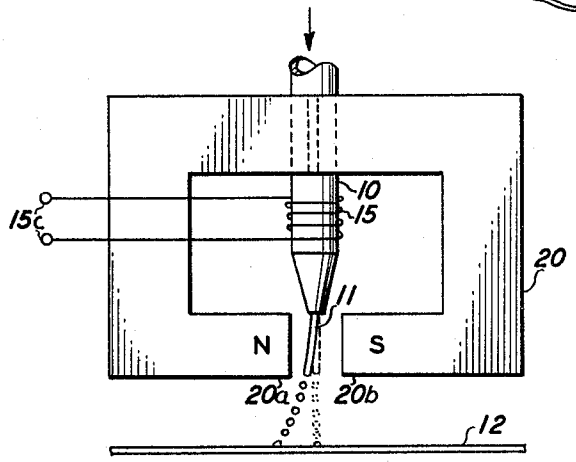

FIG. 3

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MAGNETIC INK RECORDING

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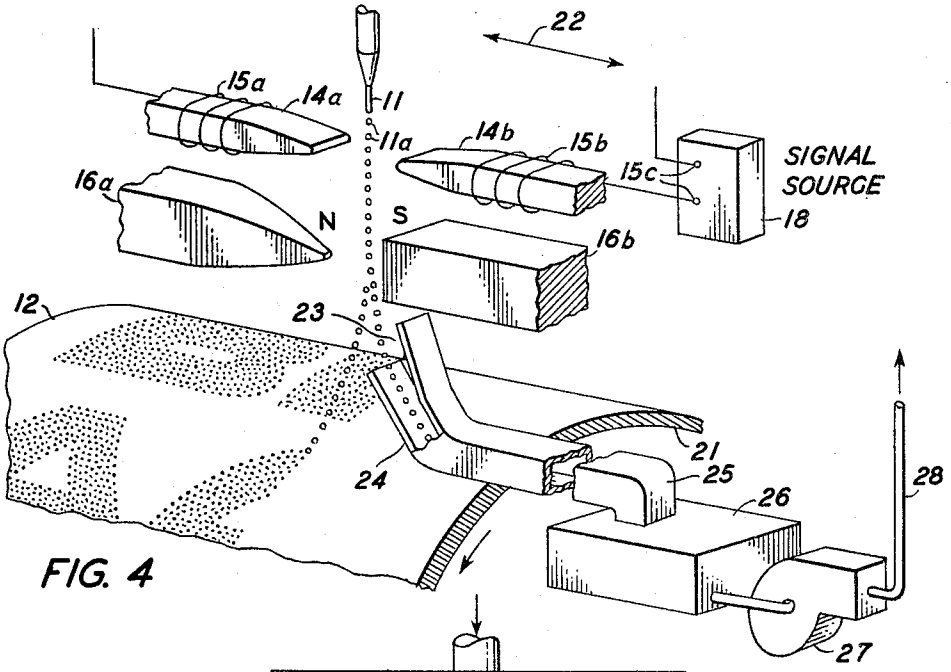

FIG. 4

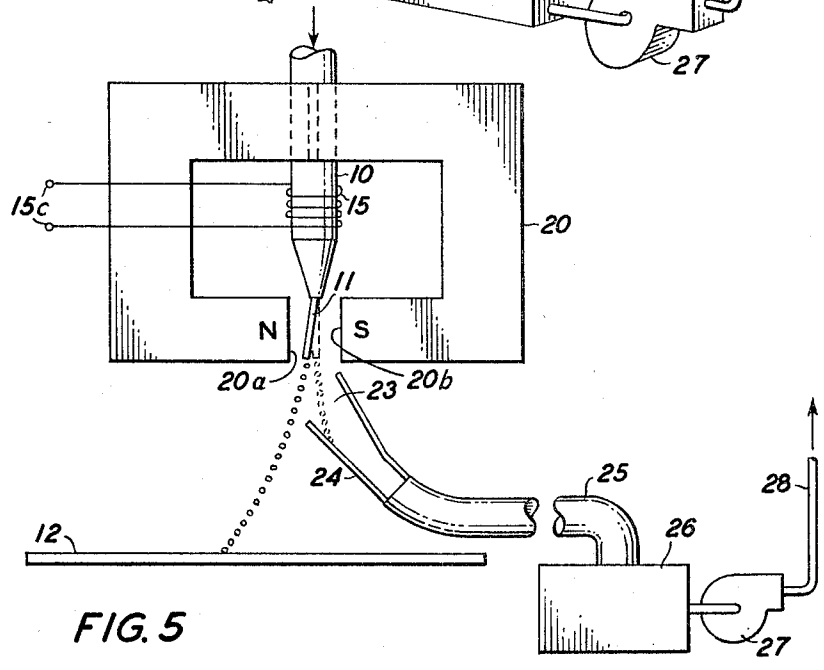

FIG. 5

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MAGNETIC INK RECORDING

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Filed Nov. 26, 1965, Ser. No. 509,758
17 Claims. (Cl. 346—1)

This application is a continuation-in-part of application Sea. No. 348,617, filed Mar. 2, 1964 and now abandoned.

The present invention relates in general to ink recording and more particularly relates to novel method and apparatus for ink recording as in a direct-writing oscillograph or facsimile systems.

Oscillograph recording by prior art techniques has generally been limited to a frequency response of between 100 and 200 cps. While higher frequency responses can be obtained with recorders using light reflected from a galvanometer onto light-sensitive paper, the light-sensitive paper is expensive and there is a time delay in developing the trace. Moreover, the traces also have a low contrast and cannot readily be produced in different colors.

On the other hand, in accordance with some prior art printing systems adapted for facsimile recording, it is usual to employ a writing head which by various means places an ink droplet of known size on copy paper whenever an electrical pulse is received. This type process has been limited in speed by the necessity of generating a droplet and moving it to the printing surface following receipt of a signal. Electrical forces available to do this have of necessity been limited to small values by the breakdown potential of air, while the speed of mechanical devices has been limited by the inertia of a moving mass. Accordingly, these prior techniques have inherently imposed speed limitations in that the time necessary to break an ink droplet away from a reservoir and move it to the printing surface is on the order of 10^{-3} sec. with 10^{-4} sec. as an extreme upper limit.

It is therefore an object of the invention to provide novel method and apparatus for the recording of intelligence information.

It is a further object of the invention to provide novel method and apparatus for recording with liquid ink in response to signals of information intelligence.

It is a further object of the invention to provide a novel recording technique that can be readily adapted for either oscillograph or facsimile recording.

It is further an object of the present invention to provide a direct-writing and, therefore, a direct-reading oscillograph that can be operated at higher speeds than heretofore possible.

It is a further object of the present invention to provide a direct-writing oscillograph having a superior frequency response limit than existing apparatus of this kind.

It is a further object of the present invention to provide an oscillograph whose traces can be produced in different color.

It is a still further object of the invention to provide a novel facsimile recording apparatus capable of selective ink deposition onto a recording sheet in response to signals of intelligence information.

These and other objects are achieved in accordance with the basic concept of the present invention by magnetically deflecting a fine stream of ink aimed at a moving recording medium. When used for oscillograph purposes, the variations in the strength of the magnetic field and, therefore, of the deflecting forces, are determined by the signal it is desired to visually record in order to control the point of deposition on the recording medium relative to a line or point of reference. For facsimile recording, the ink droplets are divided by deflection into two separate trajectories, one of which strikes a relatively moving recording medium to effect a facsimile reproduction while the other is intercepted for return to the system.

According to a basic embodiment of the invention, ink, manufactured to contain within it magnetic particles, for example, a suspension of ferrite particles in a liquid, is formed into a fine stream, about 1000th of an inch in diameter, by a nozzle which is supplied with the ink under pressure. For oscillograph purposes, the ink stream is directed at and strikes a moving chart an inch or two from the nozzle, thereby producing a permanent visual record. However, in the space between the nozzle and the recording paper, the ink is brought under the influence of two separate and distinct magnetic fields, one a fixed magnetic field and the other a variable magnetic field whose variations correspond to the input signal to be recorded. After the ink emerges from the nozzle, surface-tension forces cause the jet to break up into drops. These drops then successively pass through the first magnetic field wherein they are magnetically polarized, which has the effect of making tiny magnets out of them. Thereafter, these drops pass through the second magnetic field, which is non-uniform, wherein they are deflected in proportion to the intensity of the second field at that moment. By this means the deflecting forces follow Coulomb's law since the force on any one drop is proportional to the strength of the magnetic poles involved and, therefore, to the field strength at the point at which the drop is located. Since the drop mass is quite small relative to the magnetic field, the deflecting forces become appreciable. For facsimile purposes, the applied signal is on-off in operation or at different fixed levels of intensity corresponding to the presence or absence of information to be recorded. Thereafter as the droplets pass through the second magnetic field they are selectively deflected or deflected proportionately into separate trajectories such that only those droplets representing information stirke the recording medium.

The polarizing magnetic field is generated by means of an electrical current that flows through a pair of coils respectively wound about a pair of magnetic pole pieces positioned on either side of the path taken by the drops. As will be discussed in greater detail later, the deflecting magnetic field must also be a non-uniform field. Consequently, one of the two pole pieces of the latter is shaped differently than the other.

As previously indicated, oscillographs and facsimile recorders based on the principles of the present invention are superior in a number of respects to similar type devices of the prior art. Thus, with the present invention operating as an oscillograph, a considerably higher frequency response limit is obtained, it can operate at higher speeds, and it can provide traces in different colors. In addition, since a magnetic ink is utilized, either the oscillographic trace or the facsimile recording can in turn be fed directly to magnetic scanning devices for subsequent electrical readout, a step that was not heretofore possible.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawings in which several embodiments of the invention are illustrated by way of example. It is to be expressly understood, however, that the drawing is for the purpose of illustration and description only and is not intended as a definition of the limits of the invention.

FIGURE 1 illustrates the basic combination of elements in one embodiment of an oscillograph according to the present invention;

FIGURE 2 shows a modification of the FIG. 1 arrangement to adapt it for a specific use;

FIGURE 3 illustrates the basic construction of another embodiment of an oscillograph according to the present invention;

FIGURE 4 illustrates a variation of the embodiment of FIG. 1 as adapted for facsimile recording; and

FIGURE 5 illustrates a variation of the embodiment of FIG. 3 as adapted for facsimile recording.

For a consideration of the invention in detail, reference is now made to the drawings wherein like or similar parts or elements are given like or similar designations throughout the several figures. In the FIG. 1 embodiment for oscillograph recording, the ink is supplied under pressure at one end of a nozzle **10** wherein it flows through a very narrow passageway running along the center of the nozzle until it emerges from the orifice at the other end as a fine jet or stream of ink which, in the figure, is designated **11**. A diameter of approximately a 1000th of an inch is preferred for the stream of ink and, therefore, the diameter of the passageway through the nozzle and of the orifice at its forward end must be substantially the same. The pressure applied to the ink to force it through the nozzle may, for example, be about 50 p.s.i. The ink stream is directed toward and ultimately strikes a moving chart or reel of recording paper **12** positioned an inch or two from the nozzle. The ink itself, as previously indicated, includes as an important part thereof particles of a magnetic nature in order that the ink, after it has formed into droplets, may be magnetically polarized. Inks of this sort are well known and, therefore, need not be described with any further detail.

The ink is in the form of a column as it emerges from the nozzle but very shortly thereafter, due to surface-tension forces, the jet is caused to break up into tiny drops **11***a*. These forces may be and preferably are synchronized by vibrating nozzle **10** at a high frequency, for example 120 kilocycles, and for this purpose a vibrator device, generally designated **13**, is linked to the nozzle. While any one of a number of different kinds of vibratory devices may be used herein, the device shown in the figure is based on magnetostrictive principles and, therefore, includes a nickel magnetostrictive transducer **13***a* about which a coil **13***b* is wound. As designed, element **13***a* has the configuration of a rectangular plate and has a hole through it at one end through which the nozzle snugly fits. Coil **13***b* is wound about the other end of element **13***a* and, in order to produce the vibrations, the 120 kilocycle signal is applied to it at its terminals **13***c*. In response to this signal, the length of element **13***a* periodically increases and decreases and this, in turn, forces the nozzle to vibrate at the same frequency. These forced vibrations of the nozzle are desirable because they set the exact distance from the nozzle at which the drops form and, in addition, they make the drop size and spacing uniform.

After the ink-drops form, they pass midway between a pair of magnetic pole pieces **14***a* and **14***b* about which a pair of coils **15***a* and **15***b* are respectively wound. The current, constituting the input signal from a source **18** is applied between terminals **15***c*, with the result that the current flows through the coils to produce a strong modulated magnetic field between the pole pieces which, as may be seen from the figure, are shaped to enhance the strength of the magnetic field. As previously stated, the ink droplets pass between the faces of pole pieces **14***a* and **14***b* and, therefore, pass directly through this modulated magnetic field. Since the ink has magnetic properties of the kind previously specified, each droplet is magnetically polarized as it passes through this field to become, in effect, a tiny magnet of a magnitude and polarity determined by the instantaneous magnetic field in the gap at the time of passage of the droplet through it. Thus, it may be said that a large number of very fine

magnets of varying strength emerge from between poles **14***a* and **14***b* and that each such magnet is a sample of the modulated magnetic field and, therefore, of the input signal, at a particular moment in time. This was verified by experiment in which acicular Fe_2O_3 (iron oxide) particles 0.5 micron long and 0.08 micron in diameter were dispersed in a droplet of pharmaceutical mineral oil 0.02 inch across or in diameter. Under a microscope, prior to the application of the magnetizing field, the particles were seen to be randomly oriented throughout the droplet. After application of the magnetizing field to magnetize the particles, long parallel threads, directionally oriented similarly, were seen in the droplet.

Mounted beneath pole pieces **14***a* and **14***b* is a second set of pole pieces **16***a* and **16***b* positioned so that the already polarized droplets will also pass between them. Pole pieces **16***a* and **16***b* are designed to produce both a strong D.C. or fixed magnetic field as well as a non-uniform field and, for this reason, one of the pole pieces, namely, pole piece **16***a* in FIG. 1, is shaped differently from the other pole piece. Because this field is non-uniform, the attractive or repulsive forces applied to the droplets as they enter the field midway between the pole pieces are unequal and, therefore, are deflected in a direction that is transverse to the direction in which paper **12** is moving. The extent to which each droplet is deflected is determined by the magnitude or degree of its magnetization, with the result that, upon striking the paper, an oscillographic trace of the input signal is recorded on the paper.

A mask or ink collector can be provided for the arrangement in FIG. 1 for the purpose of intercepting all ink droplets except those which pass through the system undeflected. By this means, a straight-line trace can be produced on the paper whose intensity or density can be controlled by the input signal since the application of such a signal serves to cut off the flow of ink droplets which can arrive at the paper. A modification of the FIG. 1 arrangement along the lines mentioned is shown in FIG. 2 wherein the mask or ink collector, designated **17**, is interposed between paper **12** and pole pieces **16**. Member **17** has an opening **17***a* through it which is located so as to be midway between the pole pieces, that is to say, it is located so that in the absence of an input signal, the unpolarized and, therefore, undeflected ink droplets will pass through it to the center-line of the paper. Of course, to avoid spillage onto the paper, member **17** may be dome-shaped and formed into a trough along its edge to direct the ink collected to an outlet port **17***b* from which the ink can be drained.

Another embodiment of a magnetic ink-droplet oscillograph is illustrated in FIG. 3, and as shown therein, a standard rectangular-shaped magnet **20** is used in used in this embodiment to provide a uniform D.C. magnetic field between its pole faces **20***a* and **20***b*. Also, in this case, nozzle **10** is made of a magnetic material and is mounted so that ink column **11** emerging from its orifice extends directly into the air gap between the poles of the magnet. Finally, a coil **15** is wound around nozzle **10** and the signal to be recorded is applied to its ends **15***c*. Because the nozzle is now made of a magnetic material, a magnetic field is induced in it by the current flowing through the surrounding coil, with the result that ink column **11** becomes magnetized and may from a practical point of view, be said to be a flexible bar magnet. That is, since the fluid containing the magnetic particles fills the center of nozzle **10**, the nozzle to all intents and purposes is a solid mangetic material. When current is applied to coil **15**, the magnetic field induced thereby is distributed with substantial uniformity throughout the entire nozzle interior including its axial center containing the fluid with the magnetic particles. Since a much stronger magnetic field is produced in response to an electric current within a magnetizable as opposed to a non-magnetizable material, such as an air gap, the former

is preferred for the nozzle to provide a greater field intensity in the fluid. Consequently, the ink column is attracted to one or the other of the pole faces and as the strength and direction of its polarization varies with the input signal, the column, as well as the droplets that become detached from it, swing back and forth to provide the permanent visual image of the signal on the recording medium **12**.

As shown in FIG. 4, the apparatus previously described for oscillograph use in FIG. 1, is herein adapted to be used for facsimile recording. In this instance, as previously stated, the ink is magnetically divided generally into two distinct trajectories, one of which records by deposition onto a recording surface and the other of which is intercepted for return to the system.

For these purposes the voltage applied to the coils **15***a* and **15***b* will in its simplest form be a fixed voltage which may be turned off or on in accordance with intelligence signals emanating from information source **18**, which may be a facsimile transmitter or the like and transmitted through appropriate gating and shaping circuits (not shown). Thus, each droplet after passing between pole pieces **14***a* and **14***b* will either be magnetically polarized or unpolarized depending on whether the voltage generated by the intelligence signal was on or off when that droplet passed between the magnetic poles. In this respect, the effect is analogous to that described above in connection with FIG. 2.

Alternatively, and by way of example, the coils **15***a* and **15***b* may be switched by appropriate circuitry between two distinct non-zero voltages. By this means, the droplets polarized with the first voltage applied to the coils will have one magnetic intensity while those droplets polarized with the other voltage will have a second and different magnetic intensity. Whatever magnetic distinguishable method is employed, the droplets differentiated selectively will then as before, pass between deflecting pole pieces **16***a* and **16***b* to be deflected into their respective trajectories.

For a single line recording of information a web sheet **12** can be fed from a supply roll as before. Preferably, however, it is desired to reproduce a document or the like in its entirety in reconstituted graphic form corresponding to the original sending sheet in all respects. For these purposes therefore the recording sheet **12** is wrapped onto the periphery of a uniformly rotating drum **21**. In order to advance the magnetic components relative to the surface of sheet **12** they, along with nozzle **10**, are integrally mounted in a fixed relation to each other and to the sheet surface. By means of a lead screw or the like (not shown) they are advanced axially parallel to the drum so that the ink trajectory can incrementally charge relative to the recording surface. The recording sheet moves at a rate proportional to the nan rate.

At the same time those droplets unpolarized or polarized to a different magnetic intensity are deflected by means of the deflection field into an ink draining channel **23** formed by an interception plate **24**. The magnetic state of those droplets not subject to the signal pulse is not critical so long as it is sufficient to cause the droplets to be intercepted under the influence of the applied field. Those ink droplets intercepted by channel **23** are then funneled via a hose connection **25** to an ink reservoir **26**. A pump **37** operated by a float control (not shown) in reservoir **36** returns the surplus ink via conduit **28** to the source of ink supply.

In FIG. 5 there is an apparatus embodiment similarly adapted for facsimile recording but less acutely responsive than the embodiment of FIG. 4. That is, in this embodiment the signal from coil **15** is applied to the fluid mass in contrast to the individual droplets of the previous embodiment, such that the discreteness of droplet deflection and as a result the reproduction quality, while satisfactory is of lower quality than that obtained by the apparatus of FIG. 4. In other respects, the apparatus hereof is operative as described above in connection with FIG. 3 as modified by the ink interception and return components of FIG. 4.

By the above description there has been disclosed novel method and apparatus for high speed oscillograph recording as well as facsimile reproduction of original information transmitted in the form of intelligence signals. Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the drawings and specification shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A method of recording with liquid ink comprising the steps of: forming a droplet stream of liquid ink including therein a distribution of a magnetic polarizable component; selectively polarizing the droplets in said stream by means of an applied magnetic field responsive to a signal of information intelligence; and, applying a second magnetic field to said droplets after said last recited step to deflect at least some of said droplets relative to a surface on which droplets deposit to record said information.

2. The method according to claim **1** in which said signal for applying the polarizing magnetic field is a facsimile signal causing deflection separation of said droplets passing through said deflection field.

3. Oscillographic apparatus by means of which a visual record of a varying electrical signal is provided on a moving recording medium, said apparatus comprising: means for directing a fine jet of ink that can be magnetically polarized toward the recording medium; electromagnetic apparatus receptive of the electrical signal and operable in response thereto magnetically polarize the ink in accordance with the variations of the signal; and additional means for applying a deflecting force to said jet of ink that varies as the polarization thereof, whereby a visual record corresponding to the signal is recorded when the ink strike the medium.

4. Oscillographic apparatus by means of which a visual record of an electrical signal is provided on a moving recording medium, said apparatus comprising: means for directing a stream of ink droplets that can be magnetically polarized toward the recording medium; electromagnetic apparatus receptive of the electrical signal and operable in response thereto to produce a varying magnetic field through which said ink droplets pass to become polarized; and a magnet designed to produce a fixed non-uniform magnetic field in the path of said polarized ink droplets for deflecting said droplets according to their respective polarizations, whereby a permanent visual record corresponding to the signal is recorded when the droplets strike the medium.

5. The oscillographic apparatus defined in claim **4** wherein said means includes a nozzle adapted to provide said stream of ink, equipment to supply the ink to said nozzle at a predetermined pressure, and a device for vibrating said nozzle at a selected frequency to enhance the formation of said ink droplets.

6. Oscillographic apparatus by means of which a visual record of an electrical signal is provided on a moving recording medium said apparatus comprising: apparatus for providing a uniform fixed magnetic field; means for directing a fine column of ink that can be magnetically polarized toward the recording medium, said means including a nozzle made of a magnetic material and mounted so as to direct said column of ink through the center of said magnetic field, said means further including a coil wound around said nozzle, said coil being receptive of the signal and operable in response thereto to produce a varying magnetic field that polarizes said nozzle and the column of ink passing therethrough according to the signal variations, whereby the ink column passing through said fixed

magnetic field is variably deflected before it strikes the recording medium to produce a permanent visual record corresponding to the signal.

7. Oscillographic apparatus by means of which a visual record of an electrical signal is provided on a moving recording medium, said apparatus comprising: means for directing a fine jet of ink that can be magnetically polarized toward the recording medium; a mask device positioned above the recording medium and having an opening therethrough through which said jet of ink passes to the recording medium beneath when it is unpolarized, said mask shielding the medium from the ink when it is polarized; means for polarizing said jet of ink in accordance with the variations of the signal; and additional means for deflecting said ink away from said opening when it is polarized, whereby a straight line trace is produced on the medium whose density is controlled by the signal.

8. Oscillographic apparatus by means of which a visual record of an electrical signal is provided on a moving recording medium, said apparatus comprising: first means for directing a stream of ink droplets that can be magneticall polarized toward the recording medium; second means for insuring the formation of said droplets at a uniform rate and size; third means receptive of the electrical signal and operable in response thereto to produce a varing magnetic field through which said ink droplets pass to become polarized; and fourth means for producing a fixed non-uniform magnetic field in the path of said polarized ink droplets for deflecting said droplets according to their respective polarizations, whereby a permanent visual record corresponding to the signal is recorded when the droplets strike the medium.

9. The apparatus defined in claim 8 wherein said second means includes a vibratory mechanism coupled to said first means for vibrating it at the desired rate.

10. Apparatus by means of which a visual record of an electrical signal of information is provided on a moving recording medium, said apparatus comprising: means for directing a fine jet of ink that can be magnetically polarized toward the recording medium; electromagnetic means receptive of the electrical signal and operable in response thereto to selectively polarize the ink magnetically in accordance with said received signal; and mean operable on said ink jet after said last recited means for applying a magnetic deflecting force to said jet of ink to deflect at least a portion of said jet relative to the surface of said recording medium, whereby a visual record corresponding to the signal is recorded by the ink striking the recording medium.

11. Apparatus by means of which a visual record of an electrical signal of information is provided on a moving recording medium, said apparatus comprising: means for directing a stream of ink droplets that can be magnetically polarized toward the recording medium; electromagnetic means receptive of the electrical signal and operable in response thereto to selective produce a magnetic field through which at least some of said ink droplets pass to become polarized; and magnet in means adjacent the droplet path subsequent to said last recited means to produce a magnetic field in the path of said ink droplets for deflecting said droplets selectively similar according to the polarization thereon produced by said electromagnetic means, whereby a permanent visual record corresponding to the signal is recorded by the droplets striking the recording medium.

12. Apparatus according to claim 11 in which said signal is an on-off facsimile signal to polarize droplets passing said electromagnetic means when said signal is on.

13. Apparatus according to claim 11 in which said signal is a facsimile signal for energizing said electromagnetic means to polarize said droplets to selectively different polarizations corresponding to the presence and absence of information to be recorded.

14. Apparatus according to claim 11 in which said signal is a facsimile signal, said deflecting field effectively separates the droplets for deposit onto said recording medium from the other of said droplets and there is included separate means to receive said other of said droplets.

15. The apparatus defined in claim 11 wherein said means includes a nozzle adapted to provide said stream of ink, a supply source to supply the ink to said nozzle at a predetermined pressure, and means for vibrating said nozzle at a selected frequency to enhance the formation of said ink droplets.

16. Facsimile recording apparatus by means of which a visual record of an electrical facsimile signal is provided on a moving recording medium said apparatus comprising: means for providing a uniform fixed magnetic field; means for directing a fine column of ink that can be magnetically polarized toward the recording medium, said means including a nozzle made of a magnetic material and mounted so as to direct said column of ink through the center of said magnetic field, said means further including a coil wound around said nozzle, said coil being receptive of the signal and operable in response thereto to produce a magnetic field that polarizes said nozzle and the column of ink passing therethrough for the duration of the signal, whereby the ink column passing through said fixed magnetic field is selectively deflected to permit a portion of the ink column to strike the recording medium and produce a permanent visual record corresponding to the signal.

17. Facsimile recording apparatus by means of which a visual record of an electrical facsimile signal is provided on a moving recording medium, said apparatus comprising: first means for directing a stream of ink droplets that can be magnetically polarized toward the recording medium; second means for insuring the formation of said droplets at a uniform rate and size; third means receptive of the electrical facsimile signal and operable in response thereto to produce a magnetic field through which said ink droplets pass to selectively become polarized; and fourth means for producing a fixed non-uniform magnetic field in the path of said ink droplets for deflecting at least some of said droplets according to their respective polarizations, whereby a permanent visual record corresponding to the signal is recorded by the droplets which strike the recording medium.

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RICHARD B. WILKINSON, *Primary Examiner.*