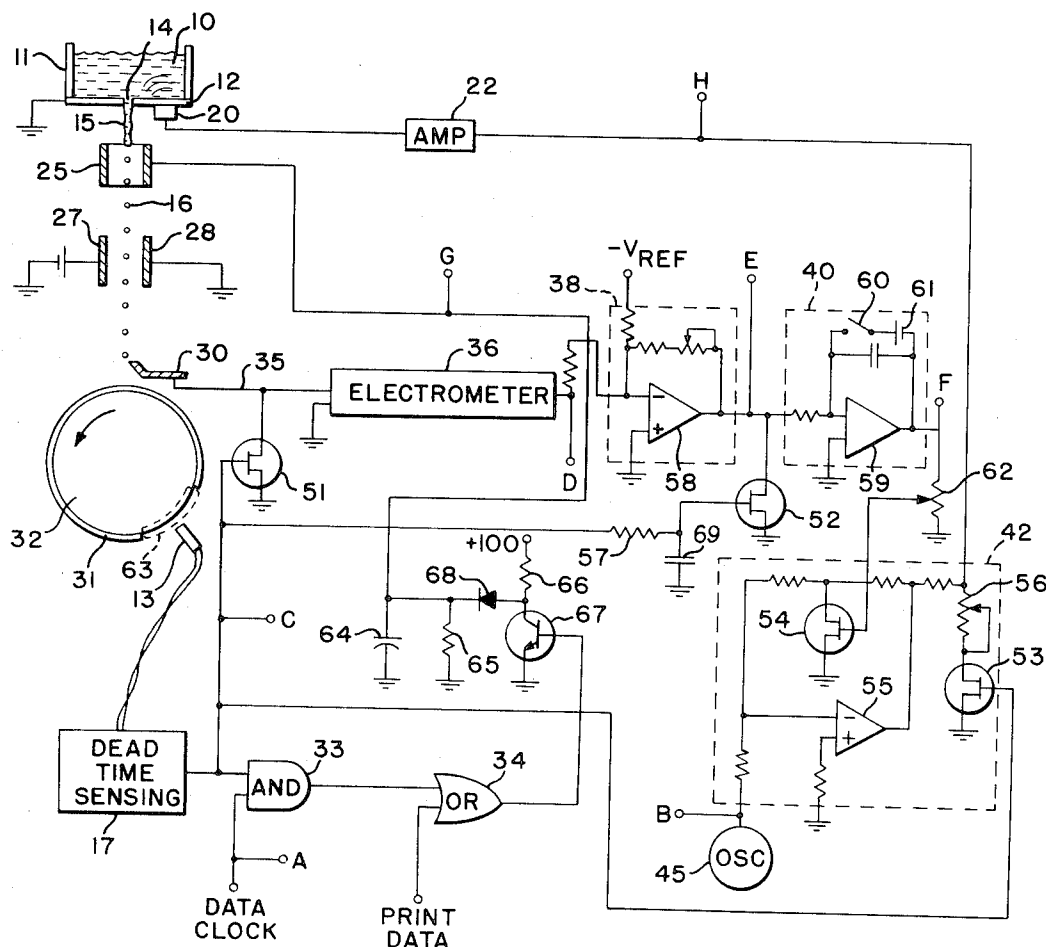


- Primary Examiner*—Joseph W. Hartary
Attorney—Lawrence B. Biebel et al.

There is disclosed a phase control system for a jet drop generator wherein the phase of drop generation is adjusted by adjusting the amplitude of a stimulating disturbance applied to the jet. A time varying electrical signal, preferably a binary or ON/OFF signal, is applied to a charging electrode located near the point of drop formation, so that newly forming drops are charged or uncharged in correspondence to the signal. During normal operation as a recording device, the charged drops pass through an electrical deflection field for deflection into an appropriately placed catcher. Drops which are uncharged pass undeflected through the deflection field and deposit on a recording sheet. During non recording or dead times a calibrating signal is applied to the charging electrode and the charge carried away by the drops formed during that period is measured by an electrometer connected to the catcher. This measurement provides an indication of the phase of drop generation relative to the phase of the calibrating signal. Deviations of this relative phase from a desired relative phase are corrected by adjusting the amplitude of the drop stimulating disturbance.

11 Claims, 5 Drawing Figures



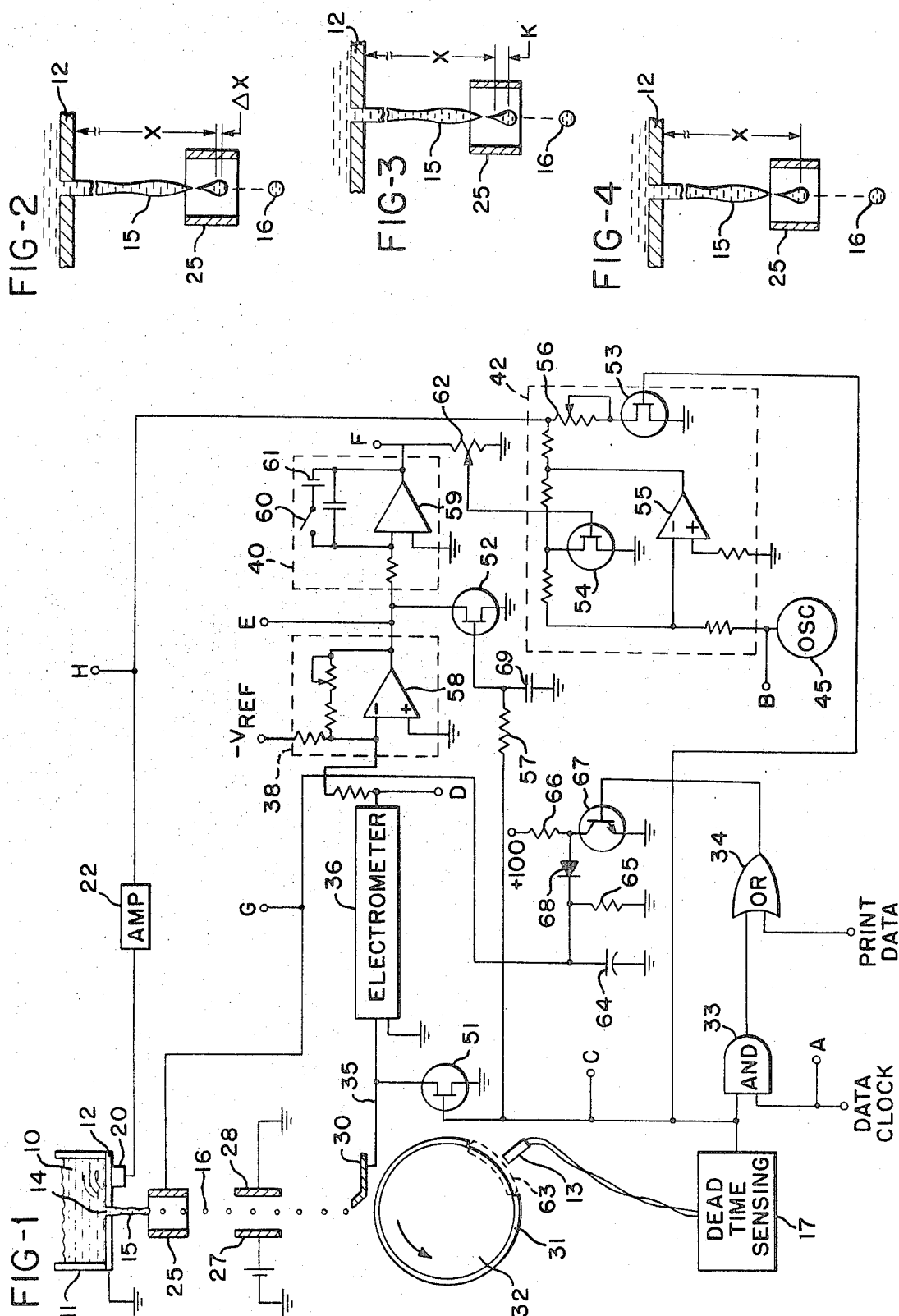
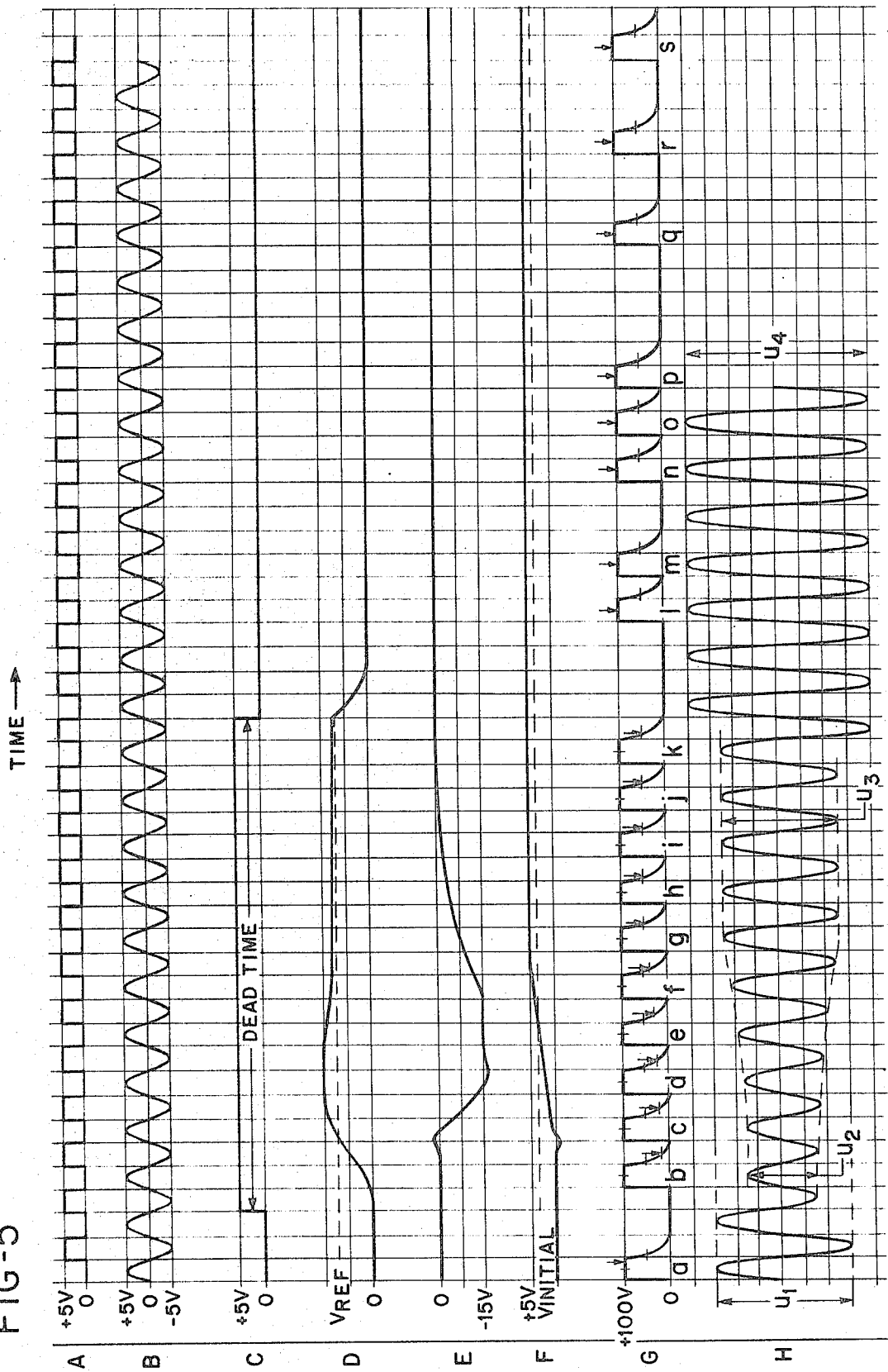


FIG-5



PHASE CONTROL FOR A DROP GENERATING AND CHARGING SYSTEM

BACKGROUND OF THE INVENTION

The invention relates to controlled phasing of the drop separation from a liquid jet or stream, particularly in systems where one or more such streams of drops are controllably placed on a receiving surface for the purpose of image reproduction or recording. U.S. Pat. Nos. 3,465,350, 3,465,351 and 3,596,276, all relate to systems and devices for varying the phase relation between drop generation and a charging signal applied to a charging electrode or tunnel which places a predetermined electrostatic charge selectively on individual drops separating from a continuous liquid filament. In U.S. Pat. Nos. 3,465,350 and 3,465,351, the phase of the stimulating vibration applied to the nozzle and the liquid filament issuing therefrom is adjusted as necessary to control the phasing of drop generation with respect to the application of charge signals to the charging electrode. In U.S. Pat. No. 3,596,276 the phase control system is applied to adjust the phase of the charging voltage with respect to the drop generation, in order to achieve essentially the same result. Both of these systems employ a constant frequency, constant amplitude stimulation source, and as noted, one type varies the phasing of the stimulation, and the other type varies the phasing of the charging signals or information.

In an article appearing in the British Journal of Applied Physics, 1964, Volume 15, by Crane, Birch and McCormack, entitled "The Effect of Mechanical Vibration on the Break-Up of a Cylindrical Water Jet in Air," at page 748, FIG. 5 and the description thereof discloses the discovery that in a liquid jet drop forming system, a change in amplitude of the stimulating vibration will produce a corresponding, approximately linear, related change in the length of the unbroken filament, or stated another way, in the point of drop separation from the issuance of the liquid stream through the nozzle orifice. This article deals generally with investigation of the break-up characteristics of a liquid jet in air, and represents modern experiences which confirm and enlarge upon the well known 19th century work of Lord Rayleigh in this field.

SUMMARY OF THE INVENTION

The present invention relates to a novel system for controlling the break-up phasing of a liquid filament in the jet of a recording or printing system using individual drops. A constant frequency, variable amplitude drop stimulating disturbance is applied to the liquid filament, and the amplitude of the stimulating disturbance is adjusted to change the length of the liquid filament and thereby correct the phase of drop breakoff relative to a system clock signal. The system clock signal also controls the phase of application of charge signal pulses to a charging electrode which is located downstream from the nozzle orifice at a location where drops separate from the liquid filament. Typical systems in which the invention is applicable are disclosed in U.S. Pat. Nos. 3,560,641 and 3,656,174, all assigned to the assignee of the present application.

In general, each of these systems utilizes an electronic printing control accomplished by electrostatically switching the trajectory of uniform drops of printing liquid, such as a conductive liquid ink. The drops

are produced from one or more liquid jets, and the break-up of the continuous filament of the jets is induced or stimulated by the application of regular frequency disturbances upstream of the desired drop separation point. The charging electrode(s) is located near the point of drop separation, and a time varying electrical signal is applied thereto. This creates a correspondingly varying electrical field at the tip of the filament thereby inducing charges in the newly forming drops which represent samples of the charging signal. The phase at which this sampling occurs depends upon the phase of drop separation relative to the phase of the applied signal.

For jet drop generators of the type herein involved, the amplitude of the applied stimulating disturbances controls the nominal filament length which in turn controls the time required for the disturbances to travel from the orifice down to the drop separation point. This travel time dictates the phase of drop separation relative to the stimulation control signal and hence the phase of drop separation relative to the drop charging signal. In a typical system the nominal filament length and hence the drop separation phase may change with time due to slight drifts in operating parameters such as liquid surface tension, viscosity, liquid supply pressure and extraneous environmental noise.

Automatic phase regulation is achieved according to the present invention by applying a calibrating charge signal to the charging electrode during a non-printing period or so called "dead time." This calibrating signal may be a square wave having a sharp rise time and a slow decay time and generated in synchronism with the drop stimulating disturbances. The stimulation energy then may be deliberately decreased to lengthen the liquid filament and cause the drops to separate therefrom during the decay time of the square wave. The drops which are so stimulated all receive a partial charge and are all caught by an appropriately placed catcher. An electrometer is connected to the catcher and measures the jet current during this dead time calibration.

The output of the electrometer is compared with a reference voltage to generate an error signal for adjustment of the amplitude of the stimulation energy. This adjustment continues until drop separation occurs precisely at a predetermined point within the decay of the calibrating square wave. Thereafter at the end of the dead time the stimulation energy level is increased a predetermined amount to shorten the liquid filament and produce drop separation in correct phase relation with the normal print charging signal.

Accordingly, the primary object of the invention is to provide a phase control system for a liquid jet drop recording or printing device, in which the amplitude of the stimulation applied to the jet or jets, is varied in accordance with the phase relation between the drop separation and the application of charge signals to a charging electrode near the drop separation point.

Other features and advantages of the invention will be apparent from the following description, the accompanying drawing and the appended claims.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic diagram illustrating the phase control system applied to a single drop generator; FIGS. 2, 3 and 4 are similar drawings of a single liquid filament, showing the change in length of the con-

tinuous filament with changes in the magnitude of the applied constant frequency stimulation; and

FIG. 5 is an illustration of the wave forms of the signals appearing at test points A through H of the system of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, a suitable supply of conductive liquid marking material, such as an ink 10 is maintained within a reservoir 11 to which is attached an orifice plate 12. There is an orifice 14 in orifice plate 12, and ink 10 which is maintained under pressure passes through orifice 14 to form a continuous filament 15 on the exit side thereof. A stimulation transducer 20, which may be a piezoelectric crystal or other convenient vibrating transducer, vibrates orifice plate 12. These vibrations are transmitted to filament 15 causing it to break up into uniformly sized and regularly spaced drops 16.

There is provided a charging electrode 25 which surrounds filament 15 near the point of drop break off. For normal printing operations a series of charge pulses are generated in synchronism with a data clock signal and applied to electrode 25 to produce selective charging of drops 16. Any drop which breaks off from filament 15 during a time when a charge is being applied to electrode 25 will be charged to a polarity opposite the charge on electrode 25. All of drops 16 fall between a pair of deflection electrodes 27 and 28 which create a steady state electrical field across the path of the falling drops. Those of drops 16 which are charged are deflected into a catcher 30 and are caught. Uncharged drops pass undeflected between plates 27 and 28 and impact on a recording medium 31 which may be mounted on a rotating drum 32.

Stimulation transducer 20 is driven in synchronism with the data clock signal, and ideally each drop separation should occur precisely at the mid-time of a clock pulse period. Furthermore each drop should separate at the same point in space. This does not ordinarily happen, and thus there appears a charging phase error as above described. As a consequence there may be printing errors due to drop flight times which are greater or less than anticipated or drops which are improperly charged due to being generated either before the associated charging pulse has reached its proper charging level or after decay of the pulse has begun. Similar errors may occur, as also mentioned above for other types of recorders wherein the charging electrode is charged to various levels for scanning deflection of the drops.

In accordance with the practice of this invention the charging phase error is corrected by adjusting the amplitude of the driving signal applied to stimulation transducer. Thus phase errors in one direction are corrected by increasing the amplitude of the stimulation and accordingly shortening filament 15. For phase errors in the other direction the amplitude of the stimulation signal is decreased to lengthen filament 15. These adjustments are made during a dead time when printing signals are not being generated.

For making the above described adjustments there may be provided a scanner 13 which observes the rotation of drum 32. Scanner 13 scans a narrow track which may be provided with a strip of colored tape or other indicating medium within a dead area 63 corre-

sponding to the space between the top and bottom of recording medium 31. When scanner 13 senses the presence of the dead area, it transmits a signal to the dead time sensing circuit 17 which in turn gates off FET 51. This removes a ground from line 35 which connects catcher 30 with electrometer 36. During this dead period all drops are charged so that the drops will be caught by catcher 30 and current will be measured by an electrometer 36. The output from electrometer 36 is fed to a level detector 38 which drives an integrating network 40. The output from integrating network 40 adjusts a voltage variable attenuator 42 which in turn drives stimulation signal amplifier 22.

In order to make an accurate adjustment of the stimulation signal amplitude, a square wave calibrating signal is applied to charging electrode 25, and filament 15 is deliberately lengthened to produce drop separation during the decay time of the calibrating signal. The drops then are all charged by a partial charge and adjustments are made to the stimulation amplitude to make the output from electrometer 36 correspond to a reference voltage V_{Ref} . At this point the drop separation time is accurately known with respect to the trailing edge of the square calibrating wave. Thereafter at the end of the dead period, the stimulation energy is increased a predetermined amount to shorten filament 15 and produce drop separation at the midpoint of the calibrating square waves. The calibrating signal is clocked by the same signal as the print data so that drop separation then occurs in correct phase with normal print charging.

FIGS. 2, 3, and 4 show the shifting of the drop separation point as above described. FIG. 2 is the initial condition where the separation point should be located a distance X from orifice plate 12, but deviates therefrom by an error distance ΔX . FIG. 2 illustrates the condition after the separation has been adjusted to occur at a predetermined time during the square wave decay. In this case the square wave has a 50 percent duty cycle and the predetermined adjustment distance is about a quarter of a wave length. FIG. 4 illustrates the condition after calibration is complete.

Lengthening of filament 15 for the above mentioned purpose is accomplished by gating on FET 53 with the output from dead time sensing network 17. Driving signals for amplifier 22 are generated by an oscillator 45 which oscillates in synchronism with the charging pulses applied to electrode 25. The output from oscillator 45 is attenuated by voltage variable attenuator 42 under the control of output signals from integrating network 40, and closing of FET 53 provides a path through resistor 56 for abruptly decreasing the amplitude of the signal applied to amplifier 22. Resistor 56 is manually adjustable to provide for diverse operating conditions.

The output from dead time sensing network 17 is also applied to AND gate 33 and through a resistor 57 to FET 52, the function of which will be explained presently. A data clock signal which is in synchronism with the output of oscillator 45, is applied to AND gate 33 so that AND gate 33 will provide data clock signals to OR gate 34 whenever scanner 13 is viewing dead area 63. The output from OR gate 34 is fed to the base of switching transistor 67. A charging voltage, as for instance 100 volts, is applied across resistor 66 to the collector of transistor 67 and also to charging electrode 25 whenever transistor 67 is gated off by application of a

pulse to the base thereof. Typically the 100 volt pulse generated by the opening of transistor 67 will have a fairly fast rise time in the order of about 0.3 microseconds. However, the pulse control network comprising diode 68, resistor 65 and capacitor 64 prevents a sharp cut off of the 100 volt pulse when transistor 67 is gated back ON. Consequently the 100 volt pulses applied to charging electrode 25 are characterized by a fast rise time and a rather slow trailing edge decay in the order of about 3 microseconds. These pulses comprise the above mentioned calibrating signal.

During normal printing periods control pulses for the base of transistor 67 are provided by a print data signal applied to OR gate 34 as one input thereof. This signal consists of a series of "NO PRINT" pulses generated in synchronism with the data clock, but only for those clock periods during which no printing mark is desired. For clock periods when a printing mark is desired, the print data signal is clamped to zero thereby disabling OR gate 34, gating ON transistor 67, and grounding the +100 volt input at the collector thereof. Consequently no charge is applied to drops generated during such clock periods. These drops avoid deflection and catching and are able to deposit on the paper 31.

Level detector 38 comprises an operational amplifier 58 having one input terminal grounded and the other input terminal connected to a summing junction to which are also connected a feedback path and a reference voltage V_{ref} . Thus the output of level detector 38 provides an error signal which varies with the variation of the output of electrometer 36 from the reference voltage. During normal printing periods FET 52 is gated ON so that the output from level detector 38 is grounded. However, during the dead time FET 52 is gated OFF and the output from level detector 38 drives integrator 40. Resistor 57 and capacitor 69 provide a switching time delay for FET 52 during which the desired error signal is being achieved.

Integrator 40 comprises a conventionally connected operational amplifier 59, a starting switch 60 and potential source 61. Switch 60 is initially closed to produce a starting output from amplifier 59 and thereafter is opened. Within voltage variable attenuator 42 there is a FET 54 which operates in the variable resistance mode. The gate of FET 54 is connected to resistor 62 which in turn is connected to integrating network 40. Thus the conductivity of FET 54 varies in accordance with the output from amplifier 59. FET 54 is connected in the feedback path around operational amplifier 55, so that variations in the conductivity of FET 54 cause variations in the gain of amplifier 55. Amplifier 55 is the driver for the stimulation amplifier 22 and supplies signals thereto from oscillator 45 at a magnitude which varies in accordance with the conductivity variations in FET 54.

The operation of the network illustrated in FIG. 1 can be understood further by referring to FIG. 5 wherein are shown a series of time varying signal wave forms as may be observed at test points A through H of FIG. 1. The signal at point A is the data clock signal which is in synchronism with the oscillator output signal observed at point B. The signal at point C is the output of the dead time sensing circuit which is applied to FET 51, FET 52, and FET 53 as above described. The output of electrometer 36 as viewed at point D begins rising as soon as the output from the dead time sensor goes from zero to a positive non-zero value. For a typi-

cal phase error the electrometer output may rise from zero to a reference voltage, overshoot the reference voltage, and thereafter reapproach the reference voltage as the stimulation phase error is corrected. The corresponding output wave forms from the level detector 38 and the integrating network 40 may be observed at points E and F respectively.

The charging pulses which are applied to charging electrode 25 may be observed at test point G as also illustrated in FIG. 5. Further illustrated with the wave form for point G are a series of arrows positioned at various locations along the charging pulses. Each arrow corresponds to the separation instant for a drop being charged in response to the charging signal. Thus the charge signal may comprise a series of pulses *a* through *s* including the pulses *b* through *k* which are generated during the system dead time. Ideally for normal non dead time operation the drop separation times should correspond precisely with the mid points for the charging pulses. For the error illustrated in FIG. 5 the system initially generates drops slightly after the mid point of the charging pulses (as shown for pulse *a*).

When the dead time sensor gates on FET 53, the stimulation drive signal as seen at point H decreases, thus lengthening filament 15 from a nominal length $X+\Delta X$ as shown in FIG. 2 to a nominal length $X+K$ as shown in FIG. 3. (The actual filament length varies cyclically a small amount about the nominal filament length with the generation of each drop). If no phase error is present when FET 53 is gated on, the pulse arrows as illustrated in FIG. 5 for the point G wave form will move from the mid point of the last print data pulse to the mid point of the trailing edges of the dead time pulses. However, for the phase error illustrated in FIG. 5, the pulse arrows move from a point within the right hand side of pulse *a* to a point on the right hand side of the trailing edge of pulse *b*. This means that phase correction may be accomplished by adjusting the length of filament 15 to bring the pulse arrows to the mid points of the trailing edges of the dead time pulses. For the illustrated case, the observed phase error causes the level detector output (point E) to go negative (after an initial positive transient) and thereafter to approach zero as the system phase error is corrected. Concomitantly the changing length of filament 15 causes the phase of the drop separation relative to the system clock to change such that the pulse arrows as illustrated for wave form G approach the mid points of the trailing edges of the dead time pulses. Thus for pulses *b*, *c*, *d*, *e* and *f* the pulse arrows progressively move left until for pulse *g* full correction is achieved. The pulse arrows remain in the corrected position for pulses *h*, *i*, *j* and *k*. Thereafter at the end of the dead time, FET 53 is gated OFF, filament 15 shortens to the corrected length X as shown in FIG. 4, and the pulse arrows shift to the center of the print data pulses as illustrated for pulses *l* through *s*.

The effect of the above described correction process upon the stimulation drive signal (as seen at point H) is also shown on FIG. 5. Thus the stimulation drive signal changes abruptly from some peak-to-peak magnitude U_1 to a smaller magnitude U_2 when FET 53 becomes conductive. Thereafter the drive signal gradually increases from the magnitude U_2 to a corrected magnitude U_3 as the system phase error is corrected. The stimulation drive signal then maintains the magnitude U_3 until FET 53 is opened. At this time the stimu-

lation drive signal abruptly increases from the level U_3 to a corrected operating level U_4 . It will be understood that a stimulation drive signal of magnitude U_1 produces a nominal filament length $X+\Delta X$ as seen in FIG. 2 while drive signal magnitudes U_3 and U_4 correspond respectively to filament lengths $X+K$ and X as shown respectively in FIGS. 3 and 4.

It will be appreciated that the invention as above described for use with an ON/OFF jet drop recording system, is also applicable to other types of jet drop recorders characterized by having charging phase control problems. Accordingly the above described apparatus is only a preferred embodiment and it is to be understood that changes may be made therein without departing from the scope of the invention.

What is claimed is:

1. Method of sampling a time varying electrical signal comprising the steps of:

1. generating a continuously flowing liquid filament,
2. applying a regular frequency drop stimulating vibration to said liquid filament,
3. applying a drop charging electrical field to said filament in the region where said vibration causes the filament to break up into drops,
4. sampling said signal by modulating said field in correspondence therewith and thereby inducing in said drops electrical charges which represent samples of said signal,
5. detecting a deviation of the phase of said sampling from a desired phase, and
6. correcting said deviation by adjusting the amplitude of said vibration to alter the length of said filament and change the timing of drop breakoff and charging.

2. In a system for control of liquid drops comprising: means for generating a continuously flowing filament of said liquid, stimulation means for applying regular frequency disturbances to said filament and causing a series of uniformly sized drops to separate at regular intervals therefrom, and a charging electrode responsive to an input charging signal for inducing electrical charges in said drops during separation from said filament; the improvement wherein said stimulation means comprises:

means for generating an error signal related to the phase of said drop separation relative to said charging signal, and means responsive to said error signal generating means for correcting said phase by adjusting the amplitude of said disturbances to change the length of said filament and correspondingly change the time required for said disturbances to travel said length.

3. The improvement of claim 1 said means for generating an error signal comprising:

means for applying a calibrating signal to said charging electrode and thereby inducing in said drops electrical charges of magnitude related to the magnitude of said calibrating signal at the instant of drop separation, means for catching the drops so charged, and means for measuring the charge carried by the drops so caught.

4. The improvement of claim 2 said measuring means

comprising means for generating a measuring signal the voltage of which corresponds to the effective current carried by the drops charged and caught as aforesaid.

5. The improvement of claim 3 said means for generating an error signal further comprising means for generating a reference voltage and means for comparing said measuring signal voltage with said reference voltage to create said error signal.

6. The improvement of claim 4 said means responsive to said error signal comprising:

an integrating network for integrating said error signal to produce a setpoint voltage.

an oscillator for generating a periodic stimulating drive signal of continually repeating waveform,

15 a voltage variable attenuator for attenuating said stimulating drive signal in accordance with the magnitude of said setpoint voltage, and

means for generating said regular frequency disturbances in accordance with the attenuated amplitude of said stimulating drive signal.

7. The improvement of claim 5 said calibrating signal being a square wave of frequency equal to the frequency of said stimulating drive signal.

8. The improvement of claim 6 said reference voltage being selected to correspond to the magnitude of said measuring signal voltage for the condition when said drops separate from said filament during transition periods for said calibrating signal.

9. In a system for control of liquid drops wherein selected drops are removed from a stream issuing from a drop generator,

said drop generator including an orifice from which liquid is expelled along a predetermined path as a filament to separate into drops,

a charging electrode spaced from said orifice, means for stimulating the liquid filament to induce regular drop separation at a point adjacent said electrode,

and means for selectively applying charging pulses to said charging electrode for electrostatically charging pre-determined ones of the drops;

the improvement comprising means for attenuating the amplitude of the stimulation energy induced into the filament by said stimulating means,

and a control for said attenuating means responsive to the quantity of charge on a succession of charged drops and connected to said stimulating means to vary the amplitude of the stimulation energy and thereby to adjust the length of said filament and produce separation of said drops in optimal phase relationship with said charging pulses.

10. A system as defined in claim 8, including means creating a deflection field adjacent said path to change the trajectory of charged drops, means for catching the charged drops, and said control means including a detector connected to said catching means to detect the quantity of charge on the charged drops.

11. A system as defined in claim 9, including means for driving said stimulating means at a preselected constant frequency; said attenuating means being responsive to changes in the output of said detector means and connected to vary the amplitude of driving energy supplied from said driving means to said stimulating means.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,761,941 Dated September 25, 1973

Inventor(s) John A. Robertson

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, after line 46 the following has been omitted:

CROSS REFERENCE TO RELATED APPLICATIONS

This application is related to copending patent application METHOD AND APPARATUS FOR AERODYNAMIC SWITCHING, Serial No. 144,841, filed May 19, 1971, now Robertson U.S. Patent 3,709,432.

Column 7, line 56, "1" should be --2--.

Column 7, line 66, "2" should be --3--.

Column 8, line 4, "3" should be --4--.

Column 8, line 9, "4" should be --5--.

Column 8, line 21, "5" should be --6--.

Column 8, line 24, "6" should be --7--.

Column 8, line 28, "callibrating" should read --calibrating--.

Column 8, line 53, "8" should be --9--.

Column 8, line 59, "9" should be --10--.

Signed and sealed this 25th day of December 1973.

(SEAL)
Attest;

EDWARD M. FLETCHER, JR.
Attesting Officer

RENE D. TEGTMEYER
Acting Commissioner of Patents

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