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"IMPROVEMENTS IN OR RELATING TO DC MOTOR DRIVEN SERIAL
PRINTERS AND PRECISION AUTOMATIC CARRIAGE CONTROL APPARATUS
THEREFOR"

This invention relates to DC motor driven serial printers and to automatic control apparatus for effecting precision control of the speed of movement of the carriage of such a printer. As will be more clearly appreciated later the invention seeks to provide automatic precision carriage control apparatus of relatively low cost, high performance and high precision and accuracy.

The invention is illustrated in and explained with the aid of the accompanying drawings, in which:-

Figure 1, which is provided for purposes of preliminary explanation, is a simplified block diagram of a known phase-locked loop control apparatus which has certain disadvantages to be described later herein,

Figure 2, which does not show a known apparatus, is also provided for purposes of preliminary explanation. Figure 2 shows the apparatus of Figure 1 modified in accordance with another invention made by the inventor of the subject of the present invention, by the addition thereto of an acceleration feedback loop for eliminating undesired oscillation effects liable to occur with the unmodified phase-locked loop control apparatus shown in Figure 1;

Figure 3 is an explanatory graphical figure illustrating, for purposes of comparison, the speed/time response curve obtained with a phase-locked loop control apparatus shown in Figure 1 and the speed/time response curve obtained with the modified control apparatus having an acceleration feedback loop and as illustrated in Figure 2;

Figure 4 is a simplified block diagram of a preferred form

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of carriage control apparatus embodying the present invention;

Figure 5 is a graphical diagram explanatory of the operation of the embodiment shown in Figure 4; and

Figure 6 shows the embodiment of Figure 4 in circuit
5 diagram form.

Like references denote like parts in the drawings.

Analog-type apparatus employing a tachometer generator has been widely used for the automatic precision control of the carriages of serial printers driven by D.C. motors. Digital type
10 detectors such as rotary encoders, linear encoders and the like have become readily available in recent years, and accordingly, control systems of the digital type utilizing such detectors have found increasing usage for printer carriage control. Because of its good control precision and relatively simple
15 circuitry, digital control apparatus of the phase-locked loop type and which compares the phase of signals from a settable reference oscillator producing a reference frequency dependent on the speed setting with that of signals from an encoder driven by the motor has been used to provide digital signals for directly switching
20 voltage applied to the motor for speed and direction of movement control of the carriage.

Figure 1 is a simplified block diagram of a typical known control apparatus as just described for providing precision automatic speed control of a printer having a carriage 13 driven
25 by a D.C. motor 4 by means of a belt running over pulleys 14 and

printing on paper 15. The illustrated control apparatus of Figure 1 includes a phase detector 2 for detecting the phase difference between reference speed pulses appearing on the output lead 6 of a reference oscillator 1 and a train of speed-dependent pulses which appear on the output lead 7 of an encoder 5 coupled to the D.C. motor 4 driving the printer. The speed and direction of rotation of the D.C. motor 4 is controlled by a switching circuit 3 controlled by pulse signals which are fed over lead 8 from the comparator 2 and the duty cycle of which varies in dependence on the detected phase difference.

Control systems as illustrated by Figure 1 have been widely employed because they have the advantages that reference oscillators such as 1 and phase comparators such as 2 are readily available in the integrated circuit form and switching circuits such as 3 can easily be composed of transistors; they are of quite high control accuracy as regards the controlled speed since this is determined by the stability of the reference oscillator 1, and the circuitry and the motor have only relatively small losses and therefore generate acceptably small amounts of heat. However, known control systems as illustrated by Figure 1 have the disadvantage that their high control loop gain, which cannot easily be changed, makes them undesirably liable to oscillate, with consequent poor stability. This disadvantage is particularly troublesome in those cases in which the control system is used in an apparatus for controlling the speed of the carriage of a serial

printer designed for high-speed response since, in such a printer, the frictional loading and the inertia of the moving parts are kept low so as to be small having regard to the output of the motor used. The practical result of instability is the production of oscillatory effects which cause irregular dot intervals and poor printing quality in dot impact printers and ink jet printers of the serial type designed to print with high dot densities in order to achieve a high quality of printing.

Although the above difficulties could be eliminated by a sufficient reduction in the control loop gain, the adoption of this expedient would involve not only undesirable complication of circuitry but also considerable reduction in the precision and accuracy of the automatic speed control.

The inventor of the invention the subject of the present application, has made another invention (which a Japanese Patent Application No. 56-9974 was filed to protect), which sought to improve stability and suppress consequent undesirable oscillatory effects in the carriage controlling apparatus by providing additional simple circuitry which enables this to be done without lowering the loop gain. Figure 2 is a block diagram illustrating this other invention. In Figure 2, the difference signal appearing on lead 8 from the phase detector 2 is converted by a circuit including a low-pass filter 9 into an analog speed signal which appears on lead 11 and which is then converted by a differentiating circuit 10 into what may be termed an acceleration

signal which appears on lead 12. This acceleration signal is employed to modulate the frequency of the output signal from the reference oscillator 1. The control system illustrated by Figure 2 is functionally equivalent to a speed control apparatus comprising an analog circuit including an acceleration feedback loop, and has the advantage that it improves stability without reducing the rapidity of response and high precision and accuracy possessed by the phase-locked loop control apparatus of Figure 1. Figure 3(a) shows at 16 a typical speed/time response curve for a phase-locked loop control apparatus as illustrated by Figure 1, and Figure 3(b) shows at 17 a typical speed/time response curve for a control apparatus as illustrated by Figure 2. In both Figures 3(a) and 3(b), the horizontal line 18 represents a speed setting (means for changing the speed setting are not shown in Figures 1 and 2) and the curves illustrate changes of speed occurring following an initial stopped condition at an initial time 0 when a speed setting signal for the speed setting 18 is applied. As will be apparent from a comparison of Figure 3(a) and Figure 3(b), the difference between the two speed/time characteristics lies in the elimination, from Figure 3(b) of the oscillations present in Figure 3(a), the two characteristics being alike in other respects.

Before proceeding to description of the present invention, it should be pointed out that the apparent overall printing speed of a serial printer can be substantially increased if the control

of the carriage is such as to cause it to move at high speed during intervals in which no actual printing is required and also to move at high speed, after printing a line, to the next printing start position. With this fact in mind the present invention seeks among other objects, to provide a control apparatus which has an improved and rapid response at times when the carriage speed is required to be reduced, and which operates at such times to cause the required lower speed to be rapidly attained without the necessity of providing a mechanical braking device for the purpose.

According to one aspect of this invention an automatic precision control apparatus for the carriage of a D.C. motor driven serial printer includes a phase-locked loop speed control circuit including an acceleration-dependent frequency modulation feedback loop which modulates the set frequency of a settable source of reference oscillations the phase of which is compared with the phase of signals produced by a signal generator driven by the motor to produce phase difference representative signals which are converted and fed into said settable source of reference oscillations; and a mode selection circuit to which phase difference representative signals are supplied and which includes means for producing a braking effect on the motor by reversing the polarity of the energising voltage supplied thereto in order to reduce the speed of the carriage rapidly when the mode selected involves reduction of the carriage speed.

According to another aspect of this invention an automatic precision control apparatus for the carriage of a D.C. motor

driven serial printer includes a signal generator driven by the motor, a settable reference oscillatory source, phase comparing means for producing signals representative of the phase difference between output signals from said generator and signals from said source, means for differentiating said phase difference representative signals to produce acceleration representative signals and utilising the same to modulate the set frequency of said source, a switching circuit subjected to control by said phase comparing means and controlling the voltage which is supplied to the motor and which determines the speed and direction of movement of the carriage, and mode selection means including means for producing, in accordance with the mode selected, a braking effect on the motor, by reversing the polarity of the motor energising voltage thereby slowing the carriage quickly.

Figure 4 is a simplified block diagram of one embodiment of the present invention. As will be seen from a comparison of Figures 2 and 4, there is added, in Figure 4, a mode selection circuit 19 interposed between the phase detector 2 and the switching circuit 3. The reference oscillator 1 receives at 24 input signals which serve the purpose of changing the reference oscillator frequency in order to change the speed setting. The output frequency appearing on lead 6 from the oscillator 1 is determined by the speed setting signal supplied to the oscillator 1 at 24. If a speed setting signal is applied at 24 to change the speed setting to a higher speed than that which

was set before application of said signal a phase-advanced signal appears on the output lead 8 from the phase detector 2 (when the phase of the oscillator output signal on lead 6 is leading with respect to that of the encoder output signal on lead 7), and is supplied through the mode selection circuit 19 and channel 20 to the switching circuit 3 to increase the speed of rotation of the motor 4 to the increased speed now set. On the new, higher, speed setting accurate and precise control of the motor speed is obtained and undesirable oscillatory effects are avoided by an automatic control process which is the same as that already described with reference to Figure 2. If, however, there is applied at 24 a speed setting signal which is such as to reduce the set speed to a lower value than that previously set, a speed reduction signal is applied to lead 25 at the same time that the new (reduced speed) setting signal is applied at 24. The signal fed in at 25 is applied to what may be called a "braking" flip-flop 23 and sets it, causing it to produce on lead 21 an output signal which causes the mode selection circuit 19 to switch its input over from the lead 8 to the lead 22, on which appears a phase-delayed signal (when the phase of the oscillator output signal is lagging with respect to the encoder output signal on lead 7). This causes reversal of the polarity of the input to the mode selection circuit and a braking effect rapidly reducing the speed of the carriage is obtained purely electrically because of the consequent reversal of the polarity

of the voltage supplied to drive the motor. As the phase-advanced signal 8 is generated when the motor speed becomes lower than the speed setting, the flip-flop 23 is reset to effect switching in the mode selection circuit 19 for re-entering the control mode existing prior to braking. As will be seen, the control ensures that substantially the same rapid response during acceleration as during deceleration is obtained. Figure 5 graphically illustrates the operations which take place when the speed settings are changed. If a speed setting signal applied at 24 is changed from level 0 to level 28 at a time 31, the speed automatically controlled by the control apparatus increases from a level 0 to a level 30 as shown by the curve 26. If, at a time 32, the speed setting signal at 24 is increased to a level 27, the speed (see curve 26) automatically controlled goes up to a level 29. If, at a time 33, the speed setting signal at 24 is reduced to the level 28 again, the automatically controlled speed is reduced to the level 30 as shown by the full line curve 26. The broken line 34 shows, for comparison purposes, the way in which this speed reduction would occur if the circuitry in Figure 4 additional to that in Figure 2 were not provided i.e. without use of the present invention. It will be at once apparent that the time taken to effect speed reduction is much longer with the broken line curve 34 than with the full line curve. The remainder of Figure 5 shows, at 8, 22, 25 and 21 signals

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appearing at places so referenced in Figure 4.

Figure 6 is a circuit diagram of the embodiment shown in block diagram form in Figure 4. Referring to Figure 6, block 101 is an integrated circuit reference oscillator capable of being frequency modulated by an acceleration signal fed to it over lead 12 from the low pass filter in block 9. The oscillator 101 supplies over lead 38 an output signal which is frequency-divided by a programmable frequency divider 37. The divider 37 divides down the input frequency it receives from the oscillator to a frequency which is determined by the speed setting signal fed in at 24 and supplies its output over lead 6 to the phase detector 2 which detects the difference in phase between the output signal on lead 6 and the signal, applied at 7, from the encoder 5 (not shown in Figure 6). The phase difference signals from the phase detector 2 are converted into analog signals by means including a suitable circuit 39, known per se (it may be a capacitative circuit of the charge-discharge relaxation type) and a low pass filter arrangement 9 which includes resistors 41, 42, 44, a capacitor 43 and an amplifier 40. The analog speed signal appears on the filter output lead 11 and is converted into the acceleration signal on lead 12 by a differentiating circuit 10 comprising capacitor 46 and resistor 45. The part of the circuit enclosed by the broken line 47 may be constituted by a commercially available integrated circuit structure designed for phase-locked loop control. A signal applied at 35 serves to

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determine the direction of movement of the carriage 13 (not shown in Figure 6 but see Figure 4). The mode selection circuit is in block 19 and is responsive to the signal 35 and to an output signal which is supplied to it over lead 21 from the braking flip-flop 23. As already stated in the description of Figure 4, the mode selection circuit switches its input between the phase-advanced signal on lead 8 and the phase-delayed signal on lead 22. The said mode selection circuit 19, which is composed of gates represented by the usual conventional symbols and connected as shown, supplies outputs over leads 20 to operate the switching circuit 3 controlling the polarity and times of supply of the voltage driving the motor 4. The circuit elements in the switching circuit are again represented by conventional symbols and are connected as shown. In block 36 is a current limiter circuit of form known per se and which serves to prevent the flow of excessively large currents when the direction of motor rotation is reversed or the motor is started from rest. As the motor has to reverse the direction of movement of the carriage or start it from rest at frequent intervals, the provision of the current limiter is very advantageous in ensuring a long service life.

The values of the elements 43 and 44 in the low-pass filter 9 are so chosen that the band width of the filter is suitably lower than the frequency of the encoder signal corresponding to the speed setting but wide enough to pass the natural frequency

of the control system. The said natural frequency can be calculated or found experimentally by actual measurement in any particular case. The resistor 42 serves for high-frequency compensation, and is chosen to be of a value suitably smaller than that of the resistor 44. The ratio of the values of resistors 41 and 44 provides a design parameter for determining the damping ratio of the control system. The time constant of the differentiating circuit 10 is determined by the product of the value of resistor 45 and that of the capacitor 46, and is chosen at such a value as to produce a differentiation effect on the natural frequency of the control system.

As will now be seen the improved apparatus illustrated in Figure 6 for controlling the carriage of a serial printer driven by a D.C. motor includes a phase locked loop automatic speed control system, with an acceleration signal detecting circuit the output from which effects frequency modulation of the reference oscillator. It is stable in operation, substantially free of oscillation effects and of high speed controlling precision and accuracy. In addition there is a mode selection circuit which operates to produce a braking effect on the motor by reverse energisation thereof during intervals which start at a moment of change of the speed to a lower value and continues until a phase difference signal is detected, thus shortening the time required to change speed and resulting in substantial improvement of printing quality when printing with high density

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dots and enabling an increased overall apparent printing speed to be achieved.



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CLAIMS

1. An automatic precision control apparatus for the carriage of a D.C. motor driven serial printer, said apparatus including a phase-locked loop speed control circuit including an acceleration-dependent frequency modulation feedback loop
5 which modulates the set frequency of a settable source of reference oscillations the phase of which is compared with the phase of signals produced by a signal generator driven by the motor to produce phase difference representative signals which are converted and fed into said settable source of reference
10 oscillations; and a mode selection circuit to which phase difference representative signals are supplied and which includes means for producing a braking effect on the motor by reversing the polarity of the energising voltage supplied thereto in order to reduce the speed of the carriage rapidly when the
15 mode selected involves reduction of the carriage speed.
2. An automatic precision control apparatus for the carriage of a D.C. motor driven serial printer, said apparatus including a signal generator driven by the motor, a settable reference
20 oscillatory source, phase comparing means for producing signals representative of the phase difference between output signals from said generator and signals from said source, means for differentiating said phase difference representative signals to produce acceleration representative signals and utilising the same to modulate the set frequency of said source, a switching
25 circuit, subjected to control by said phase comparing means, and controlling the voltage which is supplied to the motor and which



determines the speed and direction of movement of the carriage and mode selection means including means for producing, in accordance with the mode selected, a braking effect on the motor, by reversing the polarity of the motor energising voltage thereby slowing the carriage quickly.

3. Apparatus as claimed in claim 1 or 2 wherein the motor driven generator is a encoder driven by the motor.

4. An automatic precision control apparatus for the carriage of a DC motor driven printer said apparatus including a phase detector detecting the phase difference between signals from a signal generator driven by the motor and signals derived by means of a programmable frequency divider from a reference oscillator, said detector providing output pulse signals having a duty cycle varying in dependence on the detected phase difference; a converting circuit converting said output pulse signals into analog signals; a low pass filter circuit to which said analog signals are fed; a differentiating circuit which receives output from said filter circuit and modulates the frequency of said oscillator; means for applying setting signals to said programmable frequency divider to set the frequency fed thereby to the phase detector; a mode selection circuit receiving output pulse signals from the phase detector and controlling the operation of a switching circuit controlling the energising voltage supplied to the motor; and means actuated when the speed of movement of the carriage is required to be reduced, for effecting such reduction rapidly by producing a braking effect on the motor by reversing the polarity of the energising voltage applied thereto.



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5. Apparatus as claimed in claim 4 wherein the last mentioned means comprise a flip-flop which is set by a signal applied thereto at the same time that a setting signal is applied to the programmable frequency divider and which, then, under the control of the output from the phase detector switches over selectable input leads of the mode selection circuit to cause polarity reversal of the input to the mode selection circuit and consequent polarity reversal of the voltage supplied to the motor thereby rapidly slowing the carriage movement.

6. Apparatus as claimed in any of the preceding claims and including a current limiting circuit in a circuit through which energising voltage is supplied to the motor.

7. An apparatus for controlling the carriage of a D.C. motor driven serial printer comprising: a phase-locked loop speed control circuit composed of an encoder detecting the rotational speed of the D.C. motor; a reference oscillator providing reference speed pulses; a phase comparator for detecting phase difference between the output from the encoder and the output from said reference oscillator; a switching circuit controlled by output from the phase comparator for switching voltage applied to the motor; a feedback circuit in which is a low pass filter receiving output from said phase comparator and a differentiating circuit receiving output from said low-pass filter, said feedback circuit



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- effecting frequency modulation of the output from said reference oscillator by an output signal from said differentiating circuit; speed setting switching means for switching the rotational speed of the motor by changing the oscillation frequency of the reference oscillator; and a mode selection circuit effecting speed setting control of the motor, reversal of the direction of rotation thereof and mode selection of braking in response to which mode is selected.
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- 10 8. Apparatus for controlling the motor of a DC motor driven serial printer substantially as herein described with reference to Figures 4, 5 and 6 of the accompanying drawings.
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