United States Patent

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[54] **INK JET PRINTER WITH DROPLET PHASE CONTROL MEANS**
6 Claims, 5 Drawing Figs.

[52] **U.S. Cl.** **346/1,** 346/75
[51] **Int. Cl.** **G01d 18/00**
[50] **Field of Search** 346/75, 1

[56] **References Cited**

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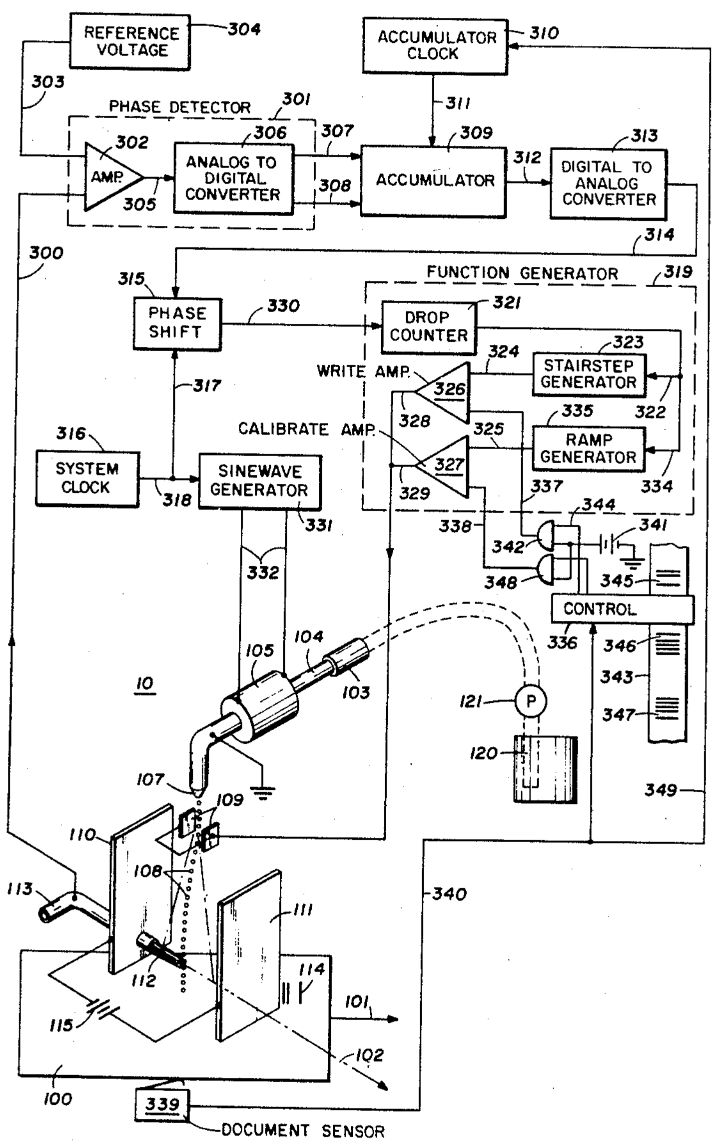
ABSTRACT: A charging voltage applied to ink droplets discharged from the nozzle of an ink-jet printer is controlled by varying the phase of the charging voltage placed upon a droplet in dependence upon the time-phase relationship between the droplet and the charging voltage.



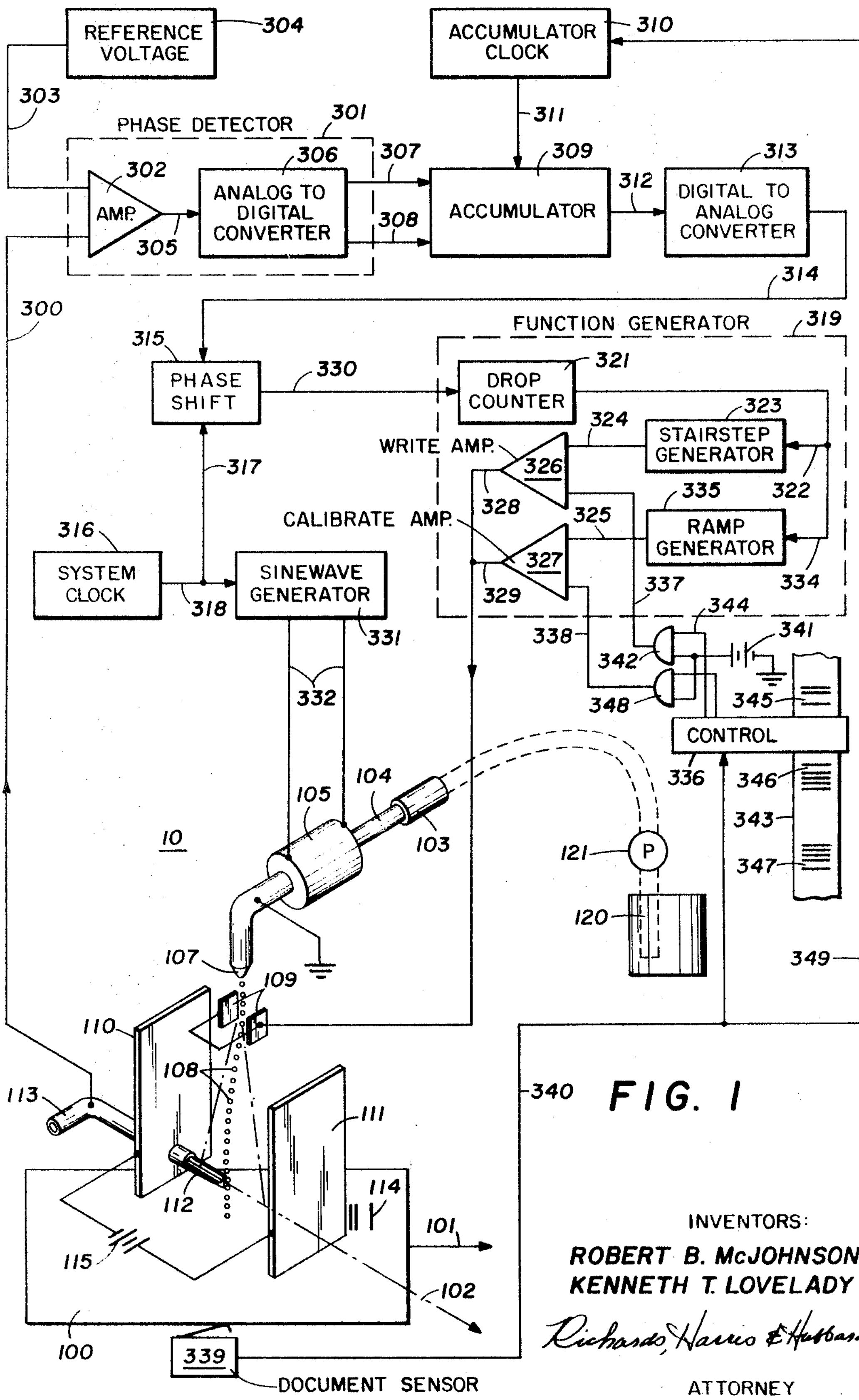


FIG. I

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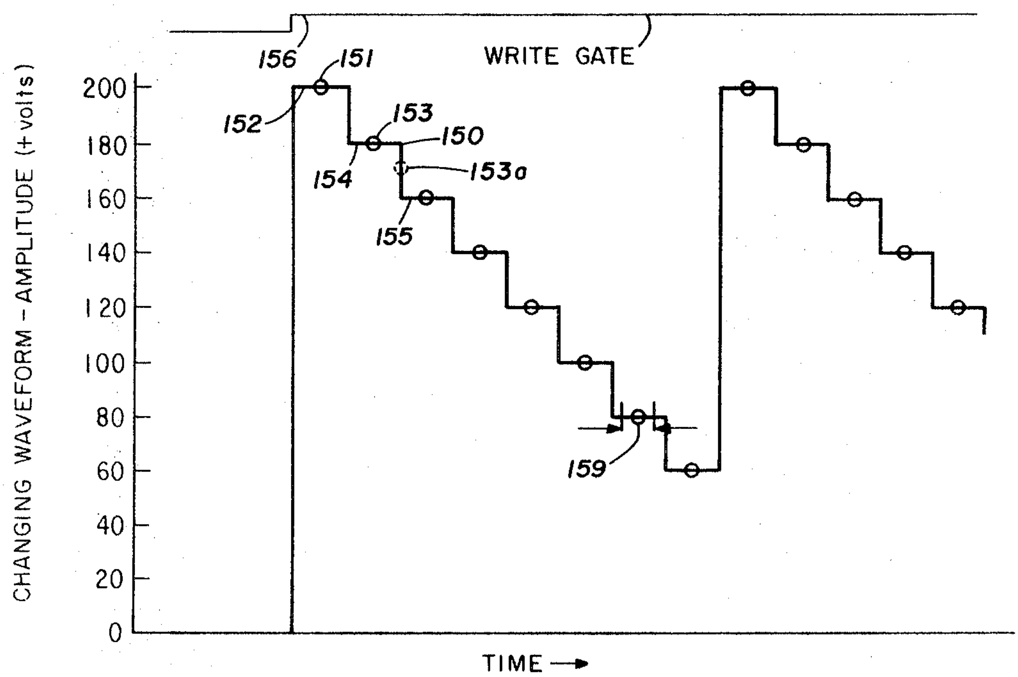

FIG. 2

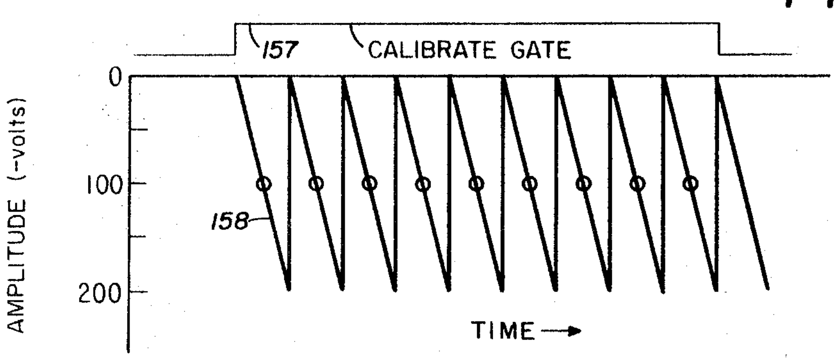

FIG. 3

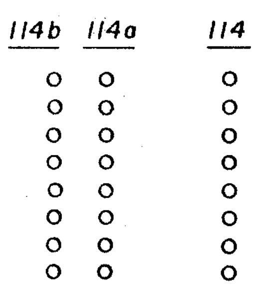

FIG. 4

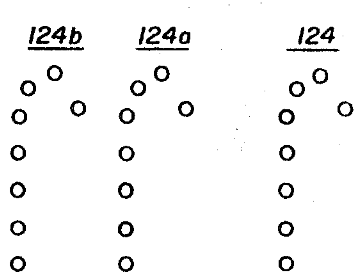

FIG. 5

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INK JET PRINTER WITH DROPLET PHASE CONTROL MEANS

This invention relates to ink-jet printing and, more particularly, to phase control of the charging voltage applied to ink droplets.

BACKGROUND

Systems have heretofore been developed for printing documents with a modulated stream of ink. In such systems, a stream of ink passes through a nozzle which is vibrated to cause the stream to break up into droplets. Just before the droplets leave the stream, they pass between a pair of charging plates which place a desired charge on each droplet. The droplets then pass through a constant space field. The reaction between the field and the charge causes the droplets to be deflected. The deflection is proportional to the charge on the drop. Such an ink-jet printer is described in copending U.S. Pat. application Ser. No. 618,923.

The time-phase relationship of the charging voltage and the instant at which the droplets break off from the ink stream is critical. Due to variations in the physical properties of the ink, such as viscosity and conductivity, and because of environmental changes in the equipment such as temperature, the time-phase relationship can change drastically, degrading the resultant printing operation. Therefore, because the breakoff instant of the droplets from the ink stream may vary, there exists a need for compensation therefor.

SUMMARY

In accordance with the present invention, the time-phase relationship between the breakoff instant of the ink droplets and the charging voltage to be placed on the droplets is detected and controlled by varying the charging voltage through a servo loop system responsive to variations in the time-phase relationship. In a more specific aspect, a charging voltage is applied to the charging plates for charging ink droplets which pass therebetween. The droplet path impinges the path of a traveling document. The droplets do not impinge the document during a phase control cycle, but, rather, are collected in an ink catcher. A phase control system is connected to the ink catcher for detecting the voltage on the catcher created upon capture of charged ink droplets. The catcher voltage is compared to a reference voltage in a phase control system to determine the time-phase relationship of the droplet breakoff instant and the charging voltage. The phase control servo will vary the phase of the charging voltage so as to position the charging voltage waveform in the correct time relation with respect to the droplet breakoff instant.

THE DRAWINGS

FIG. 1 illustrates the invention where droplets are electrostatically charged and deflected;

FIG. 2 is a time plot of the droplet charging voltage;

FIG. 3 is a time plot of the droplet charging voltage used during the phase-control cycle;

FIG. 4 illustrates a bar print when the proper time-phase relation exists; and

FIG. 5 illustrates a bar print when an improper time-phase relation exists.

THE PREFERRED EMBODIMENTS

In FIG. 1 a document **100** travels along a line and direction indicated by the arrow **101**. Ink-jet printer **10**, as indicated by arrow **102**, is askew to the direction of document travel. Ink-jet printer **10** comprises a slender conduit or tube **103** through which ink or other suitable writing fluid is fed under pressure. The ink passes through a nozzle or conduit **104** which is under control of a suitable high frequency, low amplitude vibrator, such as a piezoelectric crystal. Piezoelectric crystal **105**, energized by alternating current from source **331** by way of channel **332** imparts the desired high speed vibration to the nozzle or conduit **104**, a suitable frequency is of the order of 48 kilocycles per second. The nozzle **104** terminates in a tip **107** having a small orifice of, for example, about 0.001 inch diameter. A very fine stream of writing fluid is forced from supply **120** by pump **121** through tip **107**.

The high frequency vibration of nozzle **104** causes the flow of fluid from tip **107** to be broken into very small or fine droplets as indicated by the broken stream **108**.

A signal voltage from a generator **319** is connected by output channel **328** to two spaced charging plates **109** between which the train of droplets passes. The signal voltage from generators **319** may be varied to deflect the droplets to print bars such as bars **114** on document **100**. More particularly, as the droplets fall by gravity or are propelled under suitable pressure or force as applied to nozzle **104**, they pass through an electrostatic field created by applying a voltage from source **115** to two spaced deflection plates **110** and **111**.

Uncharged ink droplets are not affected by the electrostatic field between plates **110** and **111**. They flow or fall without deflection into a catcher **112** which is insulated from plate **110**. Catcher **112** may be drained through tube **113**. Thus, if no charge is carried by a droplet, it does not land on document **100**. However, upon application of a signal voltage to the charging plates **109**, the droplets are charged. As the signal voltage increases droplets are each more highly charged. Deflection by the electrostatic field between plates **110** and **111** as they fall on the document **100** increases with increased charge.

If the document **100** were standing still, the points of impact of droplets having successively increasing charge would lie along a diagonal line corresponding with arrow **102**. However, the rate of deposition of droplets and the deflection thereof is coordinated with the rate of travel of the document. As a result, bars may form which are parallel to the leading edge of document **100** and perpendicular to the arrow **101** which indicates the travel direction.

The droplet charging voltage normally applied to plates **109** preferably has the form shown in FIG. **2**. It is a stair step voltage synchronized with the sinewave voltage applied to vibrator **105** from generator **331**. It is necessary that the droplets employed for forming bars such as bars **114**, FIG. **1**, leave tip **107** and travel toward document **100** with the charges thereon represented by the levels on the stair step function **150**. More particularly, the first droplet **151** in a representative system would have a charge thereon represented by the 200 volt field **152** between plates **110** and **111**. The second droplet **153** would have a lower charge represented by the lower voltage **154** on plates **109**. The charging voltage is measured relative to the ground potential at which nozzle **104** is maintained.

Because of change in various physical parameters such as the viscosity of the ink, which may change in response to changing temperatures in the system, it has been found that the instant that the ink droplet actually breaks away from the tip may vary relative to the phase of the voltage on vibrator **105**.

It has been found that when the time-phase relationship changes, droplet **153** may not pass between plates **109** while plates have charge **154** thereon. Rather, it may break away at a later time, namely the time when the voltage on plates **109** relative to tip **107** is changing from level **154** to level **155**. When this is the case, the droplet may have a charge thereon which is any value which may be represented by the difference between the voltages **154** and **155**, FIG. **2**.

The present invention provides for detection of variations in the instant the droplet is formed and the phase of the sinewave voltage from generator **331** so that is will be assured that the charges on the droplets will be represented by the successive levels on the stair step function **150**.

The system includes a line **300** leading from the catcher **112** to the input of a phase detector **301**. The phase detector **301** has an input amplifier **302** the second input of which is supplied by way of channel **303** from a reference voltage source **304**. The output of amplifier **302** is connected by way of channel **305** to an analog-to-digital converter **306**. The analog-to-digital converter has two outputs **307** and **308** which lead to an accumulator **309**. An accumulator clock **310** is connected by way of channel **311** to the accumulator **309**. Output **312** of accumulator **309** is connected by way of a digital-to-analog converter **313** whose output is connected by way of channel **314** to a phase-shifting unit **315**. A system clock **316** is connected by way of channel **317** to the phase-shifter **315** and by way of channel **318** to the sinewave generator **331**. The clock pulses from source **316** pass through phase shifter **315** and are applied by way of channel **330** to a drop counter **321** in the function generator **319**. The output of drop counter **321** is connected by way of channel **322** to a stair step function generator **323** and by way of channel **334** to a ramp function generator **335**.

The generator **323** is connected to a gated output amplifier **326** by way of channel **324**. The output channel **328** leads to plates **109**. Finally the ramp function generator **335** is connected by way of channel **325** to a gated output amplifier **327** whose output is connected by way of channel **329** to channels **328**.

The printing on document **100** is conducted under the control of a control unit such as a computer **336**. During the interval that the document is passing along the path in the region of plates **110** and **111**, write gates in the form of a change in state of control voltage **156**, FIG. **2**, are applied to amplifier **326** by way of channel **337** so that the stair step function generated by the unit **323** is applied to the plates **109**. In the time interval required for travel of document **100** between locations of bars such as bar **114**, and for travel between documents, the write gate on channel **337** is removed and a calibrate gate **157**, FIG. **3**, is applied to amplifier **327** by way of channel **338** so that a predetermined number of cycles of the ramp function **158** will be applied to the plates **109**.

During the interval that the ramp function is applied to plates **109**, the charges on successive droplets impinging the catcher **112** are sensed and employed to adjust the phase shift of the system clock pulses applied to the phase-shift unit **315**. Thus, for those physical conditions in the system which exist during the calibration interval, the phase will be adjusted so that the droplets will be formed and pass between plates **109** at precise intervals synchronized with the voltage from generator **331**. Preferably, such intervals will be maintained within limit **159**, FIG. **2**. In such case, they pass between plates **109** during time intervals represented by the "treads" on the steps of function **150** rather than on the "riser."

When the droplets pass through the plates **109** in the time-phase relations indicated in FIG. **2**, then the droplets will fall on a straight line on document **100**, in the manner illustrated in FIG. **4** where bar **114** and two succeeding bars, **114***a* and **114***b*, are shown. It is this type of recording that is desired and is controlled in accordance with the present invention. When the synchronization is such that the droplets pass between plates **109** during change of the charging voltage creating the step, as in the case of drop **153***a*, FIG. **2**, then the resultant bars degenerate to be of character such as represented by bars **124***a*, **124***b*, and **124***c*, FIG. **5**.

More particularly, clock **316** applies a high frequency clock signal (for example, 48 kilocycles by way of channel **318** to sinewave generator **331**. Generator **331** thus provides a synchronized 48 kilocycle sinewave which is applied by way of channel **332** as the crystal excitation voltage to crystal **105**. Clock **316** also applies a 48 kilocycle drop clock signal by way of channel **317** to phase-shift unit **315**, the operation of which will be described later. Phase-shift unit **315** applies a delayed 48 kilocycle drop clock signal by way of channel **330** to function generator **319**.

During each printing cycle, function generator **319** provides a positive charging voltage to the charging plates **109** when bars are to be printed. When a space is desired on the document, the charging voltage will be zero and the charging plates **109** will be at zero potential, thus allowing all drops to pass to the ink catcher **112**.

The clock signal on channel **330** is applied to drop counter **321**. Drop counter **321** applies a bar rate through channel **322** to stairstep generator **323**. In one form counter **321** was a 3-stage, divide-by-two counter having 3 output lines for output pulses which were applied, one pulse per drop, to generator **323**. Generator **323** is a digital-to-analog converter that generates a stairstep voltage level, one level for each of eight pulses from counter **321** per bar, thus producing bars of eight drops each.

The stairstep output is applies through channels **324** to write amplifier **326** whose output is a stairstep waveform such as shown in FIG. **2**.

When the voltage on the charging plates is a stairstep waveform and droplets are charged on each step, a perfect bar may be formed on the document.

For each bar to be printed computer **336** applies a print command signal through channel **337** to amplifier **326**. Amplifier **326** applies the stairstep charging voltage through channel **328** to the charging plates **109**. In one embodiment, when the 48 kilocycle signal was used, the voltage is held for a period of approximately 20.8 microseconds at each step in order capacitively to charge each droplet at the instant it breaks off from the ink-jet stream. The charging voltage decreases finite voltage increments properly to charge each of the droplets in the bar. After each droplet has been charged it is individually deflected by the field between plates **110** and **111** in direct proportion to the applied charge on the droplet.

Gating for amplifier **326** may be from suitable control device such as a digital or analog computer. For purpose of this description, such unit has been designated as a control unit **336**. Control unit is enabled when a document is in transit past the printing station. Documents may be sensed by unit **339** which is connected to control unit **336** by channel **340**. When a bar is to be printed a voltage state as from a source **341** is applied to amplifier **326** by way of an AND gate **342** which energizes the control line **337**. For example, movement of a tape **343** through a reader portion of control unit **336** will produce control states on line **344** in accordance with the set **345** which corresponds with bars **114**, **114***a* and **114***b*.

When the next card is sensed set **346** will be printed thereon and set **347** on the next card, etc.

The present invention prevents deterioration of the bars by providing phase control to correct any change in the time-phase relationship between the droplet breakoff point and the charging voltage.

More particularly, the phase-control system employs a servo loop to change the delay in the synch signal passing from clock **316** to counter **321** by way of the phase-shift unit **315**. This phase-control system operates between documents so that normal printing operations are not affected. The phase-control operational period is hereinafter referred to as the calibration period.

It will be noted that the bar rate signal output of drop counter **321** is also applied by way of channel **334** to ramp generator **335**. Generator **335**, when enabled, converts the bar rate signal to a sawtooth waveform and applies the sawtooth signal by way of channel **325** to a calibration amplifier **327**. During the calibration period, control unit **336** applies a calibration command instruction through AND gate **348** and channel **338** to amplifier **327**. Amplifier **327** then applies a sawtooth charging voltage by way of channel **329** to charging plates **109**. The sawtooth voltage serves as the drop charging voltage during the calibration period.

The charging voltage or calibrate waveform is shown in FIG. **3**. This negative calibrate waveform changes from zero to about −200 volts and capacitively charges each drop with a positive charge. The drops apply a positive potential to catcher **112**. The charged droplets are analogous to an electrical current since they constitute the movement of charges past a given point in a given time interval. Catcher **112** is isolated from electrical ground and insulated from plate **110**.

The voltage created on catcher **112** as a result of collection of the charged droplets is applied through channel **300** to phase detector **301** wherein it is compared by amplifier **302** to a reference voltage. A reference voltage of approximately 200 millivolts has been found to be satisfactory, the same being produced on channel **303** by unit **304**. The reference voltage may be selected to represent the desired phase relationship of the droplet breakoff point to the charging voltage. If the voltages on lines **300** and **303** are not equal, the resulting error voltage is amplified and applied by way of channel **305** to analog-to-digital converter **306**. If the error voltage indicates a high condition, converter **306** generates an "up" phase error voltage signal on output channel **307**. Conversely, a low condition causes converter **306** to generate a "down" phase error voltage signal on output channel **308**.

The phase error voltages on channels **307** and **308** are applied to accumulator **309**. Accumulator **309** is a seven-bit, up-down counter used as an integrator or loop filter in a servo loop.

After the end of each document, as synchronized by way of channel **349**, a clock pulse from the accumulator clock **310** is applied by way of channel **311** to accumulator **309**. Upon receiving the clock pulse, accumulator **309** causes the up-down counter to increase up or down one count depending on whether an up or down phase error signal is received from phase detector **301**. The accumulator increments only during the calibration period between documents.

The signal from the accumulator **309** is applied over channel **312** to digital-to-analog converter **313** which converts the stored error voltage to a phase-control voltage on channel **314**. Channel **314** applies the phase-control voltage to phase-shift unit **315**.

Phase-shift unit **315** controls the phase delay between the charging voltage output of generator **319** and the crystal excitation voltage output of generator **331**. This phase delay is controlled by the phase error voltage signal from converter **313**. If an error is detected by phase detector **301** between the voltage applied to catcher **112** during the calibrate period and the reference voltage of generator **304**, the resulting phase error voltage produced in converter **313** applied to phase-shift unit **315** automatically to delay the 48 kc. drop clock signal output of phase-control unit **315** to the function generator **319**. Phase-shift unit **315** controls the time-phase relationship between the charging waveform to charging plates **109** and the breakoff point of ink droplets emerging from nozzle **107**.

Having described the invention in connection with the foregoing embodiment thereof, it is to be understood that further modifications may now suggest themselves to those skilled in the art, and it is intended to cover such modifications as fall within the scope of the appended claims.

We claim:

1. In an electrostatically deflected ink jet printer, the method of compensating for variation in the time-phase relation between a periodic driving function and resultant drop formation which comprises:
   - a. establishing alternate print cycle conditions and calibration cycle conditions;
   - b. generating repeated stair step functions synchronized with the resultant drop formation for establishing an electrostatic droplet charging field during the print cycle;
   - c. generating ramp functions synchronized with the resultant drop formation for establishing an electrostatic droplet charging field during the calibration cycle; and
   - d. adjusting the phase of said stair step functions relative to the resultant drop formation in response to prior variations in charges on the formed droplets during the calibration cycle as a result of the electrostatic charging field established by the ramp functions.

2. A system for compensating for variations in the time-phase relation between a periodically actuated drop forming unit and the instant of drop formation by said unit in an electrostatically deflected ink jet printer which comprises:
   - a. charging means for establishing an electrostatic droplet charging field;
   - b. first means for generating repeated stair step functions synchronized with said drop forming unit and connected to said charging means;
   - c. second means for generating ramp functions synchronized with said drop forming unit and connected to said charging means;
   - d. means to render said first means and said second means alternately effective to control the charge of said droplets; and
   - e. a phase shift unit for adjusting the phase of said stair step functions relative to said drop forming unit in response to prior variations in charges on said droplets due to said second means.

3. A system for compensating for variations in the time-phase relation between a periodically actuated drop forming unit and the instant of drop formation by said unit in an electrostatically deflected ink jet printer which comprises:
   - a. charging means for establishing an electrostatic droplet charging field;
   - b. means for establishing a uniform deflection field through which said droplets travel;
   - c. a droplet catcher;
   - d. first means for generating repeated stair step functions synchronized with said drop forming unit and connected to said charging means;
   - e. second means for generating ramp functions synchronized with said drop forming unit and connected to said charging means;
   - f. means to render said first means and said second means alternately effective to control the charge of said droplets; and
   - g. a phase shift unit connected to said catcher for adjusting the phase of said stair step functions relative to said drop forming unit in response to prior variations in charges on said droplets due to said second means.

4. The combination set forth in claim **3** wherein the means to render said first and second means alternately effective includes means operable between passage of documents through said printer to actuate said second means.

5. The combination set forth in claim **3** wherein means are provided for comparing the voltage on said catcher with a predetermined reference voltage and for setting a delay interval in said phase-shift unit in dependence upon the results of said comparison.

6. The combination set forth in claim **3** wherein an alternating current supply is connected to said drop-forming unit to produce a droplet on each cycle thereof and wherein a system clock controls both said supply and said generators, and wherein said phase-shift unit is connected between said system clock and said generators.