

BRUSHLESS MOTOR DRIVING SYSTEM

1 BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

This invention relates to a system for driving
a brushless motor used in an audio device, a visual
5 display device and the like.

DESCRIPTION OF THE PRIOR ART

High reliability and a long useful service
life are required for a motor used in an audio device,
a visual display device and the like. In order to
10 satisfy the above requirements, it is a recent tendency
to employ, in place of a conventional d.c. motor having
brushes and a commutator, a so-called brushless motor
in which a position sensor is provided to detect the
angular position of rotation of a rotor and, on the
15 basis of the output signal of the position sensor, a
plurality of drive transistors connected in series with
a plurality of drive coils of a plurality of phases
respectively are sequentially turned on so as to continu-
ously rotate the rotor.

20 The structure and operation of a prior art
brushless motor driving system will be described with
reference to Figs. 3 to 6.

Fig. 3 is a block circuit connection diagram of
the prior art brushless motor driving system. Referring to

1 Fig. 3, drive coils 401a, 401b and 401c of a brushless
motor are connected in series with drive transistors
403a, 403b and 403c respectively. The drive transistors
403a, 403b and 403c are grounded at their emitters.

5 These drive transistors 403a, 403b and 403c are connected
at their collectors to a power supply terminal 402
through the drive coils 401a, 401b and 401c respectively.
Further, the drive transistors 403a, 403b and 403c are
connected at their collectors to inverted input terminals

10 of comparators 405a, 405b and 405c respectively. The
power supply terminal 402 is also connected to non-
inverted input terminals of the comparators 405a, 405b
and 405c. These comparators 405a, 405b and 405c are
connected at their output terminals to corresponding

15 input terminals respectively of a differentiation
circuit 408, and this differentiation circuit 408 is
connected at its output terminals to corresponding
input terminals respectively of a delay circuit 409.
The delay circuit 409 is connected at its output

20 terminals to corresponding input terminals respectively
of an energization switching circuit 410, and a forward-
backward command circuit 411 is also connected at
its output terminal to a corresponding input terminal
of the energization switching circuit 410. The energiza-

25 tion switching circuit 410 is connected at its output
terminals to corresponding input terminals respectively
of an energization switching signal amplifier circuit
406. This energization switching signal amplifier

1 circuit 406 is connected at its output terminals to the
bases of the drive transistors 403a, 403b and 403c
respectively.

The operation of the prior art brushless motor
5 driving system having the structure described above
will now be described with reference to Figs. 4 to 6.
Fig. 4 shows signal waveforms appearing when the
brushless motor in the system shown in Fig. 3 is rotat-
ing in the forward rotational direction, Fig. 5 shows
10 signal waveforms appearing when the brushless motor
is rotating in the backward rotational direction,
and Fig. 6 shows signal waveforms appearing when a
backward rotation command signal is applied while the
brushless motor is rotating in the forward rotational
15 direction.

A power supply voltage V_{402} is applied to the
power supply terminal 402, and voltages E_{401a} , E_{401b} and
 E_{401c} having waveforms as shown in Fig. 4 are induced
in the drive coils 401a, 401b and 401c respectively.
20 The comparators 405a, 405b and 405c compare the voltages
 E_{401a} , E_{401b} and E_{401c} with the power supply voltage
 V_{402} and generate output signals V_{405a} , V_{405b} and V_{405c}
having waveforms as shown in Fig. 4, respectively.
For example, the output signal V_{405a} of the comparator
25 405a comparing the voltage E_{401a} with the voltage V_{402}
is V_{405a} of low level when $E_{401a} \geq V_{402}$, but it is
 V_{405a} of high level when $E_{401a} < V_{402}$. The differentia-
tion circuit 408 differentiates the leading edges of the

1 output signals V_{405a} , V_{405b} and V_{405c} of the respective
comparators 405a, 405b and 405c and generates pulse
signals Poa, Pob and Poc having waveforms as shown
in Fig. 4. These pulse signals Poa, Pob and Poc are
5 applied to the delay circuit 409 through which they are
turned into pulse signals Pa, Pb and Pc delayed by a
predetermined delay time T relative to the original
signals Poa, Pob and Poc respectively. When the forward-
backward command circuit 411 generates a forward rotation
10 command signal $V_{F/R}$, the energization switching circuit
410 generates energization switching signals Va, Vb
and Vc having waveforms determined by the pulse signals
Pa, Pb and Pc supplied from the delay circuit 409.
That is, the energization switching signal Va is
15 turned to high level in response to the application of
the pulse signal Pa, but it is turned to low level in
response to the application of the pulse signal Pb.
The energization switching signal Vb is turned to
high level in response to the application of the pulse
20 signal Pb, but it is turned to low level in response
to the application of the pulse signal Pc. The energiza-
tion switching signal Vc is turned to high level in
response to the application of the pulse signal
Pc, but it is turned to low level in response to the
25 application of the pulse signal Pa.

When the motor is rotating in the forward
rotational direction, the energization switching
signals, Va, Vb and Vc provide optimum energization

- 1 timing with respect to the induced voltage signals
E_{401a}, E_{401b} and E_{401c}. These energization switching
signals Va, Vb and Vc are applied, after having been
amplified through the energization switching signal
5 amplifier circuit 406, to the bases of the respective
drive transistors 403a, 403b and 403c, so that the motor
continues to efficiently rotate in the forward
rotational direction.

- On the other hand, when the forward-backward
10 command circuit 411 generates a backward rotation
command signal V_{F/R}, and the motor rotates in the
backward rotational direction, signal waveforms as shown
in Fig. 5 appear in the system. In this case, the
energization switching signal Va is turned to high
15 level in response to the application of the pulse
signal Pa, but it is turned to low level in response
to the application of the pulse signal Pc, the energiza-
tion switching signal Vb is turned to high level in
response to the application of the pulse signal Pb,
20 but it is turned to low level in response to the
application of the pulse signal Pa, and the energization
switching signal Vc is turned to high level in response
to the application of the pulse signal Pc, but it is
turned to low level in response to the application of
25 the pulse signal Pb.

In this case too, the energization switching
signals Va, Vb and Vc provide optimum energization
timing with respect to the induced voltage signals

1 E_{401a}, E_{401b} and E_{401c}, so that the motor continues to efficiently rotate in the backward rotational direction like in the case of the rotation in the forward rotational direction.

5 However, a problem such as pointed out below has been encountered in the prior art brushless motor driving system. That is, when the forward-backward command circuit 411 generates a backward rotation command signal $V_{F/R}$ while the motor is rotating in the
10 forward rotational direction, the switching signals may not act to produce torque which is of the opposite direction with respect to the rotational direction of the rotor, and the rotational direction of the motor may not be changed. Also, because the delay circuit 409 employed in the
15 prior art brushless motor driving system includes means such as a monostable multivibrator providing a fixed delay time, the system has not been applicable to a brushless motor whose rotational speed is variable over a wide range. Further, the prior art brushless motor
20 driving system has such an additional problem that the motor cannot be started from a standstill state because voltages are not induced in the drive coils of the individual phases in such a state of the motor.

In accordance with the present invention there is provided a system for driving a brushless motor comprising a plurality of motor drive coils of a plurality of phases respectively, a plurality of drive transistors connected to the drive coils respectively, an energization switching circuit sequentially supplying a plurality of energization switching signals to the drive transistors respectively so as to switch over energization of the drive coils, reference phase detecting means comparing voltages induced in the drive coils with

a power supply voltage for detecting a reference phase of rotation of the rotor of the motor thereby generating a plurality of reference phase pulse signals ~~corresponding to the plurality of phases respectively,~~ ~~energization switching pulse generating means for~~ ~~generating a plurality of energization switching pulse~~

signals corresponding to said plurality of phases respectively;

energization switching pulse generating means for generating a plurality of energization switching pulse signals corresponding to said
5 plurality of phases respectively, when a predetermined delay time has elapsed from the generation of said reference phase pulse signals; and

delay time setting means for setting said
10 predetermined delay time to a value proportional to a period of time from the time of generation of one of said energization switching pulse signals corresponding to a drive coil of one phase and the time of generation of one of said reference phase
15 pulse signals occurring during a de-energization time period of a drive coil of the next phase.

In the brushless motor driving system in accordance with the present invention voltages induced in the motor drive coils when the motor is rotating
20 are continuously detected to produce the energization switching signals thereby switching over energization of the drive coils, so that the motor can be continuously driven at optimum energization timing

regardless of the rotational speed of the motor.

The invention will be described now by way of example only with particular reference to the accompanying drawings. In the drawings:

5 Fig. 1 is a block circuit connection diagram showing the structure of an embodiment of the brushless motor driving system according to the present invention,

10 Fig. 2 shows signal waveforms appearing in the system shown in Fig. 1,

 Fig. 3 is a block circuit connection diagram showing the structure of a prior art brushless motor

1 driving system.

Fig. 4 shows signal waveforms appearing in the system shown in Fig. 3 when the motor is rotating in the forward rotational direction;

5 Fig. 5 shows signal waveforms appearing in the system shown in Fig. 3 when the motor is rotating in the backward rotational direction, and

Fig. 6 shows signal waveforms appearing in the system shown in Fig. 3 when the rotational
10 direction of the motor is changed.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A preferred embodiment of the present invention will now be described in detail with reference to Figs. 1 and 2.

15 Fig. 1 is a block circuit connection diagram showing the structure of a first embodiment of the brushless motor driving system according to the present invention.

Referring to Fig. 1, drive coils 2a, 2b and 2c
20 of a brushless motor are common-connected at one end to a power supply terminal 3 to which a power supply voltage V_{cc} is applied. These drive coils 2a, 2b and 2c are connected at the other ends to the collectors of drive transistors 1a, 1b and 1c respectively and
25 also to respective input terminals of a reference phase detector circuit 6 which includes comparators 11a, 11b, 11c and associated differentiators 12a, 12b, 12c.

1 The drive transistors 1a, 1b and 1c are grounded at their
emitters. The reference phase detector circuit 6 is
connected at its output terminals to corresponding
input terminals respectively of an energization switching
5 pulse generator circuit 7 and also to corresponding
input terminals respectively of a delay time setting
circuit 5. This delay time setting circuit 5 includes
comparators 20, 21, OR gates 22, 23, an RS flip-flop 24,
a capacitor 25, and transistors 30 to 38 and is
10 connected at its output terminal to another input
terminal of the energization switching pulse generator
circuit 7. This energization switching pulse generator
circuit 7 is connected at its output terminals to
corresponding input terminals respectively of an
15 energization switching circuit 8 which includes flip-
flops 15a, 15b and 15c. This energization switching
circuit 8 is connected at its output terminals to
corresponding input terminals respectively of an
energization switching signal amplifier circuit 4. This
20 energization switching signal amplifier circuit 4 is
connected at its output terminals to the bases of the
drive transistors 1a, 1b and 1c respectively.

In Fig. 1, voltages E_U , E_V and E_W are induced in
the drive coils 2a, 2b and 2c respectively when the
25 brushless motor is rotating.

The operation of the first embodiment of the
brushless motor driving system of the present invention
having the structure described above will now be

1 described with reference to Fig. 2 which shows signal waveforms appearing in the system shown in Fig. 1.

When the motor rotates, the three-phase voltages E_U , E_V and E_W having waveforms as shown in Fig. 2 are induced in the motor drive coils 2a, 2b and 2c respectively. In the reference phase detector circuit 6, these induced voltages E_U , E_V and E_W are compared with the power supply voltage V_{cc} by the comparators 11a, 11b and 11c respectively, and output signals C_U , C_V and C_W having a rectangular waveform as shown in Fig. 2 are generated from the respective comparators 11a, 11b and 11c. The differentiators 12a, 12b and 12c differentiate the trailing edges of the rectangular waveform signals C_U , C_V and C_W and generate reference phase pulse signals P_{UO} , P_{VO} and P_{WO} as their output signals respectively. These reference phase pulse signals P_{UO} , P_{VO} and P_{WO} indicate the crossing timing of the falling induced voltages E_U , E_V and E_W with the level of the power supply voltage V_{cc} and thus represent the reference phase of rotation of the rotor of the brushless motor. These reference phase pulse signals P_{UO} , P_{VO} and P_{WO} are applied to the energization switching pulse generator circuit 7 and turned into respective energization switching pulse signals P_U , P_V and P_W which are delayed by a predetermined delay time T determined by an output signal V_o of the delay time setting circuit 5. These energization switching pulse signals P_U , P_V and P_W are applied

1 to the energization switching circuit 8. The flip-flop
15a in the energization switching circuit 8 is set in
response to the application of the energization switching
pulse signal P_U . Then, when the energization switching
5 pulse signal P_V is applied, the flip-flop 15b is set,
while the flip-flop 15a is reset. Then, when the
energization switching pulse signal P_W is applied, the
flip-flop 15c is set, while the flip-flop 15b is reset.
Thereafter, the flip-flops 15a, 15b and 15c are
10 repeatedly set and reset in the order described above,
and three-phase energization switching signals OUTU,
OUTV and OUTW are generated from the energization
switching circuit 8.

It will be seen in Fig. 2 that the energization
15 switching signals OUTU, OUTV and OUTW provide optimum
energization timing with respect to the induced
voltages E_U , E_V and E_W respectively. These three-phase
energization switching signals OUTU, OUTV and OUTW
are applied, after having been power-amplified by the
20 energization switching signal amplifier circuit 4, to
the bases of the drive transistors 1a, 1b and 1c
respectively, thereby sequentially energizing the motor
drive coils 2a, 2b and 2c. Therefore, the brushless
motor continues to efficiently rotate.

25 The operation of the delay time setting circuit
5 will now be described. This delay time setting
circuit 5 includes, for example, a charge-discharge
circuit for the capacitor designated by the reference

1 numeral 25 in Fig. 1 and having a capacitance value C.
When the motor is in a standstill state and is not
rotating, the reference phase signals P_{UO} , P_{VO} and
 P_{WO} are not generated. That is, these signals P_{UO} , P_{VO}
5 and P_{WO} are not applied to the delay time setting
circuit 5. The capacitor 25 having the capacitance
value C is charged and discharged through a charge-
discharge circuit constituted by the transistors 30 to
38. The capacitor 25 is initially charged with an output
10 current I_o of the transistor 33, and the terminal
voltage V_{co} of the capacitor 25 increases. The comparator
20 compares this terminal voltage V_{co} of the capacitor
25 with a reference voltage V_H , while the comparator
21 compares the capacitor terminal voltage V_{co} with
15 another reference voltage V_L . Thus, when the voltages
 V_{co} and V_H have the relation $V_{co} \geq V_H$, the comparator
20 generates an output signal of high level. Because
the reference phase pulse signals P_{UO} , P_{VO} and P_{WO}
are not still generated at that time, the OR gate 22
20 generates an output signal P_o of low level. Therefore,
the OR gate 23 generates an output signal of high level
to set the flip-flop 24, and the flip-flop 24 generates
an output signal V_o . At this time, an inverted output
signal of low level appears from the flip-flop 24 to
25 turn off the transistor 30. When the transistor 30
is turned off, the current mirror circuit constituted
by the transistors 31 and 32 provides an output current
 $4I_o$, so that the capacitor 25 is discharged with the

1 current $3I_o = 4I_o - I_o$.

Then, when the relation $V_{co} \leq V_L$ holds, the comparator 21 generates its output signal of high level to reset the flip-flop 24, and the transistor 30 is turned on by the inverted output signal of high level appearing from the flip-flop 24. At this time, the current $4I_o$ is not supplied, and the capacitor 25 is charged by the current I_o again.

Thereafter, the charge-discharge cycle described above is repeated so that the capacitor 25 is repeatedly charged and discharged at the charge-discharge ratio of 3:1. When the motor starts to rotate, the reference phase pulse signals P_{UO} , P_{VO} and P_{WO} are generated, and the output signal P_o of the OR gate 22 has a pulse waveform such as shown in Fig. 2. The capacitor 25, which repeats the charge-discharge cycle, is discharged when the relation $V_{co} \geq V_H$ is reached to set the flip-flop 24 through the OR gate 23 to which the pulse signal P_o is applied. Thus, as shown in Fig. 2, the terminal voltage V_{co} of the capacitor 25 changes in a relation synchronous with a logical sum P_o of the reference phase pulse signals P_{UO} , P_{VO} and P_{WO} .

The coil energization timing under the above condition will now be described. Each of the pulse signals P_o representing a logical sum of the signals P_{UO} , P_{VO} and P_{WO} is generated each time the waveform of each of the falling induced voltages E_U , E_V and E_W crosses the level of the power supply voltage V_{cc} .

1 That is, the pulse signals P_0 are generated at an
angular interval of an electrical angle of 120° . The
capacitor 25 repeats its charge-discharge cycle in
synchronism with the pulse signal P_0 , and one cycle
5 corresponds to the electrical angle of 120° . Thus,
when the charge-discharge ratio of the capacitor 25
is set at 3:1, the delay time T set by the delay time
setting circuit 5 corresponds to an electrical angle of
30°. Therefore, the manner of drive coil energization
10 is such that, after the lapse of the period of time T
corresponding to the electrical angle of 30° after the
waveform of the voltage induced in the drive coil of the
first phase crosses the level of the power supply
voltage V_{cc} , energization of the drive coil of the
15 second phase is started, and, after the period of
time corresponding to the electrical angle of 120°
further elapses, energization of the drive coil of the
third phase is started. Thus, on the basis of the
energization period of time of a drive coil of the
20 present energization phase, the energization timing
and energization period of time of a drive coil of
a next energization phase are determined. Therefore,
any variation in the rotation speed of the brushless
motor can be very accurately followed up, so that the
25 optimum energization timing and period for the drive
coils of the individual phases can be maintained.
Further, the brushless motor driving system has an
additional merit from the viewpoint of costs, because

its structure is simple and it requires a very small number of external accessory parts. Also, because the energization timing and period for the drive coils of the individual phases depend only on the current charge-discharge ratio and do not depend on the capacitance value of the capacitor 25 and the levels of the reference voltages V_H and V_L , the brushless motor driving system can be easily designed and can operate with high reliability.

It will be apparent from the foregoing detailed description, that in the present brushless motor driving system the voltages induced in the drive coils of the motor are detected to sequentially switch over energization of the drive coils. Therefore, provision of a rotor position sensor such as a Hall element required hitherto for detecting angular positions of rotation of the rotor is unnecessary, so that the costs of associated parts and the number of connection wires can be decreased. Further, in the brushless motor driving system the manner of producing the energization switching signals used to switch over energization of the respective drive coils of the

motor is such that, on the basis of the period of time of energization of a drive coil of one phase, the energization timing and energization period of time for a drive coil of a next energization phase are set.

- 5 Therefore, any variation in the speed of the brushless motor can be very accurately followed up, so that the motor can always be driven at optimum energization timing. Further, the brushless motor driving system has an additional merit, since its structure is simple
- 10 and it can operate without depending on the operating characteristics of external accessory parts in setting the energization timing. Therefore the brushless motor driving system has a merit of reductions in cost and yet it can operate with high reliability.



CLAIMS:

1. A system for driving a brushless motor comprising:

a plurality of motor drive coils of a plurality of phases respectively;

a plurality of drive transistors connected to said drive coils respectively;

an energization switching circuit sequentially supplying a plurality of energization switching signals to said drive transistors respectively so as to switch over energization of said drive coils;

reference phase detecting means comparing voltages induced in said drive coils with

a power supply voltage for detecting a reference phase of rotation of the rotor of the motor, thereby generating a plurality of reference phase pulse signals corresponding to said plurality of phases respectively;

energization switching pulse generating means for generating a plurality of energization switching pulse signals corresponding to said plurality of phases respectively, when a predetermined delay time has elapsed from the generation of said reference phase pulse signals; and

delay time setting means for setting said predetermined delay time to a value proportional to a period of time from the time of generation of one of said energization switching pulse signals corresponding



to a drive coil of one phase and the time of generation of one of said reference phase pulse signals occurring during a de-energization time period of a drive coil of the next phase.
