United States Patent [19]

Dressler

[11] **3,868,698**

[45] **Feb. 25, 1975**

[54] **STIMULATION CONTROL APPARATUS FOR AN INK JET RECORDER**

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[73] Assignee: **The Mead Corporation**, Dayton, Ohio

[22] Filed: **Oct. 24, 1973**

[21] Appl. No.: **409,132**

[52] **U.S. Cl.** **346/75,** 310/8.1, 318/116, 331/143, 331/183

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

[58] **Field of Search** ...... 346/75; 331/141, 110, 109, 331/183, 116 R, 116 M; 310/8.1; 318/116, 118

[56] **References Cited**

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3,500,246	3/1970	Werner	331/141 X
3,739,393	6/1973	Lyon et al.	346/75 X
3,761,941	9/1973	Robertson	346/75 X

Primary Examiner—Joseph W. Hartary
Attorney, Agent, or Firm—Biebel, French & Bugg

[57] **ABSTRACT**

A drive circuit for a stimulation transducer suppresses generation of satellite drops in an ink jet recorder. The drive circuit is an oscillator which tracks the resonant frequency of the stimulation transducer. As the resonant frequency of the transducer changes during normal operation, the frequency of the driving signal also changes, so that the power output of the transducer remains essentially unchanged. This provides accurate regulation of the filament length for the jets being stimulated and unexpectedly also suppresses generation of satellite drops. The drive circuit comprises an amplifier, a load resistor and positive and negative feedback paths to the input terminals of the amplifier. The load resistor is incorporated within the negative feedback path as well as within the supply path for the stimulation transducer.

In general the impedance of the stimulation transducer is minimum at the resonant frequency thereof, so that for any shifting of the resonant frequency there is an increase in the input impedence to the transducer. This produces a voltage variation across the load resister which in turn alters the negative feedback to the amplifier. Means are provided for adjusting the negative feedback signal so as to maintain the amplifier in a state of continuous oscillation. The frequency at which this oscillation occurs is the frequency at which the impedance of the transducer is minimum, and therefore the drive circuit tracks the resonant frequency of the stimulation transducer.

16 Claims, 4 Drawing Figures

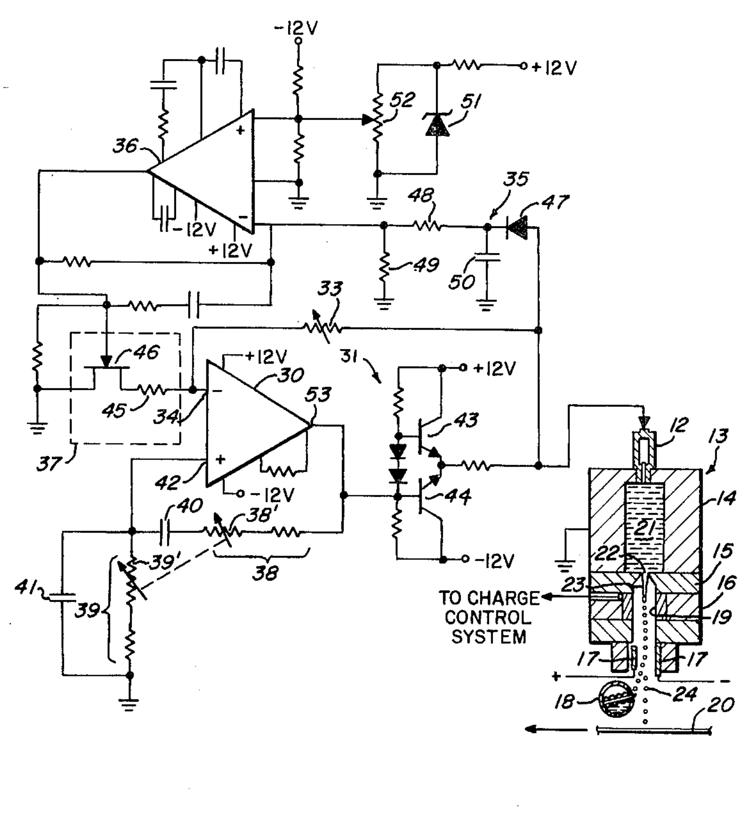
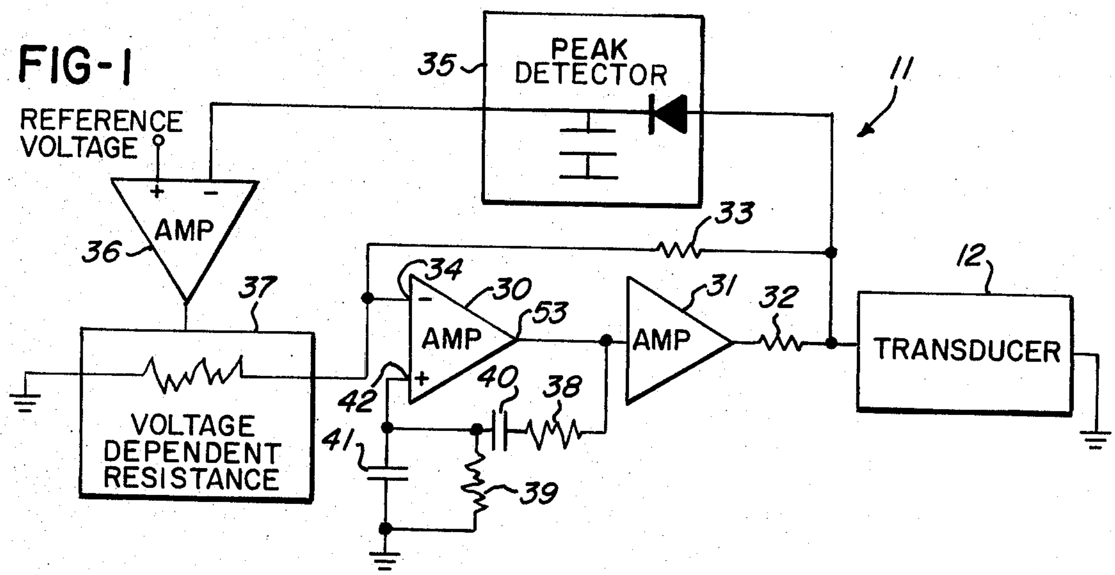


FIG-1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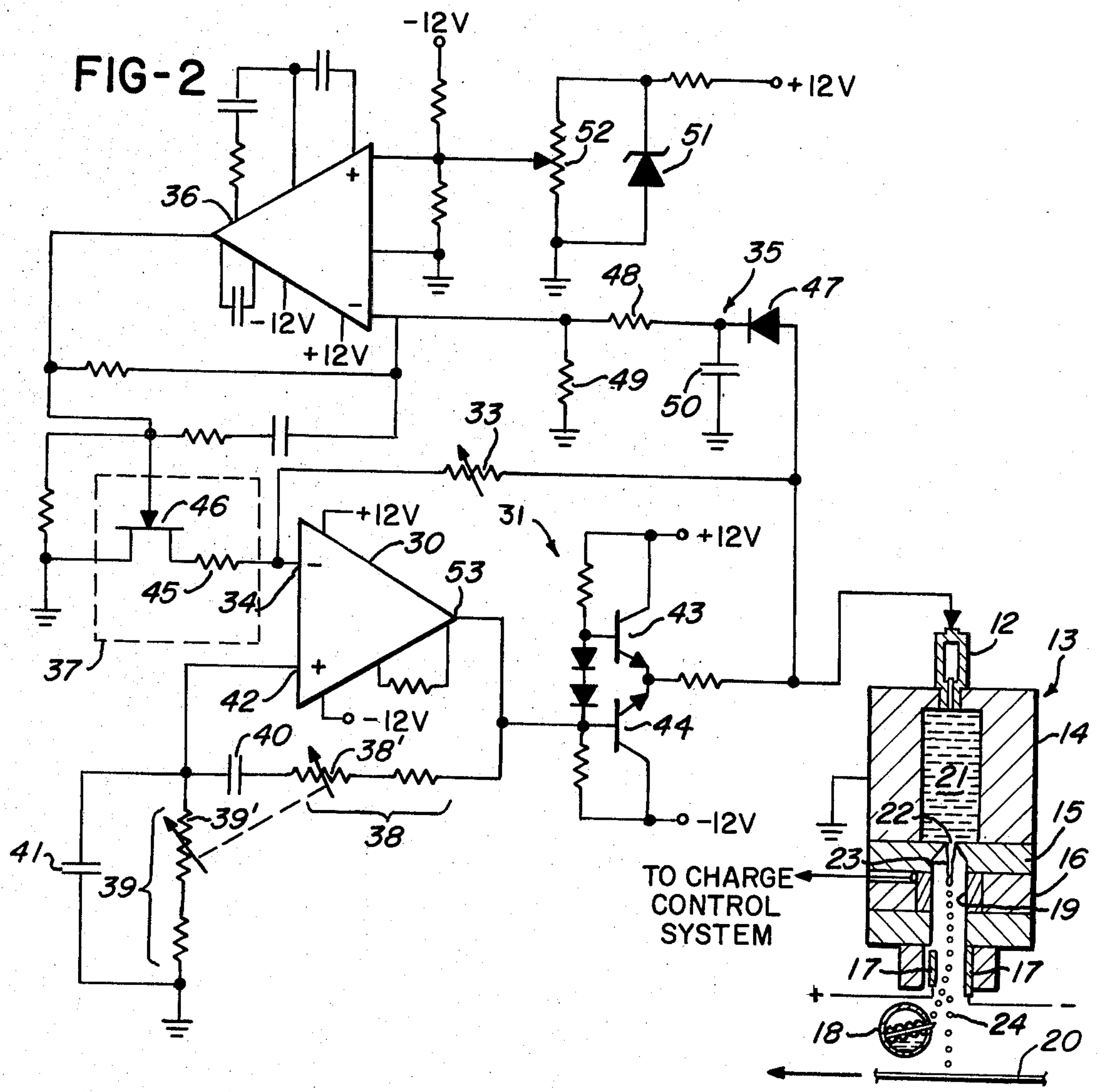
DETECTOR
35
11
REFERENCE
VOLTAGE
AMP
36
33
12
34
30
31
32
37
53
AMP
AMP
TRANSDUCER
40
38
42
41
VOLTAGE
DEPENDENT
RESISTANCE
39

FIG-2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+12V
52
51
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35
48
47
-12V
+12V
49
50
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46
+12V
31
30
+12V
45
34
53
43
12
13
37
42
-12V
44
14
40
38'
21
39'
38
-12V
15
22
23
16
41
39
TO CHARGE
CONTROL
SYSTEM
19
17
17
24
18
20

FIG-3

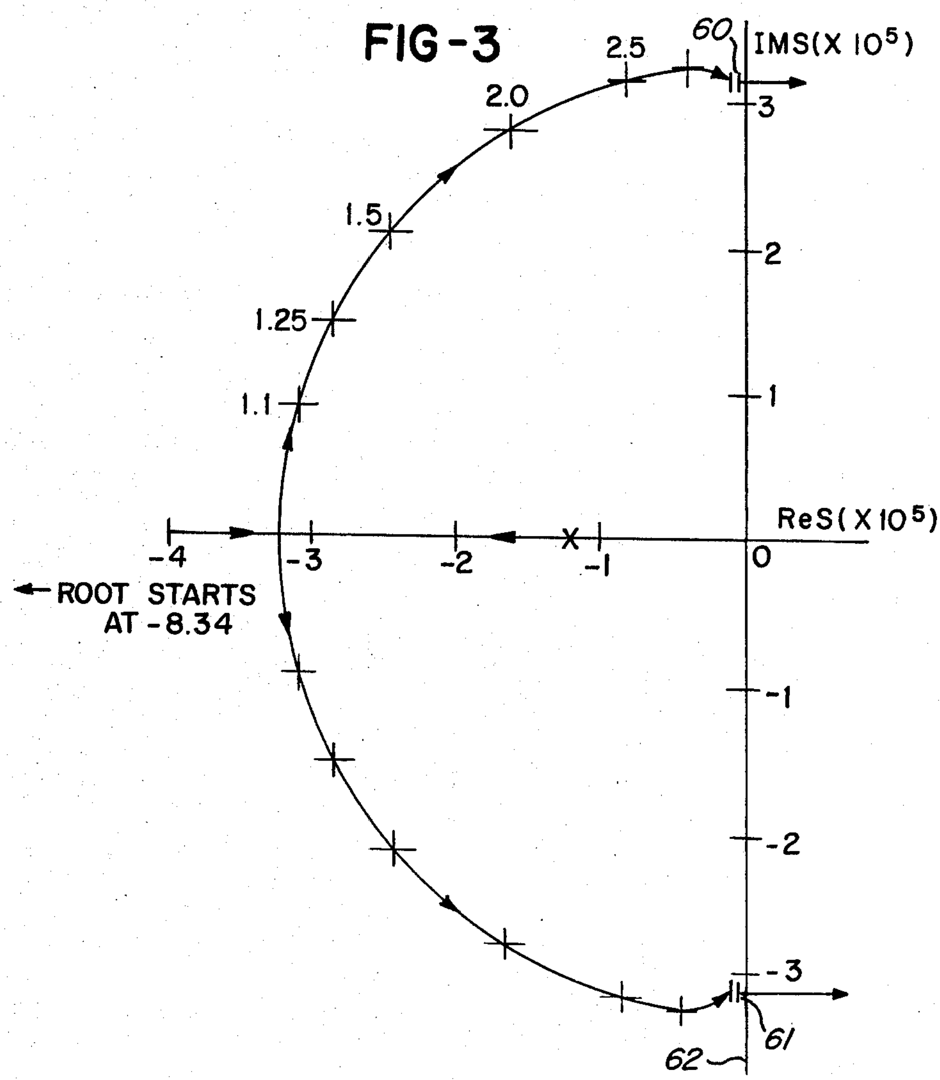
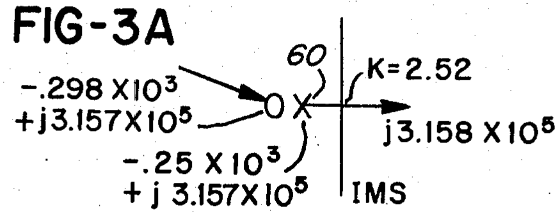

IMS(X 10⁵)
60
2.5
2.0
1.5
1.25
1.1
3
2
1
ReS(X 10⁵)
-4
-3
-2
-1
0
ROOT STARTS AT -8.34
-1
-2
-3
61
62

FIG-3A


60
K=2.52
-.298 X10³
+j3.157X10⁵
-.25 X 10³
+ j 3.157X10⁵
j3.158 X10⁵
IMS

STIMULATION CONTROL APPARATUS FOR AN INK JET RECORDER

BACKGROUND OF THE INVENTION

This invention relates to stimulation control of an ink jet recorder and has particular utility in connection with a multiple jet device of a type generally as shown in Lyon et al. U.S. Pat. No. 3,739,393. Recorders of this type comprise an orifice plate in communication with a pressurized ink manifold, and the orifice plate is provided with one or more rows of closely spaced orifices. Typically such orifice plates may be about 26 centimeters long and comprise two rows of over 600 orifices each. the orifice plate is mechanically excited by a traveling bending wave, so that filaments of ink passing through the orifices are stimulated to break up into streams of uniformly sized and regularly spaced drops. Means are provided for selective charging, deflection, and catching of the drops, all as described in detail in the Lyon et al. patent and other references cited therein. Such a recorder is capable of generating and switching over 50 million drops per second for recording of an image corresponding to stored digital data. Typically the image will be recorded on a web traveling beneath the print head at a speed of about 3 meters per second.

One of the problems in the operation of such a recording device is the generation of satellite drops. These are small unwanted drops which are formed during the liquid filament breakup process. The phenomenom of satellite drop generation is well known in the prior art, and apparatus for suppression thereof is shown in Stauffer U.S. Pat. No. 3,334,351 and in the Keur et al. U.S. Pat. No. 3,683,396. However, these prior art devices deal with single jet recorders wherein a stream of drops is generated by an elongated nozzle arrangement. In the Stauffer patent it is proposed to suppress satellite drops by a plural vibrator arrangement, and in Keur et al. the suppression is accomplished by a special design configuration for the nozzle itself. Neither of these prior art arrangements is applicable to a multiple jet arrangement of the type of interest herein.

One prior art device which has given some relief to the satellite drop problem is the rotatable transducer disclosed in Houser U.S. Pat. No. 3,701,476. This patent discloses an arrangement for accurate adjustment of the point at which stimulation energy is applied to the orifice plate. It has been found that by making careful adjustment of the point of contact between a stimulating probe and the orifice plate as disclosed by Houser, that satellite drop generation may be greatly reduced. However, it has been found that many satellite drops are still generated, and these drops manifest themselves as a very fine mist which collects on the electrical components of the print head. Over a period of time this mist buildup causes electrical shorting problems, thereby necessitating frequent shutdown for cleaning and imposing severe operational restrictions on the recording system.

It has not been found that the filament length of the liquid jets being generated by the orifice plate unexpectedly affects the generation of satellite drops. It is well known that the filament length is dependent upon a number of factors, including the amplitude of the applied stimulation energy, and the satellite drop dependence upon filament length was found during the

course of experimentation with the stimulation amplitude. It is not known exactly how the filament length affects satellite drop formation, but it has been observed that production of satellite drops by a multiple jet recording head varies profoundly with only slight changes in the level of applied stimulation energy. In general the jets in such a head are not stimulated at the same phase, and the only apparent direct effect of changes in the stimulation amplitude is a fairly uniform change in the length of all jet filaments.

It has been further found in accordance with this invention that during normal operation of a stimulation transducer there is a variation in the resonant frequency of the transducer. While this variation may represent a relatively small fraction of the nominal driving frequency (which should correspond roughly with the natural break up frequency of the liquid jets), it has a rather pronounced effect upon the amount of stimulation energy generated by the transducer. This in turn affects the jet filament length and hence the amount of satellite drops which are generated. In this connection it is to be noted that while the "resonant" frequency of the transducer undergoes a shift, the actual stimulation frequency does not change, because the oscillation circuit which drives the stimulator continues to operate at a fairly constant frequency. Therefore the principal affect of the changing resonant frequency of the transducer is a change in the electrical impedence thereof at the frequency of actual driving. This changing impedence changes the amplitude of the vibrational output, thereby altering the jet filament length and affecting the generation of satellite drops. The impedence of the transducer is minimum at its resonant frequency, and in general the driving voltage for the transducer is adjusted for production of a optimum jet filament length at the resonant condition. When the resonant frequency shifts, the jet filaments lengthen and satellite drop production increases.

SUMMARY OF THE INVENTION

This invention reduces satellite drop generation in an ink jet recorder by providing a stimulation drive circuit which tracks the resonant frequency of the stimulation transducer and alters the driving frequency in accordance therewith. Thus the stimulation transducer is driven at its resonant frequency and its power output remains relatively constant. This in turn regulates the length of the ink jet filament and suppresses generation of satellite drops. While this causes the jets to be stimulated at a frequency which may vary slightly from the natural frequency thereof, such a small departure does not appear to be in any way detrimental to the operation of the recorder. However, by driving the stimulation transducer always at its resonant frequency, the driving circuit always sees the same output impedence and greatly improved overall performance is achieved.

When the stimulation transducer oscillates, precisely at its resonsant frequency (or at one of several resonant frequencies), the impedence which is seen by the driving circuit is a local minimum. Therefore by operating as above described, there is achieved a further beneficial effect in that the driving circuit may operate at a relatively low voltage level. Thus there is avoided any requirement for high voltage circuit components and a significant cost savings is achieved.

The circuit which is employed for driving the stimulation transducer comprises an amplifier, a load resister, and positive and negative feedback paths to the amplifier input. The load resister is placed in the negative feedback path, and the input for the stimulation transducer is taken from the output side of the load resistor. Means are provided for adjusting the feedback so that sustained oscillation takes place. This oscillation occurs at the resonant frequency of the stimulation transducer because the impedence characteristic of the transducer causes the overall loop gain through the amplifier to be less than 1 at all other frequencies. As the resonant frequency of the transducer shifts there is a corresponding shift in the frequency for which oscillation is enabled. Hence the driving circuit tracks the resonant frequency of the transducer.

It is therefore seen that it is a primary object of this invention to suppress the generation of satellite drops in an ink jet recorder. Another object of this invention is to regulate the length of the filaments of recording fluid in such a recorder. Still another object of the invention is to track the resonant frequency of a stimulation transducer and to adjust the oscillation frequency of the driving circuit therefor in accordance therewith. Other and further objects and advantages of the invention will be apparent from the following description, the accompanying drawings and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a generalized diagram of a stimulation transducer driving circuit in accordance with this invention;

FIG. 2 is a detailed schematic diagram of a driving circuit for a stimulation transducer with generalized illustration of an ink jet recording head;

FIG. 3 is a root locus plot for the circuit of FIG. 2; and

FIG. 3A is an enlargement of a portion of the plot of FIG. 3.

DESCRIPTION OF THE PREFERRED EMBODIMENT

A preferred form of the invention, as illustrated generally by FIG. 1, comprises a drive circuit 11 connected for driving control of a stimulation transducer 12. Stimulation transducer 12 may be mounted in an ink jet recording head 13 as illustrated generally in FIG. 2. Thus recording head 13 may comprise an ink manifold 14, an orifice plate 15, a charge ring plate 16, a pair of deflection electrodes 17, and a catcher 18. A supply of ink 21 is maintained under pressure in manifold 14 and exits through orifice 14 via a series of orifices 22 (only one orifice 22 being illustrated) to form a series of filaments 23. As described in detail in Lyon et al. U.S. Pat. No. 3,739,393 and in Houser U.S. Pat. No. 3,701,476, stimulator 12 may have a probe which reaches downwardly for contact with orifice plate 15. Vertical oscillation of the probe generates an oscillating disturbance at one end of orifice plate 15, and these oscillations travel the length of orifice plate 15 thereby causing filaments 23 to break up uniformly into drops 24. In accordance with the practice of this invention the drops 24 are generated without concomitant generation of an excessive number of satellite drops (not illustrated).

Continuing with the description of recording head 13, it will be seen that some of drops 24 deposit on a moving web 20 while other of drops 24 are deflected into a catcher 18. Selective catching of drops 24 is accomplished by selective application of charge contol signals to a series of charge rings 19 in charge ring plate 16. An electrical filed is established between deflection electrodes 17, and those of drops 24 which are charged by charge rings 19 (each jet has its own charge ring) are deflected by the electrical field into catcher 18. As shown by the Lyon and Houser patents, there may be two rows of jets and two catchers with each catcher having a face which serves as one deflection electrode for an associated row of streams.

The construction details of transducer 12 are described in the above mentioned Houser patent wherein it is shown that the primary element may be a piezoelectric crystal which converts an electrical input signal to an output oscillation. This output oscillation is coupled through a load mass and a horn structure to the above mentioned probe for application to orifice plate 15. In general these transducers may have several resonant frequencies, one of which should correspond closely with the natural frequency of streams 23. Drive circuit 11 is designed to drive transducer 12 at the correct resonant frequency and to track that frequency as it changes normally due to heating or other causes during routine operation of the recording system.

In preferred embodiment transducer drive circuit 11 comprises a differential amplifier 30, a power amplifier 31, a load resistor 32, and negative and positive feedback loops to the negative and positive input terminals 34 and 42 of differential amplifier 30. It is not necessary that amplifier 30 be a differential amplifier, so long as summing junctions be provided for negative and positive feedback loops. Further it will be appreciated that power amplifier 31 is not an essential element of the invention and is merely employed for current amplification without voltage gain. It is, however, important that the negative feedback loop be connected to the output side of load resistor 32 and that the positive feedback loop be connected so as to exclude load resistor 32 therefrom.

As illustrated in FIG. 1, the above mentioned negative feedback loop extends from output terminal 53 of differential amplifier 30 back around to the negative input terminal 34. The negative feedback loop therefore includes load resistor 32 and branches out into two branches at the output side thereof. One of these two negative branches includes only a resister 33 whereas the other branch comprises a peak detector 35, a differential amplifier 36 and a voltage dependent resistance 37. The positive feedback loop extends from output terminal 53 of amplifier 30 back through an R-C network to the positive input terminal 42. In general the gain across amplifier 30 is extremely high, but the only signal amplified is a very small difference signal which results when the positive and negative feedback signals are combined. Therefore in computing the overall loop gain around the loop including the positive feedback path, account must be taken of the substractive effect of the negative feedback loop. For making circuit 11 deliver a steady state oscillating drive signal to transducer 12, it is necessary that the loop gain around the positive loop be exactly equal to 1.0, and resistor 33 is selected for production of this gain condition.

For reasons which are discussed below the oscillation of driving circuit 11 occurs at a frequency which closely matches the resonant frequency of transducer 12. In the special case of a transducer having only one resonant frequency, the above mentioned positive feedback loop may comprise a simple connection from the output of amplifier **30** back around to the positive terminal of amplifier **30.** In general, however, transducer **12** will have several resonant frequencies, and it is desired to drive transducer **12** at that one of its resonant frequencies which most nearly approximates the natural frequency of the liquid filaments **23.** Accordingly the positive feedback loop around amplifier **30** comprises an R-C network designed to produce oscillation of amplifier **30** at a frequency near that one of the resonant frequencies of transducer **12** which it is desired to track. Thus as illustrated in FIG. **1,** the positive feedback loop comprises resisters **38** and **39** and capacitors **40** and **41** connected in a wien bridge arrangement. The bridge arrangement has an attenuation of approximately 3 (or gain of one third) at the desired tracking frequency, and therefore the negative feedback loop (comprising two branches as above described) is designed to produce an effective gain of three across amplifier **30** from input terminal **42** to output terminal **53.** Thus the overall gain around the loop including the positive feedback path is 1.0 at the tracking frequency.

The frequency tracking operation of drive circuit **11** occurs, because of the inclusion of load resistor **32** in the above mentioned negative feedback path and the connection of the input terminal of transducer **12** to the output side of resister **32.** This arrangement causes resister **32** and transducer **12** to behave like a voltage divider, and since the voltage drop across transducer **12** is frequency dependent, the same is likewise true of the voltage drop across resistor **32.** Then because of the feedback connection to negative input terminal **34,** it may be seen that there is a frequency dependent gain condition wherein the effective gain around the loop including the positive feedback path is maximum at the frequency for which the voltage drop across resistor **32** is also maximum.

The frequency at which the voltage drop across resistor **32** is maximum necessarily must be the frequency at which the impedence of transducer **12** and the voltage drop thereacross are minimum. The frequency for which this occurs is the resonant frequency of the transducer, and hence for this frequency the conditions are such as to promote a maximum growth rate for any noise induced disturbances. The negative feedback branch through peak detector **35,** amplifier **36,** and voltage dependent resistance **37,** continually adjusts the system gain to maintain a stable oscillation condition at whatever frequency the oscillations may be occurring. What this means is that the loop gain becomes 1.0 for the above mentioned resonant frequency and less than 1.0 for all other frequencies. It follows that amplifier **30** and drive circuit **11** can oscillate only at a frequency corresponding to a resonant frequency of transducer **12.**

The above mentioned gain adjustment occurs because peak detector **35** continually monitors the peak value of the sinusoidal voltage appearing at the output side of resistor **32** and supplies a corresponding control signal through amplifier **36** to voltage dependent resistance **37.** Amplifier **36** applies a negative voltage to voltage dependent resistance **37,** and the magnitude of this voltage increases (i.e., increases in the negative direction) whenever the sinusoidal signal at the output side of resister **32** begins growing in amplitude. This then causes an increase in the resistance of resistance network **37** as well as an increase in the voltage drop thereacross. The increased voltage drop across resistance network **37** increases tht negative feedback applied to terminal **34,** thereby decreasing the amplitude of the circuit oscillation. In this respect, therefore, the gain adjusting means operates in a manner analogous to the operation of a tungsten filament lamp or other similar device frequently employed in prior art oscillation networks. In this case, however, the oscillation frequency of the circuit undergoes a controlled change, whereas the gain adjustment means of the usual oscillator enables sustain oscillation at a non changing frequency.

As described above, load resistor **32** performs a necessary function in the operation of the invention in facilitating the tracking of the resonant frequency of transducer **12.** In general drive circuit **11** locks in more easily to the resonant frequency of transducer **12** when load resister **32** has a relatively large resistance. However, resistive heating across resister **32** causes a power loss, and therefore there is an optimum resistance value for resister **32.** Preferably the resistance of resister **32** should be selected in accordance with the impedence of transducer **12** as measured at the resonant frequency (at which frequency the impedence is almost entirely resistive).

Experience with drive circuits such as drive circuit **11** has shown that resister **32** preferably should have a resistance of at least about 10 percent of the resistance of the transducer **12,** with a resistance ratio of about 25 percent being optimum. From a power disipation point of view resister **32** preferably should not have a resistance greater than the resistive impedence of transducer **12** as measured at the resonant frequency thereof. In a typical case the resonant frequency which is being tracked is about 50 KHz, and when in resonance at this frequency transducer **12** may have an internal impedence of about 200 ohms. Under such conditions a resistance of about 47 ohms for resister **32** has been found to be highly satisfactory.

A schematic diagram of drive circuit **11** is shown in FIG. 2. As shown therein power amplifier **31** comprises 2 transistors **43** and **44** connected in a push-pull arrangement. Amplifier **31** has a voltage gain of 1 and serves as a low output impedence of differential amplifier **30.** Voltage dependent resistance **37** comprises a resister **45** in series with a field effect transistor **46.** The gate voltage of transistor **46** varies with the output of amplifier **36,** and this in turn varies the resistance between the drain and the source terminals of the transistor. As a consequence thereof, the negative feedback applied to terminal **34** of differential amplifier **30** follows the voltage peaks detected by the peak detector **35.**

Peak detector **35** comprises a diode **47,** a pair of resisters **48** and **49,** and a capacitor **50** connected as illustrated to the negative input terminal of amplifier **36,** which it may be noted is preferably a high gain differential amplifier. The reference voltage which is applied to the positive input terminal of amplifier **36** is generated by a tapped resister **52** in parallel with a zener diode **51** and sources of positive and negative potential (typically about 12 volts) all connected as illustrated.

As described previously the network connected to the positive input terminal **42** of differential amplifier **30** is designed to maintain amplifier oscillation at a frequency near a specified resonant frequency of transducer **12.** For a typical resonant frequency of about 50 kilohertz resisters **38** and **39** may each have a resistance of about 1,600 ohms and capacitors **40** and **41** may each have a capacitance of about 2,000 micromicrofarads. Further as illustrated in FIG. **2**, resisters **38** and **39** may comprise ganged variable resistive elements **38'** and **39'** for simultaneous adjustment. The ganged variable resistive elements **38'** and **39'** are provided to facilitate initial frequency lock at the desired resonance frequency of transducer **12**. This initial frequency lock may be achieved by adjusting resistive components **38'** and **39'** and observing the frequency of system oscillation. The oscillation frequency will change with the changing adjustment of resistive component **38'** and **39'** until frequency lock with transducer **12** has been achieved. At this point further adjustment of the ganged resistive components will produce no further change in the system oscillation frequency.

As further illustrated in FIG. **2**, resister **33** is also variable. Preferably resister **33** is a 50,000 ohm potentiometer which may be used to bias FET **46** in the proper operating region. When resister **33** is adjusted to the correct value, the amplitude of the driving voltage to transducer **12** can be adjusted in a range anywhere from about 0 volts to about 20 volts peak to peak. Adjustment of the amplitude of the transducer driving voltage is effected by adjusting the position of the tap on resistor **52**.

A root locus plot for the circuit of FIG. **2** is presented in FIGS. **3** and **3A**. The expression for which this plot is made has the general form:

$$KG(s)/[1-KG(s)]$$

where:

$$K=(R_{37}+R_{33})/R_{37}$$

and

$$G(s)=\frac{Z(s)+R_{32}}{Z(s)}\,\frac{R_{39}C_{41}S}{(R_{39}C_{41}S)^2+3R_{39}C_{41}S+1}$$

Z is the transfer function for transducer **12** which in a typical case has been found to be given approximately by the equation:

$$Z(S)=\frac{0.87\times10^9\,[S^2+0.5\times10^3\,S+(3.157\times10^5)^2]}{S\,[S^2+0.5\times10^3\,S+(3.252\times10^5)^2]}$$

When the system is oscillating the resistance of voltage dependent resistance **37** (and thus also K) is adjusted for a stable condition. This stable oscillation condition corresponds to the point at which two of the poles **60** and **61** cross the real axis **62** of FIGS. **3** and **3A**. As shown in FIG. **3** and more particularly in enlarged form in FIG. **3A**, the axis crossing occurs when K has a value of about 2.52 to produce system oscillation at a frequency of 3.158×10^5 radians per sec. or about 50 KHz. It is noted that the poles which cross the real axis at this gain are poles which for a gain of zero have a real part of −250 and an imaginary part of 3.157×10^5. These poles are produced by the zeros of transducer **12**. The plot, therefore, confirms that it is the low impedence resonance of transducer **12** which controls the frequency of system oscillation.

While the form of apparatus herein described constitutes a preferred embodiment of the invention, it is to be understood that the invention is not limited to this precise form of apparatus, and that changes may be made therein without departing from the scope of the invention.

What is claimed is:

1. Apparatus for stimulating a filament of recording fluid to break up into uniformly sized and regularly spaced drops comprising electically driven vibrating means having a naturally resonant frequency near the natural frequency of said filament, an amplifier for supplying an electrical driving signal for said vibrating means, and positive and negative feedback means for causing oscillation of said amplifier; said negative feedback means comprising means for generating a negative feedback signal corresponding to the impedance of said vibrating means and causing oscillation of said amplifier to occur at a frequency which minimizes said impedance.

2. Apparatus for stimulating a filament of recording liquid to break up into a stream of uniformly sized and regularly spaced drops comprising:

1. a transducer which responds to an oscillating electrical operating current by producing mechanical vibrations at a common frequency therewith, said transducer having a naturally resonant frequency at which its impedance to said operating current is minimum, and said naturally resonant frequency being near the natural frequency of said filament and subject to minor shifting during operation,
2. means mounting said transducer for vibrational stimulation of said filament,
3. means for producing said electrical operating current and adjusting the frequency thereof for correspondence with said naturally resonant frequency, and
4. amplitude adjustment means for regulating the peak amplitude of said operating current.

3. Apparatus for stimulating a filament of recording liquid to break up into a stream of uniformly sized and regularly spaced drops comprising:

1. a transducer which responds to an oscillating electrical operating current by producing mechanical vibrations at a common frequency therewith, said transducer having a naturally resonant frequency at which its impedance to said operating current is minimum, and said naturally resonant frequency being near the natural frequency of said filament and subject to minor shifting during operation,
2. means mounting said transducer for vibrational stimulation of said filament,
3. an amplifier for producing a driving signal which drives said operating current at a common frequency therewith,
4. a load resister connected to the input side of said transducer so that at least a portion of said operating current passes therethrough whereby the voltage drop across said resister varies inversely with the electrical impedance of said transducer,
5. feedback means connected to the input side of said amplifier for causing said driving signal and said operating current to oscillate at a frequency which maximizes the voltage drop across said load resister, and
6. feedback adjustment means for applying to the input side of said amplifier an adjustment signal which regulates the peak amplitude of said operating current.

4. Apparatus according to claim **3** said amplifier having both positive and negative feedback terminals for connection to said feedback means.

5. Apparatus according to claim **4** the portion of said feedback means connected to said negative feedback terminal comprising a path joining said negative input terminal to the input side of said transducer.

6. Apparatus according to claim **5** further comprising a second amplifier having its input side connected for receiving said driving signal from the first aforesaid amplifier and its output side connected to the side of said load resister which is remote from said transducer, whereby said second amplifier generates said operating current and delivers it to said load resister.

7. Apparatus according to claim **6** the portion of said feedback means connected to said positive feedback terminal comprising a path joining said positive feedback terminal to the input side of said second amplifier.

8. Apparatus according to claim **7** said path joining said positive feedback terminal comprising means for producing initial oscillation of said driving signal at a frequency near the naturally resonant frequency of said transducer.

9. Apparatus according to claim **7** said resistance-capacitance network comprising wien bridge circuit.

10. Apparatus according to claim **6** said initial oscillation producing means comprising a resistance-capacitance network.

11. Apparatus according to claim **3** said load resister having a resistance between about 10 and 100 percent of the impedance of said transducer when driven at said naturally resonant frequency.

12. Apparatus according to claim **3** said load resister having a resistance equal to about 25 percent of the impedance of said transducer when driven at said naturally resonant frequency.

13. Apparatus according to claim **3** said feedback adjustment means comprising a voltage peak detector for detecting peak values of said operating current as seen at the input to said transducer and a voltage dependent resistance responsive to said peak detector.

14. Apparatus according to claim **13** said voltage dependent resistance comprising a field effect transistor.

15. In a jet drop recording system comprising an orifice plate for generating a row of filaments of recording liquid, an electrically driven and frequency resonant transducer for launching drop stimulating bending waves along said orifice plate and means for charging and deflecting the drops which are generated by said liquid filaments; driving means for driving said transducer at a resonant frequency thereof comprising:

1. a high gain differential amplifier having positive and negative input terminals and an output terminal,
2. a power amplifier having an input terminal and an output terminal, said input terminal being connected to the output terminal of said differential amplifier,
3. a load resister connected between the output terminal of said power amplifier and an imput terminal of said transducer,
4. a first negative feedback branch comprising a feedback resister and connected between said input terminal of said transducer and the negative input terminal of said differential amplifier,
5. a second negative feedback branch comprising gain adjusting means and connected between said input terminal of said transducer and said negative input terminal of said differential amplifier, and
6. positive feedback comprising a frequency selective resistance capacitance network connected between the output terminal of said differential amplifier and the positive input terminal of said differential amplifier.

16. Apparatus according to claim **15** said resistance-capacitance network being tuned for passage of frequencies near the resonant frequency of said transducer and comprising adjustment means for facilitating initial locking of said driving means to the resonant frequency of said transducer.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 3,868,698

DATED : February 25, 1975

INVENTOR(S) : John L. Dressler

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

Column 1, line 61, "not" should be --now--.

Column 2, line 35, "a" should be --an--; line 58, after "its" "resonsant" should be --resonant--.

Column 4, line 1, "filed" should be --field--.

Column 5, line 35, "positive" should be in Italics.

Column 6, line 2, "tht" should be --the--

Column 10, line 30, after "feedback" insert --means--.

Signed and sealed this 17th day of June 1975.

(SEAL)
Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 3,868,698

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Column 1, line 61, "not" should be --now--.

Column 2, line 35, "a" should be --an--; line 58, after "its" "resonsant" should be --resonant--.

Column 4, line 1, "filed" should be --field--.

Column 5, line 35, "positive" should be in Italics.

Column 6, line 2, "tht" should be --the--

Column 10, line 30, after "feedback" insert --means--.

Signed and sealed this 17th day of June 1975.

(SEAL)
Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks