TO: NST-44/Scientific and Technical Information Division
  Attn: Shirley Peigare
FROM: GP-4/Office of Assistant General Counsel
      for Patent Matters/Nancy L. Fonseca
SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP-4 and Code NST-44, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No.: 4,249,116
Government or Corporate Employee: Caltech/JPL
Supplementary Corporate Source (if applicable): Pasadenca, CA 90406
NASA Patent Case No.: NPD-13,970-1

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

YES [X] NO [ ]

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words "...with respect to an invention of..."
An improved motor speed and torque controller for brushless DC motors which provides an unusually smooth torque control arrangement. The controller provides a means for controlling a current waveform in each winding of a brushless DC motor by synchronization of an excitation pulse train from a programmable oscillator. Sensing of torque for synchronization is provided by a light beam chopper mounted on the motor rotor shaft. Speed and duty cycle are independently controlled by controlling the frequency and pulse width output of the programmable oscillator. A means is also provided so that current transitions from one motor winding to another is effected without abrupt changes in output torque.

6 Claims, 9 Drawing Figures
FIG. 5

PROGRAMMABLE OSCILLATOR (FIG. 8)
FROM OR (S) T GATE 68

OUTPUT FROM INVERTER 112

OUTPUT FROM COMPARATOR 100

INPUT TO 114

OUTPUT OF 114

THRESHOLD OF COMPARATOR 100 (SET BY 106)

VOLTAGE AT CAPACITOR 86

VOLTAGE AT OUTPUT OF COMPARATOR 96

DEGREES OF SHAFT ROTATION

FIG. 9
CONTROLLER FOR COMPUTER CONTROL OF BRUSHLESS DC MOTORS

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract and subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 USC 2457).

FIELD OF THE INVENTION

This invention relates to electrical motor excitation and control systems and, more particularly, to improvements therein.

BACKGROUND OF THE INVENTION

A problem encountered with conventional DC brushless motor control systems is to provide electrical excitation signals which simulate the combination of an automobile engine and transmission. Conventional control systems frequently control motor speed as a function of the frequency of an oscillator which applies excitation to the motor windings, but have difficulty in duplicating the variable torque as required which simulates power transferred by an automatic transmission. In particular, difficulty has frequently been experienced in obtaining smooth torque and speed variations from control signals applied to the winding excitation oscillator. Also, a phenomenon called notching is frequently experienced during slow rotation of motors utilizing conventional motor control systems. Notching occurs as a result of the transfer of excitation from one winding of the motor to an adjacent winding. The present invention solves the above problems by providing a control system having unusually smooth torque and frequency control.

OBJECTS AND SUMMARY OF THE INVENTION

An object of this invention is to provide a novel speed and torque controlling system for a brushless DC motor.

Yet another object of this invention is to provide a system for smoothly controlling the torque of a brushless DC motor.

A further object of this invention is to provide a system with a minimum number of devices to conserve power.

The foregoing and other objects of the invention are achieved in a system wherein a sensor on the motor rotor shaft provides feedback signals proportional to motor shaft rotation to a decoder circuit. The decoder circuit utilizes some of the feedback signals to derive a synchronization signal which is supplied to an oscillator for the purpose of controlling a phase lead or lag in the oscillator output. The oscillator output is supplied to the decoder circuit which combines it with outputs derived from the sensor, the resulting signals being used to precisely gate power transistors which furnish power to the motor windings for smooth operation of the motor. The oscillator is programmable, that is, its frequency and duty cycle are controlled by suitable signals from other sources, one of which could be a computer.

The novel features of the invention are set forth with particularity in the appended claims. The invention will be best understood from the following description when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a block-schematic diagram of an embodiment according to the present invention; FIG. 2 is an elevational view of the motor and sensor; FIG. 3 is taken along line 3-3 of FIG. 2; FIG. 4 is taken along line 4-4 of FIG. 2; FIG. 5 is a schematic diagram of the decoder; FIG. 6 is a waveform drawing illustrating the waveform outputs derived from the chopper wheel and sensors associated with the motor shaft; FIG. 7 is a waveform drawing illustrating the waveform outputs applied to the decoder to the power transistors; FIG. 8 is a schematic diagram of the oscillator; and FIG. 9 is a waveform drawing illustrating various waveforms within the programmable oscillator.

DETAILED DESCRIPTION

As required, a detailed illustrative embodiment of the invention is disclosed herein. This embodiment exemplifies the invention and is currently considered to be the best embodiment for such purposes. However, it is to be recognized that other means for controlling the frequency and the duty cycle of the programmable oscillator could be utilized and other types of sensors could be used for determining shaft rotation. Accordingly, the specific embodiment disclosed is representative in providing a basis for the claims which define the scope of the present invention.

Referring to FIG. 1, a standard 3 phase AC power motor 10 having its armature modified for operation in a brushless DC mode is utilized. The motor 10 has first, second, and third armature windings 11, 12, and 13, respectively. The first armature winding 11 is supplied power by a first complimentary transistor pair 14 and 15, the second armature winding 12 by a second transistor pair 16 and 17, and the third armature winding 13 by a third transistor pair 18 and 19. Enabling pulses to these transistors, which will be explained in detail below, are provided by outputs from a decoder 20. Thus decoder output signals 22, 25, 16', 17', 18', and 19' are provided to transistors 14, 15, 16, 17, 18, and 19, respectively. Transistors 14 and 15 are serially connected across a power supply 21. That is, the emitter of transmitter 14 is connected to a positive terminal of the power supply 21, the collector of transistor 14 is connected to the collector of transistor 15, and the emitter of transmitter 15 is connected to a common or ground terminal of the power supply 21. The junction of the collectors of transistors 14 and 15 is connected to the first winding 11 of the motor 10. This junction is also connected to the junction of two diodes, 14D and 15D, which are serially connected across the power supply 21. These diodes effectively perform a dual function, the first being to protect the transistors 14 and 15 across which they are connected and the second being to return current back into the power supply 21 in an action similar to that of a generator. For example, if the power supply 21 were a rechargeable battery, then the action of the two diodes 14D and 15D would allow the batteries to be charged during motor coasting.

Transistor 16 and 17 are also serially connected across the power supply 21 in the same manner as previously described for transistors 14 and 15. The junction of the collectors of transistor 16 and 17 is connected to...
a junction between two serially connected diodes D1 and 17D, also serially connected across the power supply 21. The junction is also connected to the second winding 12 of the motor 10. Transistors 18 and 19 are also serially connected across the power supply 21 in the same manner as described for transistors 14 and 15. Again, the junction of the collectors of these transistors is connected to the third motor winding 13, and also to the junction of two serially connected diodes 18D and 19D, which are also connected across the power supply 21.

An input transistor 22 has its collector terminal connected to a load resistor 24 which in turn is connected to the positive terminal of the power supply 21. The input transistor 22 emitter terminal is connected to the common or ground terminal of the power supply 21. The base of the input transistor 22 is connected to the decoder 20 through an input resistor 26. The base of the transistor 14 is connected to the load resistor 24.

In this particular embodiment, synchronization signals for the decoder 20 are derived from a shaft rotation sensor 23. Referring to FIGS. 2, 3 and 4, the shaft rotation sensor 23 includes six photodiodes D1 through D6, a photodiode mounting plate 24, a rotating chopper wheel 25, and six light emitting diodes E1 through E6. The mounting plate 24 is fixedly attached to the motor shaft 28. The mounting plate 24 is fixedly attached to the common or ground terminal of the power supply 21. The base of the input transistor 22 is connected to the decoder 20 through an input resistor 26. The base of the transistor 14 is connected to the load resistor 24.

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20, and more specifically to the AND gates 60, 62 and gramming operation of the motor 10. The output is supplied by the comparator 96 to the decoder 20. When a charge on capacitor 86 exceeds the output voltage of amplifier 98, the output voltage from the comparator 96 is removed.

The collector of transistor 82 is also connected to another comparator 100, and to a transistor 104 through a resistor 102. The comparator 100 has a voltage level as an input which must be exceeded by the output of capacitor 86 in order for it to provide an output, this voltage level being determined by a potentiometer 106 connected across a voltage source. A biasing voltage is selected by the potentiometer 106 arm and applied through a resistor 108 to one input terminal of the comparator 100.

The output of the comparator 100 which occurs when the capacitor 86 voltage exceeds the voltage selected from the potentiometer 106 is applied to a NOR gate 110. Another input to the NOR gate 110 is the output of an inverter 112 which has as an input the output of the OR gate 68 shown in FIG. 5. Either in the presence of an output from the comparator 100 or in the presence of a feedback signal from the decoder 20 as represented by an output from the inverter 112, an output is obtained from the NOR gate 110. This output or reset pulse triggers a one-shot multivibrator 114. When the one-shot multivibrator 114 is set, its output designated at Q is high. This Q signal is connected through a resistor 116 to the base of transistor 104, thereby causing transistor 104 to become conductive and discharge the capacitor 86. As one can appreciate, this provides control over the pulses to be supplied to the decoder 20.

To summarize operation of the programmable oscillator 32, reference should be made to FIG. 8 in conjunction with the waveforms of FIG. 9. The output from OR gate 66 in the decoder 20 is shown as waveform A, this output being inverted by the inverter 112 as shown in waveform B. A pulse output from the comparator 100 is shown in waveform C, this output occurring each time that a charge on the capacitor 86 reaches a predetermined voltage level in accordance with a setting of the potentiometer 106. The input to and output from the one-shot multivibrator 114 are shown in waveforms D and E respectively. As previously explained, each output pulse from the multivibrator 114 causes the capacitor 86 to discharge to ground through the transistor 104.

Referring to waveform F, it can be seen that voltage on the capacitor 86 builds up at a constant rate until an output pulse from the multivibrator 114 is generated, these pulses being generated for every 120 degrees of motor shaft rotation and also for each time the voltage on the capacitor 86 reaches a predetermined level. The time required for the capacitor 86 voltage to reach the predetermined level is controlled by the frequency control source 34. The output waveform G provided by the comparator 96 is determined by the duty cycle controller 36, the waveform returning to zero each time the comparator 96 threshold is reached as previously explained. Thus, the output of the comparator 96 comprises a square wave which is initiated at each 120 degrees increment of shaft rotation and has a frequency determined by the frequency control source 34 and a duration, or duty cycle, determined by the duty cycle controller 36. Any output frequency can be selected as can be seen by comparing waveform G of FIG. 9 with those of FIG. 7.

The frequency control source 34 and duty cycle control 36 may be signals provided by a computer for programming operation of the motor 10.
There has accordingly been shown and described herein a novel and useful means for controlling the speed and torque of a brushless DC motor.

What is claimed is:

1. A speed and torque controlling system for a brushless DC motor of the type having three phase windings comprising:
   means for deriving synchronizing signals from a motor shaft of said motor as said motor rotates;
   decoder means to which said synchronizing signals are applied for producing, in response thereto, first and second gating signals;
   means for generating correlation signals related to said first gating signals;
   a first signal source;
   a second signal source;
   a programmable oscillator having an output signal related to said correlation signals, said programmable oscillator comprising means responsive to said first signal source for determining the frequency of said output signal, said programmable oscillator further comprising means responsive to said second signal source for determining the duty cycle of said output signal;
   means for altering said first gating signals by said programmable oscillator output signal to provide third gating signals; and
   driving means responsive to said second gating signals and said third gating signals for applying current to the windings of said motor.

2. The system as recited in claim 1 in which said programmable oscillator comprises integrating means responsive to said first signal source for producing an integrated signal output; and
   driving means responsive to said second gating signals and said third gating signals for applying current to the windings of said motor.

3. The system as recited in claim 2 further comprising:
   means for generating a reset signal responsive to said correlation signals; and
   means responsive to said reset signal for resetting said integrating means.

4. The system as recited in claim 1 in which said first signal source and said second signal source comprise a computer.

5. The system as recited in claim 1 wherein said second gating signals comprise three gating signals and said third gating signals comprise three gating signals, said driving means comprising:
   three pairs of transistors each having base, emitter and collector electrodes;
   means for connecting the collector electrodes of each pair of transistors together;
   a power supply having output terminals;
   means for connecting the emitters of each pair of transistors across said power supply output terminals;
   means for connecting the collectors of each pair of transistors to a different one of said DC motor three phase windings;
   means for applying one of said second gating signals to the base electrode of one of the transistors in each pair for enabling them to become conductive; and
   means for applying one of said third gating signals to the base electrode of one of the other transistors in each of said three pairs of transistors.

6. A method for controlling a brushless DC motor of the type having three phase windings, the steps comprising:
   deriving synchronizing signals from a motor shaft of said motor as said motor rotates;
   deriving first and second gating signals in response to said synchronizing signals;
   generating correlation signals related to said first gating signals;
   generating an oscillator output signal having frequency and duty cycle characteristics related to said correlation signals, the output of a first signal source for determining the frequency of said oscillator output signal, and the output of a second signal source for determining the duty cycle of said oscillator output signal;
   altering said first gating signals by said oscillator output signal to provide third gating signals; and
   applying current to the windings of said motor in response to said second gating signals and said third gating signals.