

[54] **ADAPTIVE MOTOR ACCELERATION**
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[51] Int. Cl. **H02p 1/04, H02p 3/08**
[58] Field of Search **318/270, 271, 274, 369, 318/396, 397, 398, 450, 463, 464, 612, 618, 603**
[56] **References Cited**
UNITED STATES PATENTS
3,737,751 6/1973 Lima 318/398

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Assistant Examiner—Thomas Langer
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[57] **ABSTRACT**

A magnetic tape unit's DC capstan motor is closed-loop speed controlled from a rest position to a steady-state speed and is subsequently controlled from the steady-state speed to a rest position. The motor's acceleration and/or deceleration profile, during the acceleration and/or deceleration interval, is adaptively defined by a read-only-store, or memory. An address counter selects a unique command speed from the store at the occurrence of an output pulse from the motor's digital feedback tachometer. The address counter begins counting as soon as a motor start and/or stop command is received. In this manner, the addresses used during a given acceleration and/or deceleration interval are adaptively variable in accordance with the unique motor rest position from which acceleration begins, and/or the motor's unique position from which deceleration begins, as these positions relate to time-subsequent or adjacent digital tachometer pulses.

21 Claims, 8 Drawing Figures

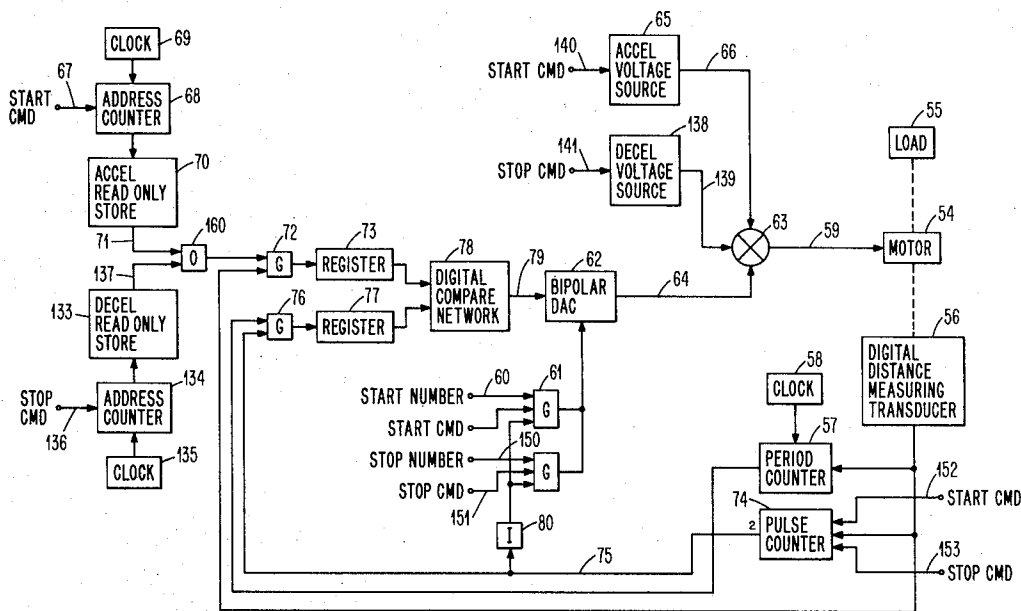


FIG. 1

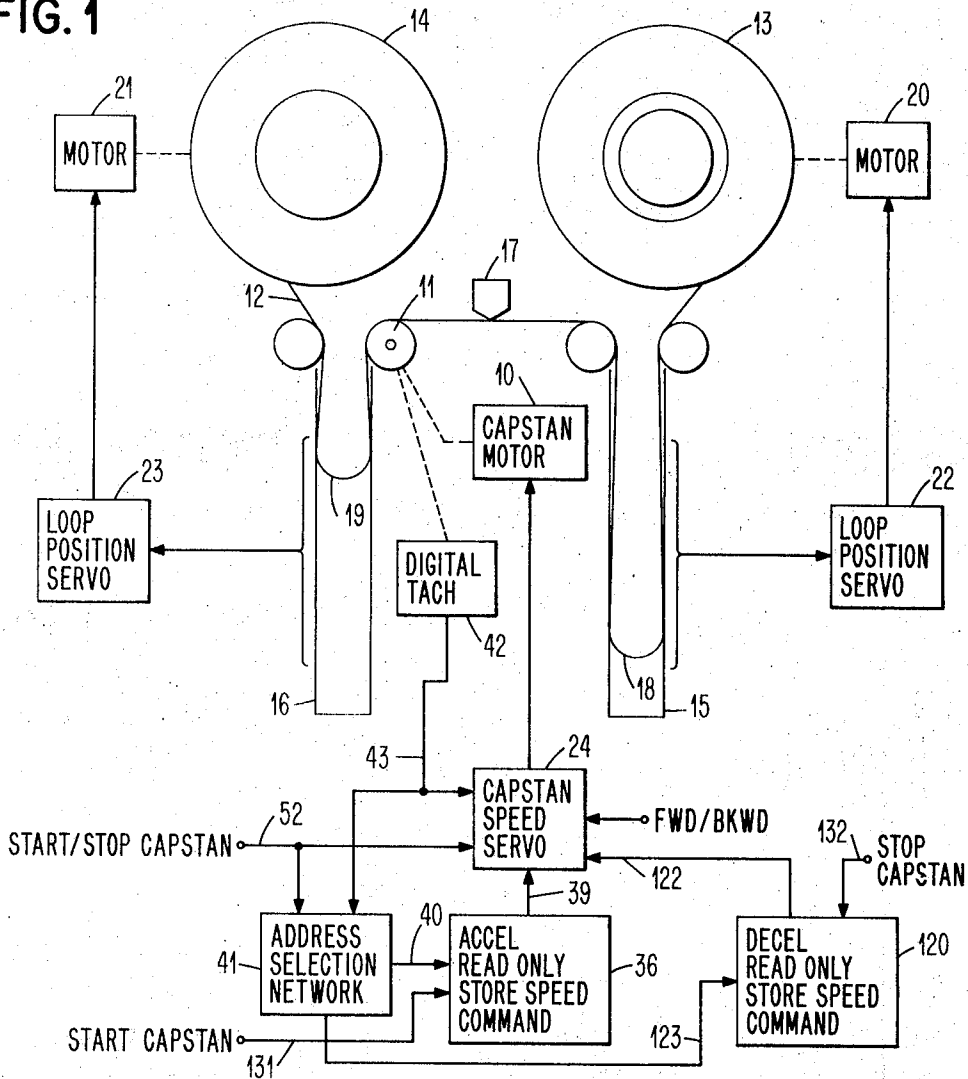


FIG. 2

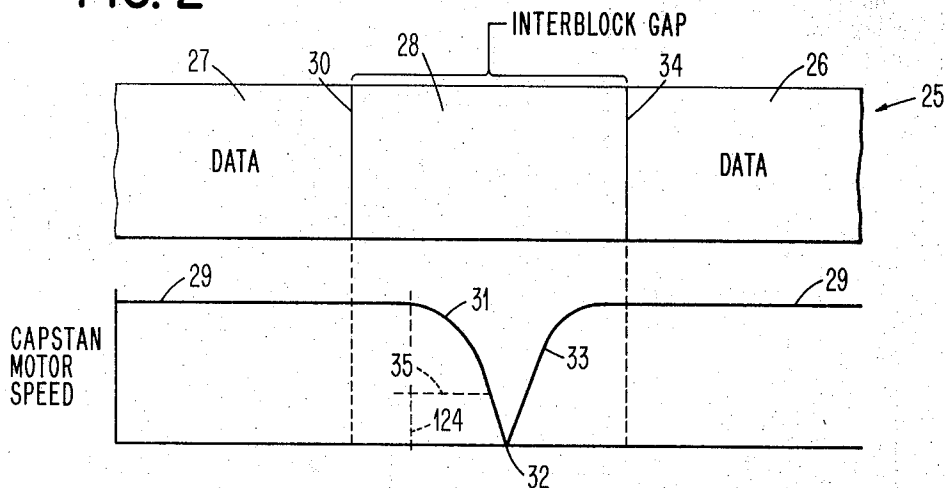


FIG. 3

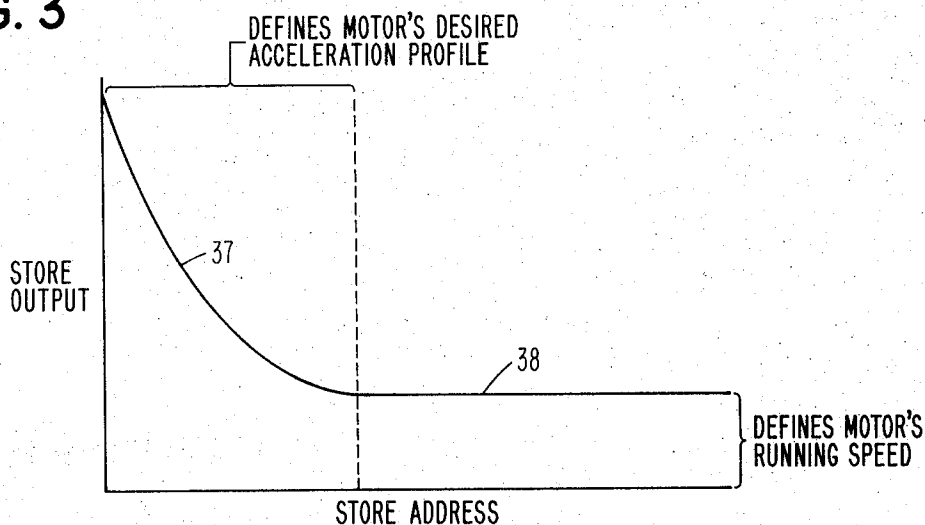


FIG. 4

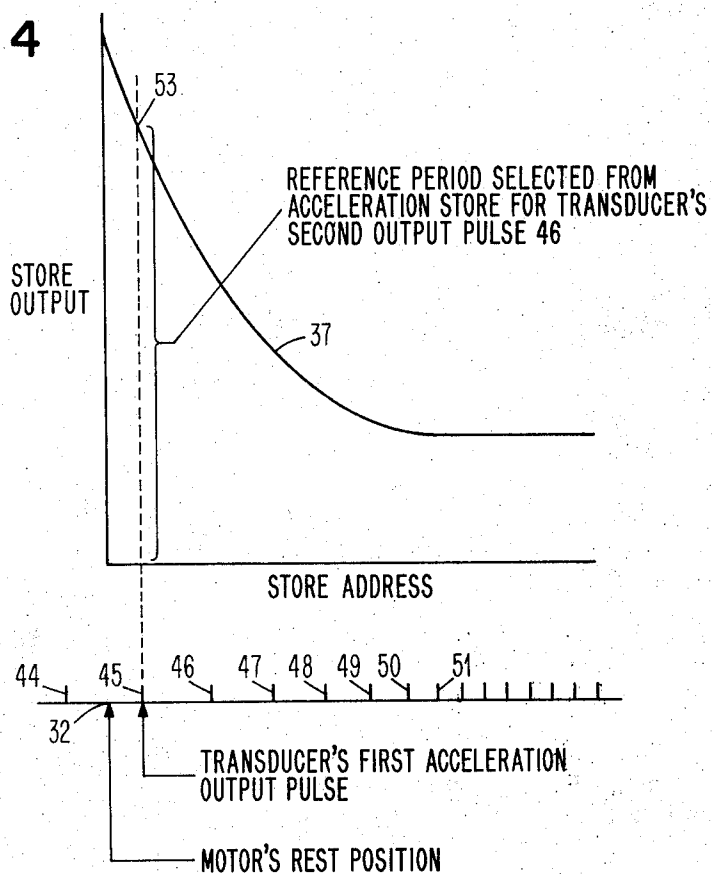


FIG. 5

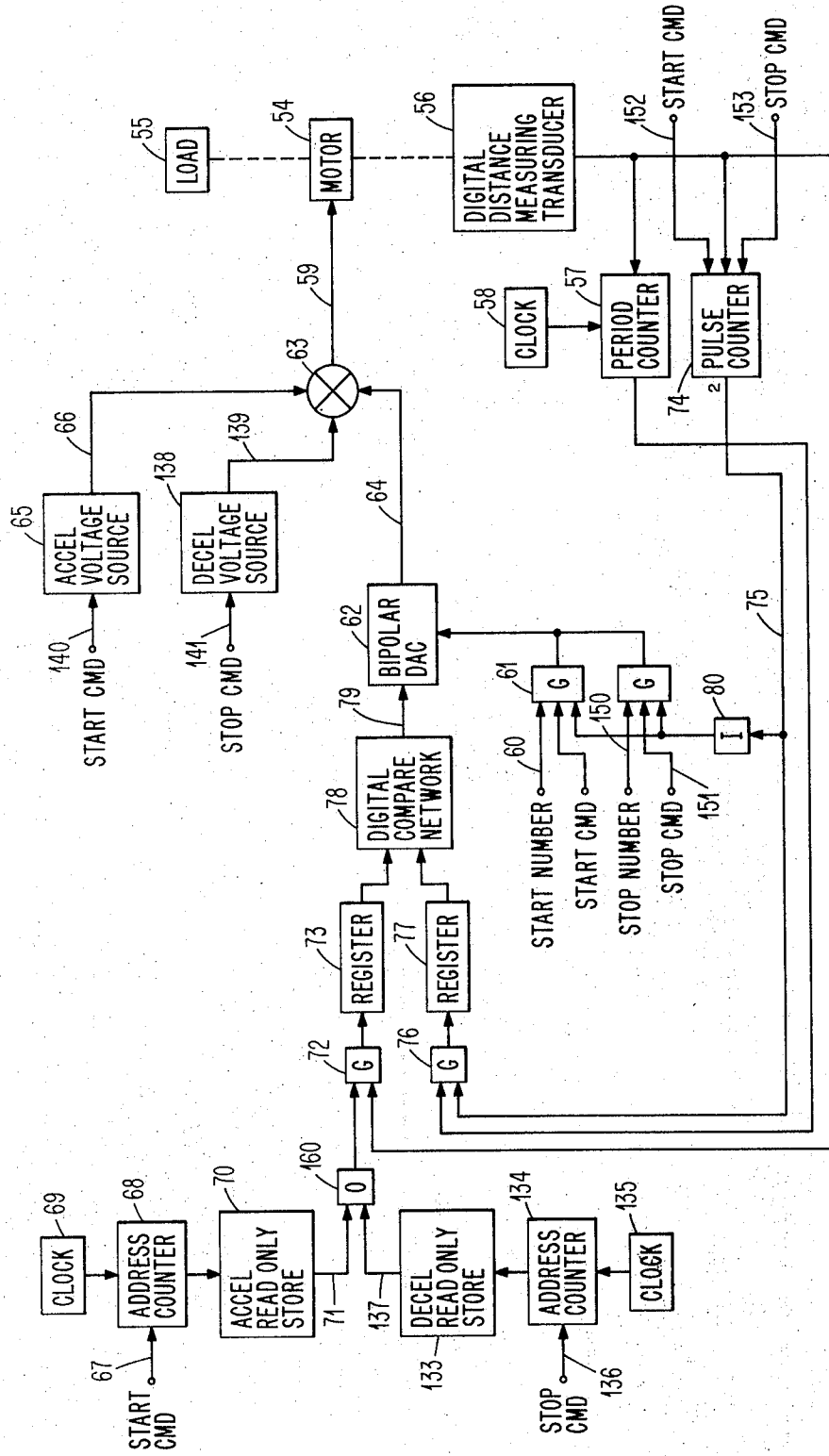


FIG. 6

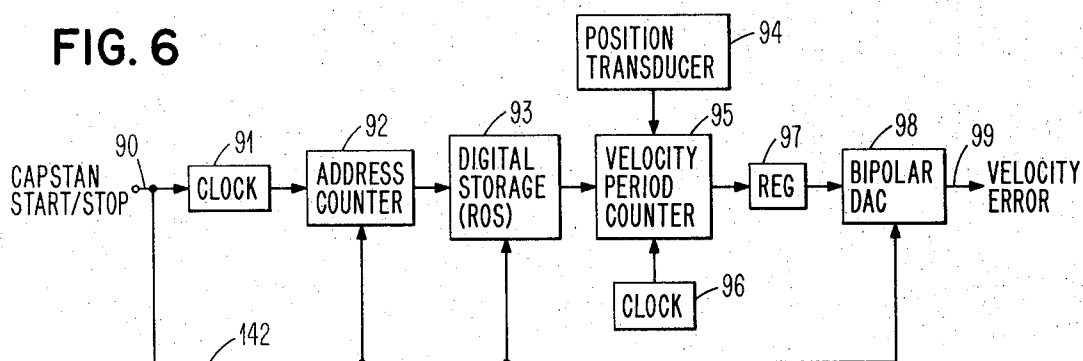


FIG. 7

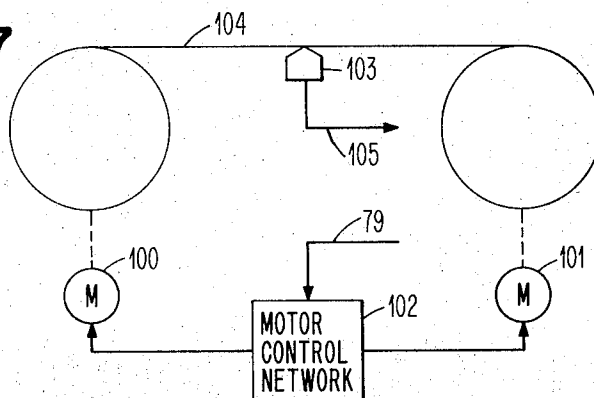
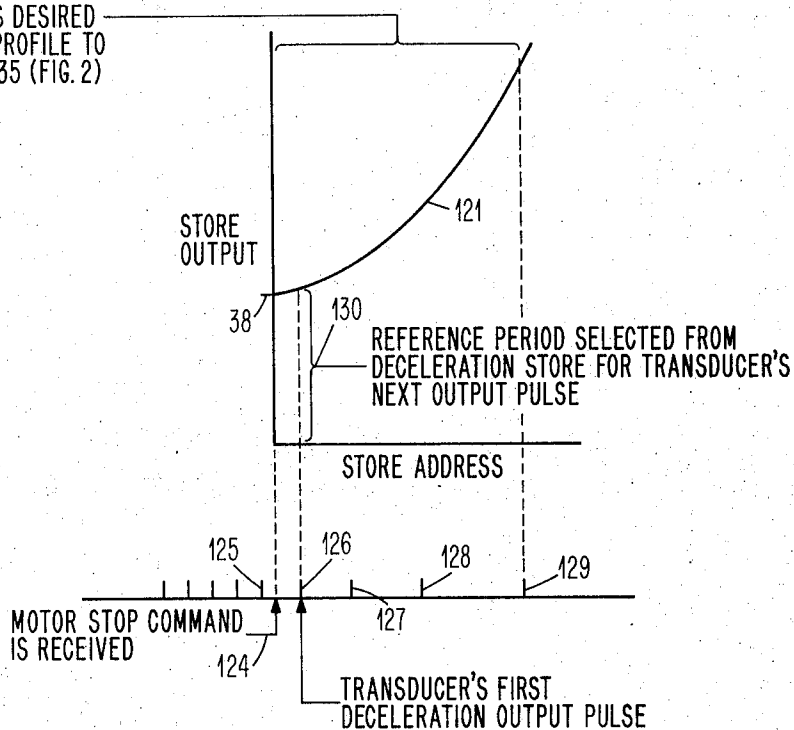


FIG. 8

DEFINES MOTOR'S DESIRED
DECELERATION PROFILE TO
TARGET SPEED 35 (FIG. 2)



ADAPTIVE MOTOR ACCELERATION

BACKGROUND AND SUMMARY OF THE INVENTION

This invention relates to the field of motive power systems of the electrical type, and particularly to an electrical motor control or servomechanism having an acceleration and/or deceleration control feature. This invention is more specifically related to the field of closed-loop, sampled-data motor speed servomechanisms which operate in a start/stop mode. Such servos provide motor speed feedback samples which are calculated during relatively long sample times as the motor is accelerating and decelerating, as compared to the sample times during the period of steady-state motor speed operation. That is, the sample time is an appreciable portion of the total acceleration and deceleration interval. This invention finds particular utility in the acceleration and/or deceleration control of a magnetic tap unit's capstan motor.

As used herein, the term acceleration is defined as a speed change from one level, for example a rest state, to a higher level, for example a steady-state speed. The term deceleration is defined as a speed change from a second level, for example the above-mentioned steady-state speed, to a lower level, for example the above-mentioned rest state. The terms acceleration and deceleration are generically defined as a change in speed from one speed state to a different speed state.

Prior art is known wherein both the actual acceleration and deceleration profile of a motor is servo controlled to follow a predefined curve or profile.

One such prior art device incorporates a digital servo whose motor drives a digital tachometer. When a start command is received, a unique number is entered into a counter. As the motor accelerates, the tachometer's output pulses decrement the counter. At the end of a fixed time interval the content of the counter will be zero only if the motor is accelerating properly. The

content of the counter is a measure of acceleration error and is used to control motor energization. At the end of each such fixed time interval a new number is entered into the counter. The magnitude of this new number is equal to the number of tachometer pulses which should occur during the next sample time interval. In this manner, the motor's acceleration is controlled.

Another prior art device provides a store whose contents define the desired motor deceleration profile. The occurrence of a motor stop command is delayed, and deceleration is inhibited, until the subsequent occurrence of a digital tachometer pulse. The occurrence of this tachometer pulse enables the use of the store to control the motor's deceleration to follow the deceleration curve defined by the store.

The prior art ignores the fact that the motor's unique position, from which it begins its acceleration profile, or at which a stop command is received, is a variable position. That is, the unique motor position is variably spaced from the first tachometer pulse which will occur as the motor moves into its acceleration and/or deceleration profile.

As used herein the term unique motor position is generically defined as (1) the motor's rest position from which acceleration begins, and (2) the motor's position

at the time that a stop command is received and from which deceleration begins.

The present invention is an adaptive system in that the predefined desired acceleration and/or deceleration profile is dynamically used or addressed, for each individual start and/or stop occurrence, as a function of the distance from the motor's unique position, at which a start and/or stop command is received, to the first tachometer pulse. In this manner, the desired acceleration and/or deceleration profile is adaptively followed for each motor start and/or stop occurrence.

Specifically, the present invention utilizes an addressable memory means in the form of a read-only-store. The store content defines the motor's desired acceleration and/or deceleration profile. The store's output is the servo command parameter which is used to servo control motor acceleration and/or deceleration. This store is addressable, to thereby call out from the store a unique output in accordance with a unique address. An address selection network is controlled by the motor's digital tachometer. This selection network is operable to address the store on the occurrence of each tachometer pulse. In this manner, the store's output is uniquely related to the motor's unique position, that is, the position at which a start and/or stop command is received, as this position relates to the first tachometer pulse which occurs as the motor accelerates and/or decelerates.

More specifically, the address selection network is an address counter which is controlled by the occurrence of a motor start and/or stop command to begin counting at a fixed rate. For example, the counter is driven by a constant frequency clock and begins incrementing from an initial state. When a subsequent tachometer pulse occurs, the then-existing content of the counter is used to address the store. The store's output is constructed and arranged to define the time interval which should occur between that tachometer pulse and the next tachometer pulse. When the next tachometer pulse in fact occurs, the previously selected store output is compared to a period measuring means in the form of a period counter. The comparison results are then used to servo control motor energization so that the motor is forced to follow the desired acceleration and/or deceleration profile.

The foregoing and other features and advantages of the invention will be apparent from the following more particular description of preferred embodiments of the invention, as illustrated in the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a schematic showing of a single capstan magnetic tape unit embodying the present invention;

FIG. 2 is a graphical representation of a short length of tape and a typical capstan motor speed profile which is followed as the capstan decelerates from a steady-state speed to a rest position, and then accelerates from rest to the steady-state speed, to form the interblock gap (IBG) which separates two adjacent data blocks;

FIG. 3 is a graphical representation of FIG. 1's acceleration read-only-store content, showing the store's output related to the store's addresses;

FIG. 4 is a graphical representation, similar to FIG. 3, wherein a typical motor rest position is graphically related to the motor's digital tachometer pulses and to the operation of the address selection network which

addresses unique locations in the acceleration store in accordance with the relationship of the motor's rest position to its time-subsequent tachometer pulses;

FIGS. 5 and 6 are further schematic showings of the present invention, as it is used to control a motor such as the capstan motor of FIG. 1;

FIG. 7 is a schematic showing of the manner of utilizing the present invention, as disclosed in FIG. 5, to control the speed parameter of a reel-to-reel magnetic tape unit; and

FIG. 8 is a graphical representation of FIG. 1's deceleration read-only-store, showing the store's output related to the store's addresses, and showing a typical motor position at the time that a stop command is received, all of which are graphically related to the motor's time-subsequent digital tachometer pulses and to the operation of the address selection network which addresses unique locations in the deceleration store in accordance with the relationship of the motor's unique position to its subsequent tachometer pulses.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The single capstan magnetic tape unit shown in FIG. 1 utilizes the present invention to adaptively control the acceleration and/or deceleration of DC capstan motor 10. This motor is directly connected to bidirectional capstan 11. By way of example, this motor/capstan configuration may be of the type shown in U.S. Pat. No. 3,490,672 which issued to G. A. Fisher and H. E. Van Winkle. A length of one-half inch wide magnetic recording tape 12 runs between file reel 13 and machine reel 14. Two tape loops are buffered in vacuum columns 15 and 16, respectively. Again by way of example, the use of vacuum columns to isolate the low inertia capstan from the high inertia reels is disclosed in U.S. Pat. Nos. 3,057,568 and 3,057,569, issued to J. A. Weidenhammer and W. S. Buslik, and to J. A. Weidenhammer, respectively.

Tape processing station 17 is located between capstan 11 and vacuum column 15. This station may include a read/write head, an erase head, a tape cleaner and an end-of-tape/beginning-of-tape (EOT/BOT) sensor. The length of tape running between the two reels is maintained in tension by the vacuum force in columns 15 and 16. A wrap of tape is maintained about a portion of the circumference of capstan 11. In this manner, capstan movement is translated into tape movement, since the tape unit is constructed and arranged to insure that no tape slip occurs at the capstan/tape interface.

This magnetic tape unit operates under the control of a central processing unit, not shown. Capstan motor energization and deenergization (start/stop) occurs in a manner to read and/or write machine convertible information on tape 12 in accordance with commands received from the central processing unit. As a result of this servo control of motor 10, the position of tape loops 18 and 19, in columns 15 and 16 respectively, is disturbed. The position of the loops shown in FIG. 1 is the preferred position when the capstan is rotating in a counterclockwise direction, this being designated the forward tape direction. Reels 13 and 14 are directly connected to DC reel motors 20 and 21, respectively. These motors are servo controlled to maintain loops 18 and 19 at predetermined positions or zones within the vacuum columns, depending upon the direction of ro-

tation of capstan 11. As diagrammatically shown in FIG. 1, loop 18 is under the servo control of loop position servo 22 whereas loop 19 is under the servo control of loop position servo 23. By way of example, this manner of servo control may provide continuous sensing of the loop position, as in U.S. Pat. Nos. 3,027,059 and 3,122,332, issued to D. N. Streeter and F. G. Hughes, Jr., respectively, or may provide discrete zone sensing as in U.S. Pat. Nos. 3,550,878 and 3,673,473, issued to J. M. Crisp and R. W. Van Pelt, and to A. J. Werner, respectively.

The motion of capstan motor 10 is controlled by capstan speed servo 24. This speed servo variably controls the capstan motor energization to achieve the distance-speed profile graphically represented in FIG. 2. In this figure, a short length of magnetic recording tape 25 is shown as having two data blocks 26 and 27 separated by an interblock gap 28. Capstan motor speed is maintained at steady-state target speed 29 so long as the length of tape associated with tape processing station 17 is processing data within one of the blocks 26 or 27. Assuming that the tape is moving from right to left, and that data is being written thereon, when the read portion of tape processing station 17 reaches the boundary 30 between data block 27 and interblock gap 28, a "stop capstan" command is received and the mode of capstan motor energization is servo controlled to achieve deceleration 31. At this time the write portion of the tape processing station is positioned at point 124. As a result of the stop command, the velocity or speed profile of capstan motor 10 follows the deceleration profile shown by curve 31. The tape is brought to rest, that is zero speed, with the write portion of processing station 17 located at point 32 within the interblock gap. When a "start capstan" command is subsequently received by capstan speed servo 24, the capstan acceleration profile follows curve 33. As can be seen, the capstan reaches steady-state target speed 29 prior to the write portion of tape processing station 17 encountering the boundary 34 between the interblock gap and data block 26.

The mode of deceleration control hereinafter defined is such that the capstan motor is reverse energized, that is plugged, until the capstan reaches a target speed identified as 35 (FIG. 2), whereupon the capstan motor is thereafter allowed to coast to a stop or, alternatively, is dynamically braked to a stop at 32.

Adaptive motor acceleration is achieved for capstan motor 10 by way of read-only-store 36. Adaptive motor deceleration is achieved by way of read-only-store 120. By way of example, stores 36 and 120 may be a programmable ROS or may be the memory element of a mini computer. These stores are constructed and arranged to contain desired acceleration/deceleration profiles for capstan motor 10. For example, the acceleration profile is shown as 33 in FIG. 2, and in FIGS. 3 and 4; whereas the deceleration profile is shown as 31 in FIG. 2, and in FIG. 8.

With reference to FIG. 3, curve 37-38 defines the motion profile for capstan motor 10, including motor acceleration profile 37 and steady-state speed profile 38. The output of store 36, on conductor 39, FIG. 1, is provided in accordance with the address furnished to store 36 by way of conductor 40. This address is adaptively selected by address selection network 41, in accordance with the unique starting position 32 of the capstan motor in interblock gap 28.

With reference to FIG. 8, curve 121 defines the motion profile for capstan motor 10. Reference numeral 38 identifies the motor's steady-state speed. The output of store 120, on conductor 122, FIG. 1, is provided in accordance with the address furnished to store 120 by way of conductor 123. This address is adaptively selected by address selection network 41, in accordance with the unique position 124, FIG. 2, from which the motor begins following its deceleration curve 31.

More specifically, motor 10 is directly connected to a distance measuring device in the form of digital tachometer 42. This tachometer is the well known type which, for example, includes a transparent disk having a large number of alternating opaque and transparent sections evenly positioned about the circumference of the disk. This disk rotates with the capstan. An associated light source/photocell provides output pulses as this disk rotates. This pulse frequency is directly related to the speed of the capstan, that is, the faster the capstan is rotating, the higher is the pulse frequency. Obviously then, during initial acceleration of the capstan from a rest position, the time interval between adjacent tachometer pulses is relatively long, as compared to the time interval between these pulses when the capstan is running at its target steady-state speed. Also, during the latter portion of the deceleration interval, when the motor is running relatively slow, the time interval between adjacent tachometer pulses is relatively long. The adaptive nature of the present invention facilitates control of address selection network 41 and read-only-store 36, 120 in accordance with the variable starting position 32 of the capstan, and/or the variable position from which deceleration of the capstan begins, in relation to the first tachometer pulse which is received from tachometer 42 as the motor enters its acceleration and/or deceleration profile from these unique positions. The output of digital tachometer 42 appears on conductor 43 and is applied as an input to both capstan speed servo 24 and address selection network 41.

With reference to FIG. 4, the content of store 36, and particularly the acceleration portion 37 thereof, is shown associated with an exemplary series of digital tachometer output pulses 44-51. Pulse 44 is defined herein as a deceleration pulse, whereas pulses 45-50 are defined as acceleration pulses. Pulse 44 represents the last deceleration output pulse from tachometer 42 which occurred as the capstan motor sought rest position 32 while decelerating along its deceleration profile 31, FIG. 2. Subsequently, a "start capstan" command is received on conductor 52 of FIG. 1. The effect of this start command is to initially control capstan speed servo 24 in a manner to energize capstan motor 10, open loop, with a preselected level of energization known to cause optimum acceleration of the capstan, with no tape slip. In addition, this start command enables address selection network 41 to begin its address calculation for read-only-store 36. More specifically, address selection network 41 calculates, measures or determines the time interval between the occurrence of a start command, and the resulting simultaneous starting of motor 10, and the first tachometer acceleration pulse 45 which is received from digital tachometer 42 as the capstan motor accelerates from its rest position. This unique address, which is an unknown variable since the motor may have started from any position 32 between adjacent tachometer pulses 44 and 45, selects a unique output from read-only-store 36 to be used by

capstan speed servo 24 as a speed command. This speed command is compared to the actual capstan speed, which is calculated by sampled data techniques between tachometer pulses 45 and 46. With specific reference to FIG. 4, the command speed selected from store 36 at the occurrence of first tachometer pulse 45 is represented by magnitude 53, this being a point on the acceleration portion 37 of the store's content. This magnitude, preferably in the form of a binary number, is transmitted by way of conductor 39 to capstan speed servo 24. This binary number represents a command speed which should equal the actual capstan motor speed calculated at the occurrence of the second tachometer output pulse 46. A well known technique for calculating the sampled data capstan speed in the interval 45-46 is to enable a counter to begin counting a high frequency oscillator at the occurrence of tachometer pulse 45, and to disable this counting at the occurrence of the second tachometer pulse 46, followed by a comparison of the binary number within the counter at the occurrence of pulse 46 with the binary number 53 selected from store 36.

This comparison indicates the relationship of the actual capstan speed to the desired speed defined by store profile 37. For example, if the binary number selected from the store at the occurrence of pulse 45 is larger than the binary number representing the actual motor speed at the time of pulse 46, the actual capstan speed is faster than the command speed and the state of motor energization is reduced, causing the capstan to follow profile 37.

Address selection network 41 is operative to continually address store 36 upon the occurrence of each of the tachometer pulses. The major portion of FIG. 4 is acceleration profile portion 37 of the store contents. By the time tachometer pulse 51 has been received, the capstan motor has entered its steady-state running speed condition. Thereafter, each subsequent tachometer output pulse selects the same magnitude binary number from store 36, this binary number being calculated to maintain the capstan at the steady-state speed.

As shown in FIG. 8, the content 121 of deceleration store 120 is shown associated with an exemplary series of digital tachometer output pulses 125-129. Pulses 126-129 are defined herein as deceleration pulses. Pulse 125 represents the last output pulse from tachometer 42 which occurred prior to the capstan motor receiving a stop command, such as indicated at 124; also, see FIG. 2. The effect of this stop command is to initially control capstan speed servo 24 in a manner to reverse-energize or plug capstan motor 10, open loop, with a preselected level of energization known to cause optimum deceleration of the capstan, with no tape slip. In addition, this stop command enables address selection network 41, FIG. 1, to begin its address calculation for read-only-store 120.

More specifically, address selection network 41 calculates or determines the time interval between the occurrence of the capstan stop command at 124 and the first tachometer deceleration pulse 126 which is received from digital tachometer 42 as the capstan motor decelerates from its steady-state speed 29, FIG. 2. This unique address, which is an unknown variable since the motor may have received a stop command at any position 124 between adjacent tachometer pulses 125 and 126, selects a unique output from read-only-store 120

to be used by capstan speed servo 24 as a speed command. This speed command is compared to the actual capstan speed, which is calculated by sampled-data techniques between tachometer pulses 126 and 127.

By way of example, a specific means for servo controlling motor 10 so as to force its deceleration profile to follow a stored deceleration profile may be as described in U.S. Pat. No. 3,737,751, issued to P. J. Lima, or alternatively, as described in U.S. Pat. No. 3,731,176 issued to J. O. Mitchell, S. D. Roberts and R. W. Van Pelt.

With specific reference to FIG. 8, the command speed selected from store 120 at the occurrence of the first tachometer deceleration pulse 126 is represented by magnitude 130, this being a point on the deceleration curve 121 of the store's content. This magnitude, preferably in the form of a binary number, is transmitted by way of conductor 122 to capstan servo 24. This binary number represents a command speed which should equal the actual capstan motor speed calculated at the occurrence of the second tachometer pulse 127.

A comparison of the actual capstan speed to the desired speed defined by store profile 121 indicates the relationship of the actual capstan deceleration profile to the desired deceleration profile. For example, if the binary number selected from the store at the occurrence of pulse 126 is larger than the binary number representing the actual motor speed at the time of pulse 127, the actual capstan speed is faster than the command speed and the state of motor reverse energization is increased, causing the capstan to decelerate more rapidly, to follow profile 31, FIG. 2.

Address selection network 41 is operative to continually address store 120 upon the occurrence of each of the tachometer deceleration pulses 126-129. By the time tachometer pulse 129 has been received, the capstan motor has been slowed to target speed 35, FIG. 2, and at this point the motor is allowed to coast to a stop at 32 or, alternatively, is dynamically braked to a stop.

As is readily apparent from the above description, store 36 is effective to control the motor's acceleration whereas store 120 is effective to control the motor's deceleration. Capstan start and stop commands, on conductors 131 and 132, respectively, control the enabling of these two stores.

While the present invention may be implemented by a number of well known structural configurations, as is apparent to those of skill in the art, FIGS. 5 and 6 present two further schematic showings of embodiments of the present invention.

In FIG. 5, direct current motor 54 is directly connected to control a load 55, for example, FIG. 1's capstan 11. This motor additionally controls the movement of digital distance measuring transducer 56. The actual speed of motor 54 is measured by sampled-data techniques. Specifically, period counter 57 is controlled by transducer 56 to accumulate a number of cycles of clock 58 between adjacent output pulses received from transducer 56. Of course, clock 58 is of a relatively high frequency, known to be higher than the maximum frequency of output pulses to be received from transducer 56. In a well known manner, the occurrence of each transducer pulse is effective to cause related structure to interrogate the counter to determine its contents, and to then initialize the counter to begin

counting clock 58 for a new sampled-data interval, that is the interval to the next transducer pulse.

Assuming that motor 54 is standing at a rest position, the motor is deenergized, for example by way of an open circuit in conductor 59, not shown. When a start command is received for motor 54, conductor 59 is completed and conductor 60 is operative, by way of gate 61, to enter a binary number into bipolar digital-to-analog converter (DAC) 62. As a result, a voltage, arbitrarily designated as positive, is applied to summation junction 63 by way of conductor 64. At summation junction 63 this positive voltage is summed with a similar positive voltage provided by steady-state voltage source 65 and conductor 66. Source 65 is enabled by a start motor command on conductor 140. The summation of these two positive voltages determines an initial open loop mode of energization of motor 54 and the motor begins accelerating from its rest position.

As an alternate, gate 61 and its function may be replaced by a voltage source, such as source 65, which is programmed to provide initial high magnitude energization upon receiving a start command on conductor 140.

The occurrence of the motor start command also enables conductor 67 associated with address counter 68. This enabling of address counter 68 causes the counter to begin counting the cycles of clock 69. Address counter 68 addresses acceleration read-only-store 70. The output of the store appears on conductor 71 and is applied to OR 160. As motor 54 enters its acceleration profile, the first acceleration output pulse of transducer 56 is effective to enable gate 72, causing the then existing output of store 70 to be held in register 73. As has been explained, this output may, for example, be a binary number whose magnitude represents the desired speed of motor 54 which is to be calculated by period counter 57 during the time interval between this first transducer pulse and the second transducer pulse.

The occurrence of the start command, at conductor 152, initializes counter 74, and this counter thereafter begins counting the output pulses from transducer 56. The occurrence of the second transducer pulse enables an output from pulse counter 74, by way of conductor 75. Pulse counter 74 is constructed and arranged to provide a continuous output on conductor 75 for all pulses subsequent to and including the second pulse. The enabling of conductor 75 opens gate 76 and causes the then existing binary number contained within period counter 57 to be transferred to register 77. The content of period counter 57 at the occurrence of the second transducer pulse is a sampled-data measurement of the speed of motor 54, as calculated during the time interval between the first and second transducer pulse. This binary number should be equal to the number contained in register 73. Digital compare network 78 compares the contents of register 73 with the contents of register 77 and originates an error output on conductor 79. By way of example, compare network 78 may be constructed as an arithmetic logical unit (ALU) which is set to subtract the binary numbers contained in registers 73 and 77.

The occurrence of the second transducer pulse is also effective, by way of inverter 80, to inhibit further operation of gate 61. With gate 61 now inhibited, the output of compare network 78, on conductor 79, is effective to control bipolar DAC 62 such that the magnitude of the voltage applied to summation junction 63 is vari-

ably controlled to cause motor 54 to follow the acceleration profile contained within store 70.

As has been described, the occurrence of each transducer pulse is effective to select a binary number from store 70, as represented in FIG. 4. This binary number is held in register 73 for use with the number contained within period counter 57 at the occurrence of the subsequent transducer pulse, the contents of the period counter at that time being transferred to register 77.

In summary, the occurrence of the first transducer pulse causes a unique address to be selected from store 70 and a unique binary number is transferred to register 73. The occurrence of the second tachometer pulse causes the contents of counter 57 to be transferred to register 77. The contents of registers 73 and 77 are now transferred to digital compare network 78 where their difference is calculated. In addition, a new number is selected from store 70 on the occurrence of the second tachometer pulse.

In the time interval between the second and third tachometer pulses, motor 54 is controlled in accordance with the output of digital compare network 78.

This mode of operation continues until motor 54 has achieved its target steady-state speed, wherein all subsequent store locations of store 70 contain the same binary number designating this steady-state speed.

Assume that motor 54 is running at its target steady-state speed, 29 of FIG. 2 and 38 of FIGS. 3 and 8. When a command is received to stop the motor, plugging voltage source 138 is enabled by way of conductor 141 and address counter 134 is enabled by way of conductor 136. Pulse counter 74 is reset by stop command 153, and stop number 150 is gated into the bipolar DAC 62 by stop command 151. Source 138 plus the output of the bipolar DAC constitute the deceleration energization for motor 54 for the time interval between the stop command and the second tachometer deceleration pulse 127; see FIG. 8.

The occurrence of the motor stop command enables address counter 134, causing the counter to begin counting the cycles of clock 135. Address counter 134 addresses deceleration read-only-store 133. The output of this store appears on conductor 137. As motor 54 enters its deceleration profile, the first deceleration output pulse 126 of transducer 56 is effective to enable gate 72, causing the then existing output of store 133 to be transferred through OR 160 and gate 72 to be held in register 73. This output may, for example, be a binary number whose magnitude represents the desired speed of motor 54 which is to be calculated by period counter 57 during the time interval between this first transducer pulse 126 and the second transducer pulse 127, FIG. 8.

The occurrence of second transducer deceleration pulse 127 enables an output from pulse counter 74, by way of conductor 75. The enabling of conductor 75 opens gate 76 and causes the then existing binary number contained within period counter 57 to be transmitted to register 77. The content of period counter 57 at the occurrence of the second transducer pulse 127 is a sampled-data measurement of the speed of motor 54, as calculated during the time interval between first transducer pulse 126 and second transducer pulse 127. This binary number should be equal to the number contained in register 73. Digital compare network 78 compares the contents of register 73 with the contents of

register 77 and originates an error output on conductor 79.

Bipolar DAC 62 is now effective to apply a variable polarity voltage to summation junction 63 so as to control the deceleration energization of motor 54, causing the motor to follow the deceleration profile contained within store 133.

The occurrence at each transducer pulse is effective to select a binary number from store 133, as represented in FIG. 8. This binary number is held in register 73 for use with the number contained within period counter 57 at the occurrence of the subsequent transducer pulse, the contents of the period counter at that time being transferred to register 77.

In summary, the occurrence of the first transducer deceleration pulse 126, which occurs after the motor stop command is received, causes a unique address to be selected from store 133 and a unique binary number is transferred to register 73. The occurrence of the second tachometer pulse 127 causes the contents of counter 57 to be transferred to register 77. The contents of registers 73 and 77 are now transferred to digital compare network 78 where their difference is calculated. In addition, a new number is selected from store 133 on the occurrence of the second tachometer pulse 127.

This mode of operation continues until motor 54 has achieved its relatively low target speed 35, FIG. 2. Thereafter, the motor is allowed to coast to a stop at 32, or, alternatively, is dynamically braked to a stop.

The structure of FIG. 5 has been explained in a general motor control environment. However, motor 54 thereof may be FIG. 1's capstan motor 10, load 55 may be capstan 11 and the tape moved thereby, transducer 56 may be digital tachometer 42, address counters 68 and 134 and clocks 69 and 135 may be address selection network 41 and capstan speed servo 24 may be implemented by way of period counter 57, registers 73 and 77, as well as compare network 78 and bipolar DAC 62.

Preferably, the magnitude of steady-state voltage source 65 is selected to be approximately equal to a precalculated magnitude thought to normally maintain motor 54 at its steady-state target velocity. The output of bipolar DAC 62 is capable of reversing its polarity such that it may either add to or subtract from the magnitude of voltage source 65, to thereby accurately control the speed of motor 54 to a steady-state target speed.

FIG. 6 discloses a somewhat different form of the invention. In this figure, the motor is not shown.

The occurrence of a "start capstan" command on conductor 90 is effective to start operation of clock 91. This clock increments address counter 92 from an initial state. The binary content of counter 92 continually addresses digital storage 93 which contains the desired motor acceleration and/or deceleration profile in the form of a unique binary number for each addressable storage location.

The motor, as it rotates, controls digital position transducer 94. At the occurrence of each transducer pulse, velocity period counter 95 is initialized to contain a binary number as selected from store 93 by the then-existing address in counter 92. Subsequently, during the time interval to the next transducer pulse, clock 96 decrements counter 95 from its initialized state.

At the time of occurrence of the next transducer pulse, the content of counter 95 is transferred to register 97. If the motor speed is equal to the desired speed, register 97 contains a binary zero. If the motor speed is either greater or less than the desired speed, register 97 contains a binary number whose magnitude indicates the magnitude of the speed error, and whose sense (positive or negative) indicates the sense of the speed error (fast or slow). This speed error signal, in register 97, controls bipolar DAC 98 and an output voltage 99 is furnished, to be used as is voltage 64 of FIG. 5.

When a stop command is received, conductor 142 informs address counter 92, digital store 93 and bipolar DAC 98 that controlled deceleration of the motor must be implemented. Thereafter, the binary content of counter 92 continually addresses digital storage 93, and particularly DAC 98 begins deceleration energization of the motor. At the occurrence of each transducer pulse, the content of register 97 is interrogated. If the motor speed is either greater or less than the desired speed, as indicated by the deceleration portion of store 93, register 97 contains a binary number whose magnitude indicates the magnitude of the speed error, and whose sense indicates the sense of the speed error. This speed error signal, in register 97, controls bipolar DAC 98 and the plugging output of the motor is controlled accordingly, causing the motor's deceleration profile to follow the stored profile.

A reel-to-reel magnetic tape unit, as schematically shown in FIG. 7, may have its tape speed parameter controlled by the use of the present invention, for example, by the structure of FIG. 5. Such a reel-to-reel tape unit is described in the copending applications of W. B. Phillips, Ser. No. 198,925, filed Nov. 15, 1971, and J. P. Mantey, Ser. No. 267,301, filed June 29, 1972, both commonly assigned. In both of these tape units, the two reel motors 100 and 101 are jointly controlled by motor control network 102 to maintain a desired tape tension and tape speed at magnetic head 103. Tape 104 carries digital data as well as a timing track. This timing track is read by head 103 and thereby performs the function of digital distance measuring transducer 56 of FIG. 5. Thus, the output signal on conductor 105 provides an input to pulse counter 74, period counter 57 and gate 72 of FIG. 5.

The speed error calculated by the apparatus of FIG. 5, as above described, appears on conductor 79. This speed error is used by motor control network 102 to jointly control the energization of motors 100 and 101, as described in the above-identified copending applications.

For reasons of simplicity, the tension sensing and tension control portions of the above-identified copending applications are not disclosed in FIG. 7, and reference can be had to those applications for a description thereof.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. Motor speed-control servomechanism, comprising:

a variable speed motor capable of accepting variable energization,
a controllable network connected to said motor and operable to control the energization of said motor,

sample data distance measuring means connected to said motor and operable to provide a discrete output for each unit of motor movement,
period measuring means controlled by said distance measuring means and operable to measure the time interval required for the motor to move a unit distance,

addressable memory means having a plurality of unique memory locations each of which is accessible by a different address, said memory means being constructed and arranged to define an acceleration and/or deceleration profile which the motor is to follow as the motor accelerates and/or decelerates from different unique motor positions, between time adjacent discrete outputs of said sample data distance measuring means, to a different speed condition,

an address selection means controlled by said distance measuring means and operable to address unique memory locations in accordance with the relationship of said unique motor position and said time adjacent discrete outputs of said distance measuring means,

said unique memory locations adaptively defining points on said acceleration and/or deceleration profile in accordance with said unique motor position, and

comparison means connected to compare the output of said period measuring means to the output of said memory means and operable to control said controllable network in accordance with the comparison.

2. A motor control servomechanism as defined in claim 1 wherein said distance measuring means is constructed and arranged to provide an output pulse for equal incremental units of motor motion, and wherein said address selection means is controlled in accordance with the relationship of said unique motor position to a predetermined output pulse which occurs as said motor accelerates and/or decelerates from said unique position.

3. A motor control servomechanism as defined in claim 2 wherein said address selection means includes counter means, a clock, and means enabling said counter means to begin counting said clock upon speed change of said motor from said unique position, said predetermined output pulse being effective to enable said counter means to address said memory means upon the occurrence of said predetermined output pulse.

4. A motor control servomechanism as defined in claim 3 wherein said counter means is operable to select a unique period measure from said memory means which is indicative of the desired time interval to a subsequent predetermined output pulse, and wherein said comparison means is effective to compare this desired time interval to the actual time interval upon the occurrence of said subsequent predetermined output pulse.

5. In a sampled-data motor speed-control servomechanism wherein the motor drives a digital tachometer and is variably energized during acceleration and/or

deceleration to follow a predefined acceleration and/or deceleration profile, an improved means for defining said profile, comprising:

addressable memory means containing a plurality of addressable locations which define said profile, 5
address selection network means operable to uniquely address said memory means locations, means connecting said digital tachometer in controlling relation to said address selection network means to control the same in a manner to adaptively select memory locations which are uniquely related to the unique motor position at which the motor begins its acceleration and/or deceleration as this position is distance related to the next subsequent pulse derived from said digital tachometer, 10
and

motor energizing means controlled by said digital tachometer and by said memory means and operable to variably energize said motor during acceleration and/or deceleration, causing the motor's acceleration and/or deceleration profile to follow the profile defined by the data stored in said memory means. 15

6. A sampled-data motor control servomechanism as defined in claim 5 wherein each location of said memory means contains data defining a unique time period which should exist between a tachometer output pulse which has just occurred and a preselected subsequent tachometer output pulse, and wherein said motor energizing means includes time period measuring means including a time reference controlled by said tachometer, comparison means operable to compare the data selected from said memory means to the measured time period to said subsequent tachometer output pulse, and means controlled by said comparison means for variably energizing said motor. 20

7. In a magnetic tape unit wherein a length of tape is adapted to be maintained in continuous engagement with a single rotatable capstan, such that capstan movement is directly translated into tape movement, and wherein the tape is adapted to contain a format of data blocks separated by interblock gaps, said capstan having a rest position which places a magnetic head in said gap and being capable of decelerating from a steady-state target speed to said rest position and subsequently accelerating to said steady-state target speed such that said head enters and traverses an adjacent data block at said target speed, the improvement comprising: 25

an electric motor directly connected to said capstan,

a digital tachometer connected to said motor, said tachometer providing an output pulse for equal units of motor rotation,

memory means having a plurality of addressable locations which define a desired motor deceleration and acceleration profile from said target speed to said rest position and from said rest position to said target speed, 30

means providing a capstan stop command and a capstan start command,

address selection means controlled by said capstan stop command and said capstan start command and by said first tachometer deceleration output pulse and said first tachometer acceleration output pulse, and the succeeding output pulses which occur during deceleration and acceleration, and operable to address unique locations of said mem- 35

ory means in accordance with the distance said motor moves from the occurrence of a capstan command to said tachometer output pulses, measuring means controlled by said tachometer and operable to measure the motor's actual deceleration profile from said first deceleration pulse to said rest position, and additionally operable to measure the motor's actual acceleration profile from said first acceleration output pulse to said target speed, and comparison means operable to variably energize motor in accordance with a comparison of the output of said measuring means to said memory means. 40

8. A magnetic tape unit as defined in claim 7 wherein the first deceleration output pulse and the first acceleration output pulse, and all subsequent deceleration and acceleration output pulses, are operable to select data from said memory means indicative of the desired time interval to the subsequent output pulse, wherein said measuring means is operable to measure the actual time interval between each tachometer output pulse and a subsequent output pulse as a measure of the motor's actual deceleration and acceleration profile, and wherein said comparison means is operable to variably energize said motor upon the occurrence of said second tachometer output pulses. 45

9. A magnetic tape unit as defined in claim 10 including means controlled by said capstan start command to provide preselected energization of said motor, which preselected energization is maintained until the occurrence of the second acceleration output pulse. 50

10. A magnetic tape unit as defined in claim 11 wherein said address selection means includes time interval measuring means initially operable to select data from said memory means in accordance with the time interval between the occurrence of said capstan start command and said first acceleration output pulse, and operable thereafter to select data in accordance with the time interval between adjacent acceleration output pulses, said data being indicative of the desired time interval to a subsequent tachometer pulse in accordance with the desired acceleration profile. 55

11. A magnetic tape unit as defined in claim 10 wherein said memory means locations additionally define said target speed by containing data indicative of equal time intervals between adjacent tachometer output pulses. 60

12. A magnetic tape unit as defined in claim 9 including means controlled by said capstan stop command to provide preselected plugging energization of said motor, which preselected energization is maintained until occurrence of the second deceleration output pulse. 65

13. A magnetic tape unit as defined in claim 12 wherein said address selection means includes time interval measuring means initially operable to select data from said memory means in accordance with the time interval between the occurrence of said capstan stop command and said first deceleration output pulse, and operable thereafter to select data in accordance with the time interval between adjacent deceleration output pulses, said data being indicative of the desired time interval to a subsequent tachometer pulse in accordance with the desired deceleration profile. 70

14. A magnetic tape unit as defined in claim 13 wherein a means responsive to a given motor speed

lower than said target speed is effective to interrupt further plugging energization of said motor.

15. A sample-data motor acceleration servo for use in accelerating a motor from rest to a target speed comprising:

a distance measuring transducer connected to said motor and providing an output pulse for each distance unit of motor movement subsequent to the first output pulse, said first output pulse occurring at variable distances less than said unit distance, in accordance with the rest position of said motor,

a period counter,

a high frequency clock connected to increment said period counter from an initial state, said frequency being higher than the frequency of said transducer output pulses when said motor is running at said target speed,

means connecting said transducer in controlling relation to said period counter to initialize said period counter upon the occurrence of each said transducer output pulses such that the content of said period counter prior to initializing is indicative of the time interval between adjacent transducer output pulses,

memory means containing a plurality of storage locations, each one of which contains a unique number indicative of the desired contents of said period counter prior to initialization during different portions of the motor's acceleration profile from rest to said target speed,

address selection means controlled both by the occurrence of a motor start command and by said transducer output pulses, initially operable to address a memory location whose number decreases as the time interval for the motor to move from its variable rest position to the occurrence of said first transducer output pulse increases, and thereafter operable to address a memory location whose number additionally decreases in accordance with the additional time for the motor to move to the subsequent transducer output pulses,

comparison means operable to compare the memory location number which was selected upon the occurrence of a transducer output pulse to the content of said period counter which exists upon the occurrence of the subsequent transducer output pulse, and

means controlled by said comparison means and operable to energize said motor in accordance with said comparison, said energization being operable to cause said motor to achieve said acceleration profile.

16. A sample-data motor acceleration servo as defined in claim 15 wherein said address selection means includes an address counter which is driven at a constant frequency from an initial setting, said address counter drive being initiated by the occurrence of said motor start command, and said address counter being interrogated by said transducer output pulses, with the then-existing contents of said address counter being used to effect selection of a number from said memory means.

17. A sampled-data motor deceleration servo for use in decelerating a motor from a target speed to rest, comprising:

a distance measuring transducer connected to said motor and providing an output pulse for each dis-

tance unit of motor movement subsequent to the first output pulse to occur after a motor stop command is received, said first output pulse occurring at variable distances less than said unit distance, in accordance with the unique motor position at which a stop command is received,

a period counter,

a high frequency clock connected to increment said period counter from an initial state, said frequency being higher than the frequency of said transducer output pulses when said motor is running at said target speed,

means connecting said transducer in controlling relation to said period counter to initialize said period counter upon the occurrence of each of said transducer output pulses such that the content of said period counter prior to initializing is indicative of the time interval between adjacent tachometer output pulses,

memory means containing a plurality of storage locations, each one of which contains a unique number indicative of the desired contents of said period counter prior to initialization during different portions of the motor's deceleration profile from said target speed to rest,

address selection means controlled both by the occurrence of said motor stop command and by said transducer output pulses, initially operable to address a memory location whose number increases as the time interval for the motor to move from said unique position to the occurrence of said first transducer output pulse increases, and thereafter operable to address a memory location whose number additionally increases in accordance with the additional time for the motor to move to the subsequent transducer output pulses,

comparison means operable to compare the memory location number which was selected upon the occurrence of a transducer output pulse to the contents of said period counter which exists upon the occurrence of the subsequent transducer output pulse, and

means controlled by said comparison means and operable to energize said motor in accordance with said comparison, said energization being operable to cause said motor to achieve said deceleration profile.

18. A sampled-data motor deceleration servo as defined in claim 17 wherein said address selection means includes an address counter which is driven at a constant frequency from an initial setting, said address counter drive being initiated by the occurrence of said motor stop command, and said address counter being interrogated by said transducer output pulses, with the then-existing contents of said address counter being used to effect selection of a number from said memory means.

19. In a closed-loop sampled-data motor speed servo which receives a motor speed feedback signal from a digital transducer whose pulse frequency is proportional to the motor's speed, an improved apparatus for accelerating and/or decelerating the motor between a given speed and a variable rest position, comprising:

storage means containing a plurality of predefined numbers indicative of desired transducer pulse time intervals commensurate with said motor accelerating and/or decelerating from one of a range

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of unique variable motor positions defined by the two transducer pulses which bracket the unique position from which acceleration and/or deceleration begins,
 an address counter,
 means providing motor start and stop commands,
 means controlled by said motor start and stop commands for advancing said address counter as said motor begins its acceleration and/or deceleration from said unique position,
 means controlled by a given transducer pulse which occurs after beginning of acceleration and/or deceleration to interrogate said address counter and to select a unique number from said storage means in accordance with said address, said unique number representing the desired time interval to a subsequent transducer pulse,
 motor speed measuring means controlled by said digital transducer and operable to measure the speed of said motor as a function of the time interval between transducer pulses, and
 motor energizing means controlled by said speed measuring means and said unique number selected from said storage means and operable to variably energize said motor in a manner to cause the time interval between transducer pulses to be as defined

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by said unique number.

20. The motor speed servo defined in claim 19 wherein said motor speed measuring means includes, a speed counter,
 a high frequency clock connected to increment said speed counter,
 means controlled by said digital transducer and effective to initialize said counter on the occurrence of said given transducer pulse, and wherein said motor energizing means includes,
 comparing means effective to compare said unique number to the contents of said speed counter upon the occurrence of said subsequent transducer pulse.

21. The motor speed servo defined in claim 20, wherein said motor energizing means includes, means controlled by said comparing means and operable to servo control motor acceleration and/or deceleration for the time interval between said subsequent transducer pulse and a further subsequent transducer pulse in accordance with the error between said unique number and the contents of said speed counter at the occurrence of said subsequent transducer pulse.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,836,833 Dated September 17, 1974

Inventor(s) John P. Harris, John P. Mantey and David R. Wood

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

Column 14, line 28, "10" should read --8--.

line 34, "11" should read --9--.

line 50, "9" should read --8--.

Signed and sealed this 24th day of December 1974.

(SEAL)
Attest:

McCOY M. GIBSON JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

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