(12) UK Patent Application (19) GB (11) 2 314 703 (13) A

(43) Date of A Publication **07.01.1998**

(21) Application No **9713251.8**

(22) Date of Filing **23.06.1997**

(30) Priority Data
(31) **96018546U** (32) **28.06.1996** (33) **KR**

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(51) INT CL[6]
H02P 7/05 , H02H 7/085

(52) UK CL (Edition P)
H2K KSD1X K252 K452 K512 K621
H2J JCSR JEP J11P J11TR J11VV

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(58) Field of Search
UK CL (Edition O) **H2J JEP , H2K KSD1A KSD1X**
INT CL[6] **H02H 7/08 7/085 , H02P 1/16 3/06 5/05 7/05**
Online: WPI

(54) Driving circuit for a switched reluctance motor

(57) A driving circuit for a switched reluctance motor includes a current sensor 50 which senses current flowing into the motor driving circuit and outputs a signal V1. A comparator 60 compares the signal V1 with a reference current level Vref, and outputs a stop signal V2 if the current flowing in the motor driving circuit exceeds the reference level. A signal selecting unit 70 receives the signal V2 from the comparator, a pulse width modulated signal and a rotor position signal, and outputs gate controlling signals for turning off motor phase switching elements during an input of the stop signal from the comparator. The protection of the driving circuit against excess current improves reliability of the motor, as well as eliminating the ripple component in the driving current (torque ripple) generated at the time of an initial start-up of each phase, which reduces the noise produced by the motor.

FIG.6

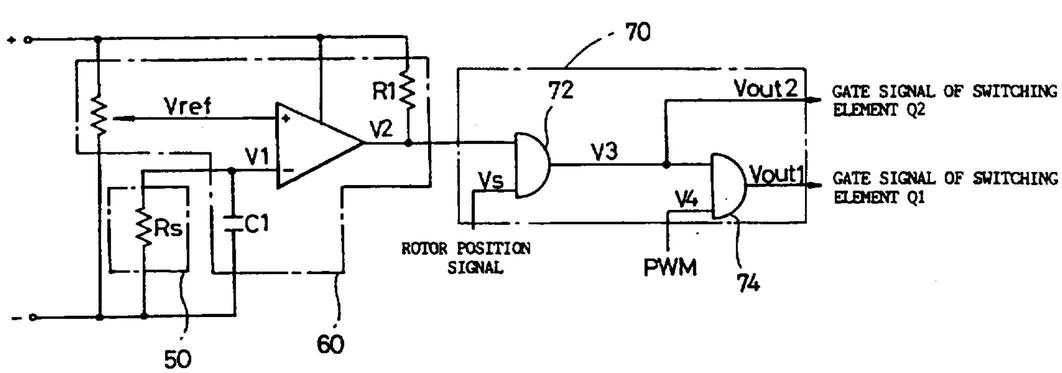

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FIG. 1
(PRIOR ART)

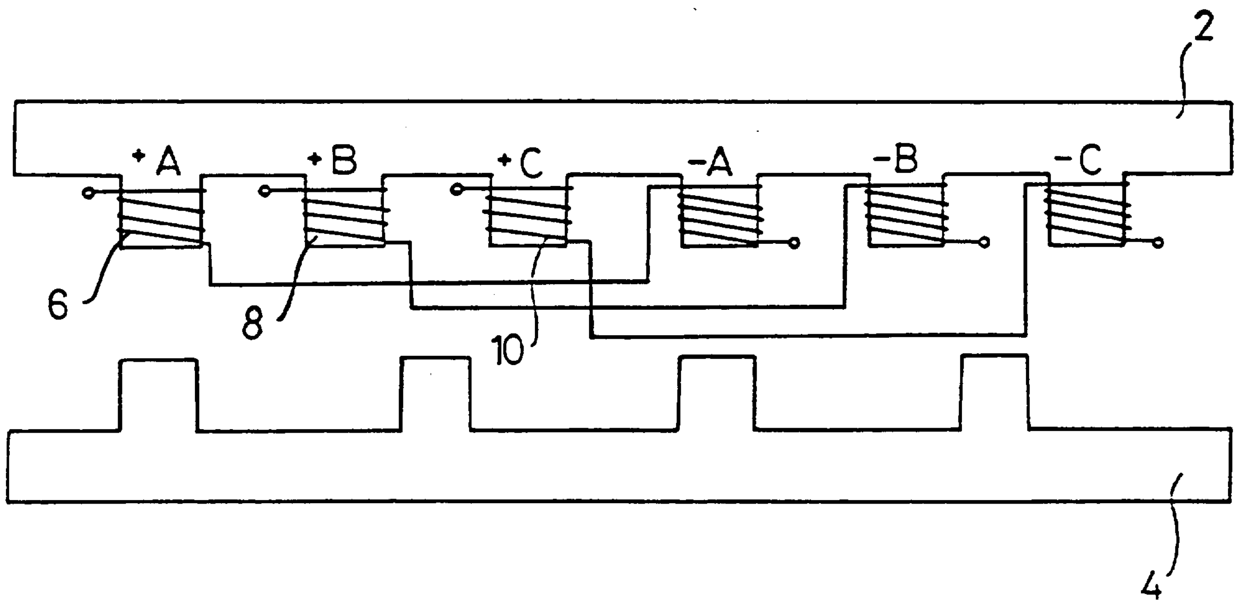


FIG. 2
(PRIOR ART)

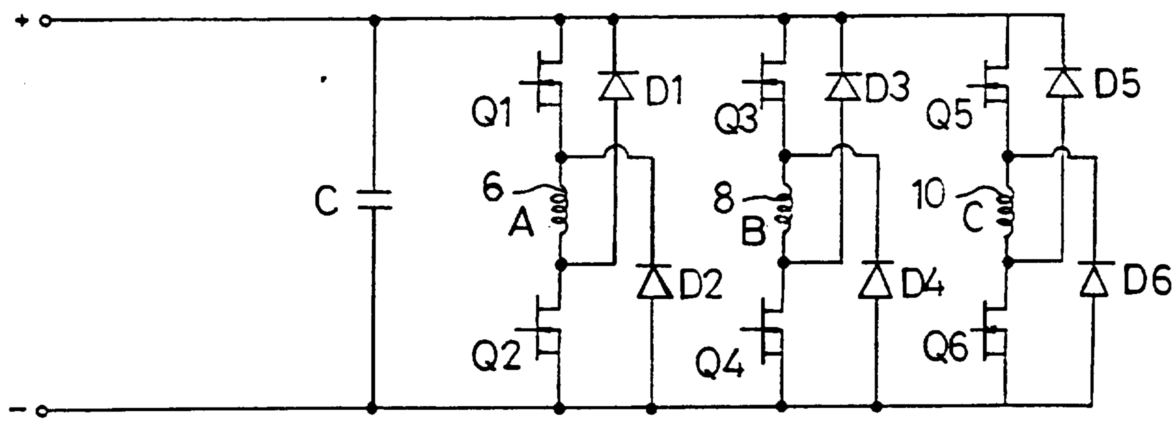
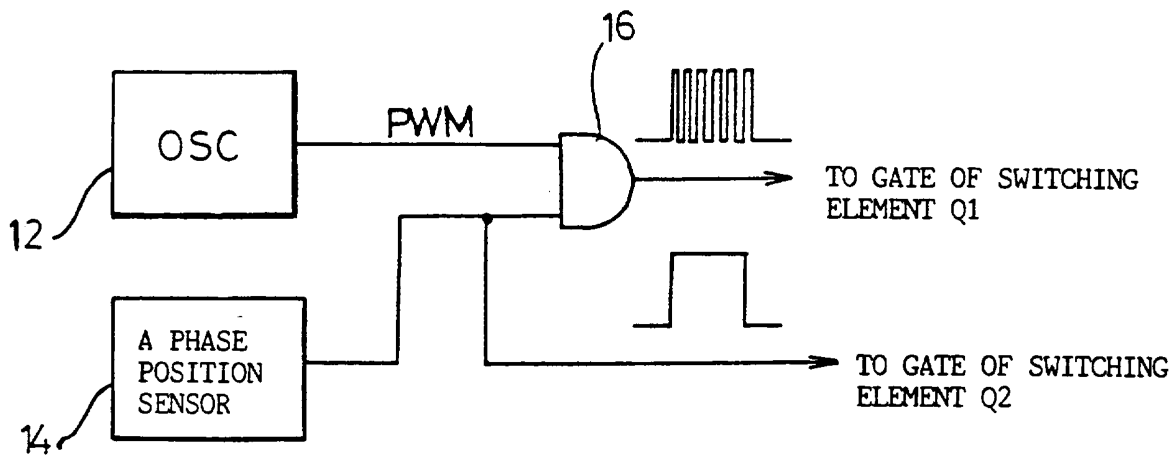


FIG. 3
(PRIOR ART)



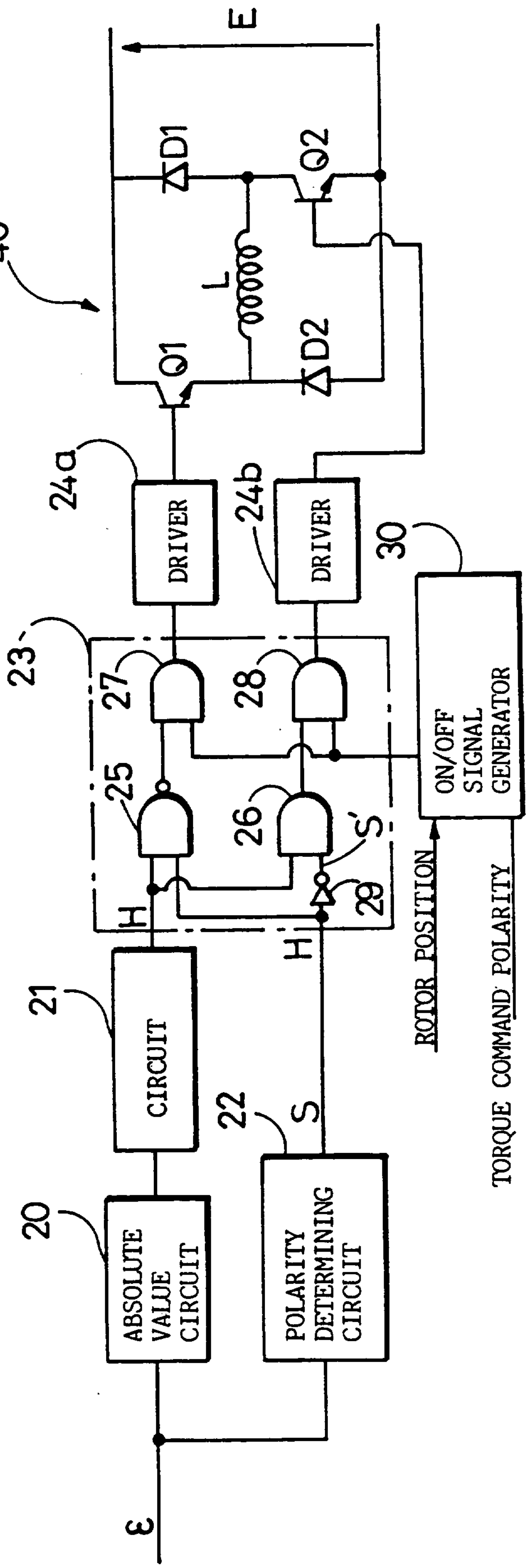


FIG.4
(PRIOR ART)

FIG.5

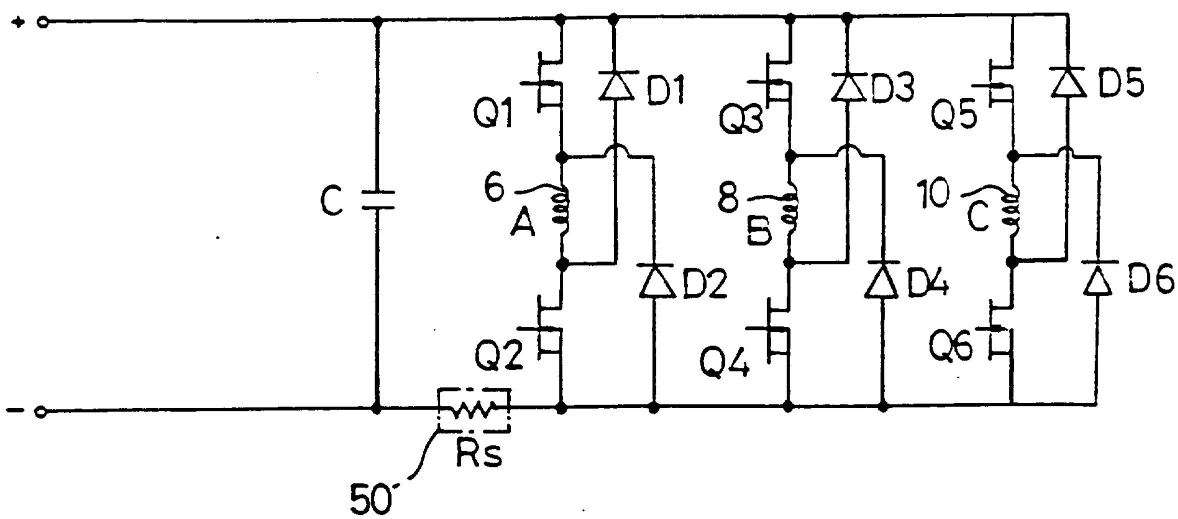
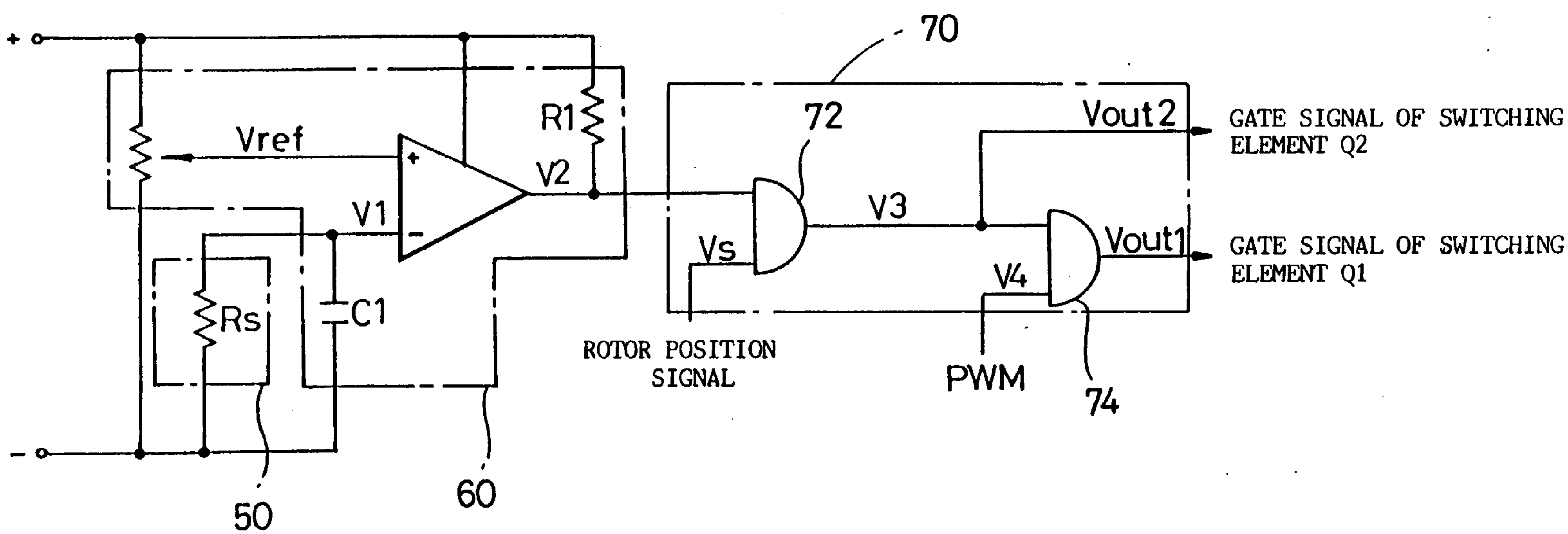


FIG. 6



+
-
Vref
R1
V1
V2
Rs
C1
50
60
70
72
V3
Vs
ROTOR POSITION SIGNAL
V4
PWM
74
Vout2
Vout1
GATE SIGNAL OF SWITCHING ELEMENT Q2
GATE SIGNAL OF SWITCHING ELEMENT Q1

FIG.7

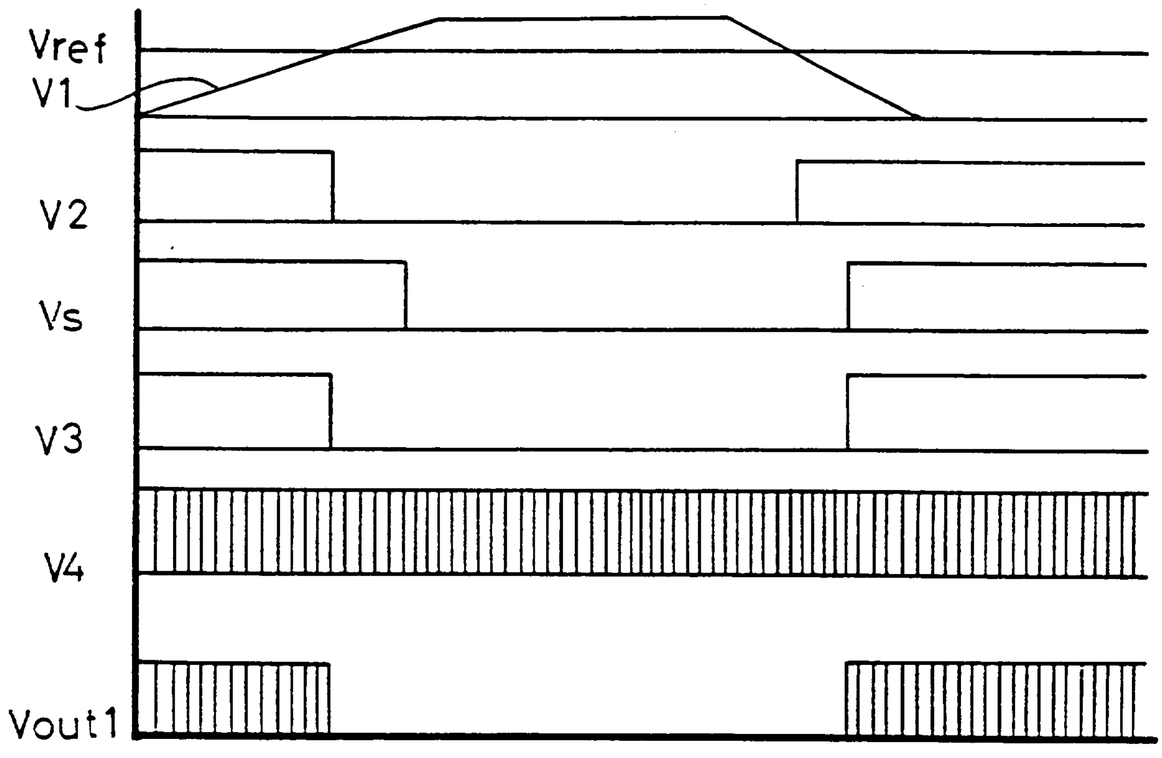
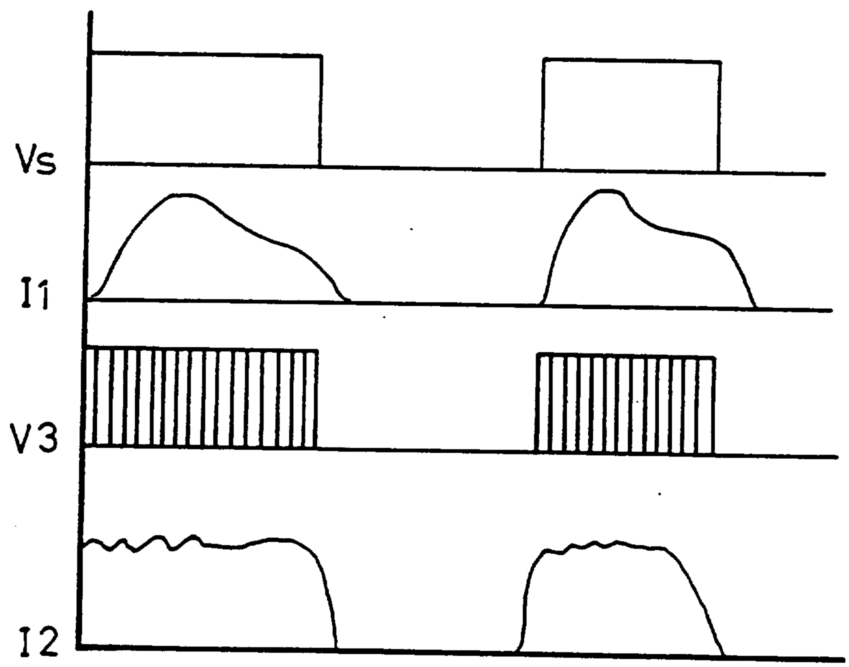


FIG.8



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Driving Circuit for a Switched Reluctance Motor

Description

The present invention relates to a driving circuit for a switched reluctance motor.

Referring to Figure 1, a switched reluctance motor includes a stator 2 and a rotor 4. The stator 2 has three pairs of poles +A, -A, +B, -B, +C, -C (or, salient pole C) on which an A phase coil 6, a B phase coil 8, and a C phase coil 10 are respectively wound. A driving circuit for such an switched reluctance motor consists of, as shown in Figure 2, a smoothing capacitor C for producing a dc voltage, a plurality of switching elements Q1, ..., Q6 for applying driving voltagages to respective phase coils 6, 8, and 10, six diodes D1, ..., D6 for protecting the switching elements against the back electromotive forces created when the respective switching elements Q1, ..., Q6 are turned off.

The switching of the A-phase switching elements Q1, Q2 is controlled by a signal produced by a gate signal generating unit. This unit includes, as shown in Figure 3, an oscillator 12 which outputs a pulse width modulated (PWM) signal, an AND logic gate 16 which produces the logical product of the PWM signal and a position information signal provided by an A phase position sensor 14 when the rotor 4 faces the A phase pole of the stator 2. The signal from the AND logic gate 16 is applied to the upper A phase switching element Q1 and the position information signal from the A phase position sensor 14 is applied to the lower A phase switching element Q2.

An application of a power to the A phase of the switched reluctance motor is achieved by applying the operational signals, from the logic gate 16 and the A phase position sensor, to the gates of A phase-related switching elements Q1, Q2. When turned on, the A phase switching elements Q1, Q2 allow electric current to flow through the A phase coil of the stator 2, resulting in magnetization of the poles +A and -A of the stator 2. The magnetized poles pull on the nearest poles of the rotor 4.

The B and C phase coils 8, 10 are driven in a similar manner to the A phase coil 6. The coils 6, 8, 10 are energized in the order A B C causing the rotor to rotate.

However, reliabile operation of a switched reluctance motor cannot be guaranteed when abnormal operations and surge currents occur in the drive circuit. This reduces the efficiency of the motor. Moreover, there is a problem in that the motor becomes noisy as a result of drive current ripple and torque ripple phenomena during initial start-up of each phase.

Figure 4 shows a schematic block diagram of a control circuit for a variable reluctance motor, which is disclosed in US-A-5225758, wherein the drive circuit controls the motor in such a manner that the average voltage, that is to be supplied to the coil for a current deviation or current command, linearly varies. For this, the control circuit has an absolute value circuit 20, a PWM circuit 21, a polarity determining circuit 12, a signal selection circuit 23, first and second drivers 24a, 24b, an On/Off signal generator 30, and a driving circuit 40.

The absolute value circuit 20 receives both a current command from a computer and a current deviation, for a current in reality, compares them with a carrier signal, and produces an output representing an absolute value for the current deviation. The output is applied to the PWM circuit 21 to obtain a PWM signal which is output to the signal selection circuit 23.

In the case of the current deviation being above 0, the polarity determining circuit 22 outputs a low level signal to turn on a first transistor Q1 in the driving circuit 40. When the output signal from the On/Off signal generator 30 is high, a second transistor Q2 is turned on and off in dependence on the PWM signal output from the PWM circuit 21.

In the case of the current deviation being below 0, the second transistor Q2 is turned off by the signal selection circuit 23 and the first transistor Q1 is turned on and off by the PWM signal.

As a result, the average coil voltage linearly varies with respect to the current deviation, or the current command, by which proper control of the motor can be readily achieved.

The above-described control circuit for a switched reluctance motor determines a duty ratio for the PWM in response to the current deviation or the current command, and selects and operates switching elements for applying the PWM signal based upon the polarity of the current deviation, so as to produce a linear variation in the average coil voltage with respect to the current deviation or the current command.

According to the present invention, there is provided a driving circuit for a switched reluctance motor comprising switching means for sequentially energizing the coils of a switched reluctance motor, and a sensor for producing an output in dependence on the current supplied by the circuit to a motor coil, wherein the switching means is responsive to the output of the sensor indicating that the current supplied to the energized coil exceeds a threshold value to de-energize an energized motor coil.

Preferably, the switching means includes switching devices for energizing coils of a motor and a comparator for comparing the output of the sensor with a reference and gate means for selectively enabling and disabling the supply control signals to the switching devices in dependence on the output of the comparator.

More preferably, the gate means comprises a first AND-gate having the output of the comparator and a rotor position signal as its inputs, and a second AND-gate having the output of the first AND-gate and a PWM motor control signal as its inputs, the outputs of the first and second AND-gates being control signals applied respectively to two switching devices for energizing one phase of a motor.

An embodiment of the present invention will now be described, by way of example, with reference to Figures 5 to 8 of the accompanying drawings, in which:
Figure 1 schematically shows the construction of a conventional switched reluctance motor;
Figure 2 is a circuit diagram of a conventional switched reluctance motor driving circuit;
Figure 3 is a circuit diagram of a conventional circuit for controlling the switching elements of Figure 2;
Figure 4 is a schematic block diagram of a prior art control circuit for a switched reluctance motor;
Figure 5 is a circuit diagram of a driving circuit for a srm according to the present invention;
Figure 6 is a circuit diagram of a control circuit for controlling a switched reluctance motor in accordance with the present invention;
Figure 7 shows the waveforms at various points in Figure 6; and
Figure 8 shows the electric current waveform after electric current control.

Referring to Figure 5, a switched reluctance motor driving circuit includes a smoothing capacitor C for producing a dc voltage, a plurality of switching elements Q1, ..., Q6 for applying the voltage to respective phase coils 6, 8, 10, six diodes D1, ... D6 for protecting the switching elements against the back electromotive forces created when the respective switching elements Q1, ..., Q6 are turned off., and a resistor Rs which serves to sense the electric current flowing through the switching elements Q1, ..., Q6 and generate a voltage proportional to the sensed current.

Referring to Figure 6, the switched reluctance motor driving control circuit consists of current sensing means 50 (i.e. the resistor Rs in Figure 5) which senses the current flowing into the driving circuit of an switched reluctance motor and outputs a signal representing the current flowing in the driving circuit, comparing means 60 which compares a reference current value with the sensed current, and outputs a stop signal in the case of the current flowing in the driving circuit exceeding the reference current value, and signal selecting means 70 which receives output signals from the comparing means 60, a pulse width modulated (PWM) signal and a rotor position signal, and outputs gate controlling signals for turning off the switching elements during input of the stop signal from the comparing means 60.

The resistor Rs of the current sensing means 50 is coupled to negative (-) terminal of the switched reluctance motor driving circuit.

The comparing means 60 consists of a variable resistor VR for setting a reference voltage Vref, a capacitor C1 for eliminating noise components contained in the voltage signal output from the current sensing resistor Rs, and an op-amp which outputs a low level signal when a voltage value of a voltage signal applied through the capacitor C1 is larger than that of the reference voltage Vref, and outputs a high level signal when the voltage value of a voltage signal applied through the capacitor C1 is smaller than that of the reference voltage Vref.

The signal selecting means 70 consists of a first AND-gate 72 which produces the logical product of the output signal from the comparing means 60 and the rotor position signal and outputs it for controlling the gate of the upper switching element Q1, and a second AND-gate 74 which produces the logical product of the output signal from the first AND-gate 72 and the PWM signal and outputs it for controlling the gate of the upper switching element Q2.

Reference symbol R1 denotes a bias resistor.

The operation the switched reluctance motor driving control circuit will now be described with reference to Figures 5 to 8.

A direct voltage is applied to the A-, B- and C-phase coils 6, 8, 10 of the driving circuit through identical voltage application procedures. For the purpose of applying electric power to the A-phase coil 6, if operation signals are provided to the gates of the switching elements Q1, Q2, electric current flows into the A-phase coil 6 of the stator, so that the poles +A and -A of the stator are magnetized. The magnetized poles of A-phase generate a force for attracting nearby rotor poles, which causes the rotation of the rotor.

Similarly, the above procedures are also applied to B- and C-phase coils 8 and 10. The stators of A-, B-, and C-phases are sequentially magnetized in the above-mentioned order, resulting in the continued rotation of the rotor.

When the A phase-related switching elements Q1, Q2 are off, and the B phase-related switching elements are on, a voltage remaining in the A phase coil charges the capacitor C through the diode D2, A phase coil 6 and then diode D1. The charge stored in the capacitor C is afterward utilized during the subsequent operation. This action improves the efficiency of the motor.

The current sensing resistor Rs connected to the negative terminal of the driving circuit senses the electric current flowing into the driving circuit and outputs a voltage signal whose level is determined according to Ohm's Law by the well-known fundamental equation, V=IR.

As shown in Figure 7, if the voltage value V1 of the voltage signal from the current sensing resistor Rs exceeds the reference voltage Vref, produced from the variable resistor VR, the OP-amp outputs a low level signal.

The voltage V2 output from the OP-amp is input to the first AND-gate 72 which also receives the rotor position signal Vs. The output V3 of the first AND-gate 72 is supplied to the gate of the switching element Q2. Also, the PWM signal V4 for changing the speed is input to the second AND-gate 74 which also receives the output signal V3 from the first AND-gate 72. The output Vout1 of the second AND-gate 74 is supplied to the gate of the switching element Q1.

Accordingly, during output of a low level signal from the op-amp, the gate signals for the switching elements Q1, Q2 are not output regardless of the rotor position signal Vs, so that the driving circuit is maintained in a pause state.

In Figure 8, there are shown peak currents I1 and I2 sensed at the start-up of each phase, the former I1 not being subjected to the current control, and the latter I2 being when the current control is made according to the present invention. Since the smoothing of the initial peak current also results in the elimination of torque ripple, the torque ripple of the motor is reduced.

According to the present invention, the protection of the driving circuit against excess current improves the reliability of the srm, as well as eliminating the ripple component in the driving current (torque ripple) generated when each phase is energized, which makes the motor less noisy of the motor.

Claims

1. A driving circuit for a switched reluctance motor comprising switching means for sequentially energizing the coils of a switched reluctance motor, and a sensor for producing an output in dependence on the current supplied by the circuit to a motor coil, wherein the switching means is responsive to the output of the sensor indicating that the current supplied to the energized coil exceeds a threshold value to de-energize an energized motor coil.

2. A driving circuit according to claim 1, wherein the switching means includes switching devices for energizing coils of a motor and a comparator for comparing the output of the sensor with a reference and gate means for selectively enabling and disabling the supply control signals to the switching devices in dependence on the output of the comparator.

3. A driving circuit according to claim 2, wherein the gate means comprises a first AND-gate having the output of the comparator and a rotor position signal as its inputs, and a second AND-gate having the output of the first AND-gate and a PWM motor control signal as its inputs, the outputs of the first and second AND-gates being control signals applied respectively to two switching devices for energizing one phase of a motor.

4. A driving circuit for a switched reluctance motor (SRM), the circuit having a plurality of switching elements operated in response to gate signals input from an external, for applying or cutting off a direct voltage to each phase coil, the circuit comprising:

current sensing means which senses current amount flowing into a driving circuit of the SRM and outputs a signal representing current amount flowing in the driving circuit;

comparing means which compares a reference current amount with current amount flowing in the driving circuit in response to the output signal from the current sensing means, and outputs a stop signal in case the current amount flowing in the driving circuit of the SRM exceeds the reference current amount; and

signal selecting means which receives output signals from the comparing means, a Pulse Width Modulated (PWM) signal and a rotor position signal, and outputs a gate controlling signal for turning off the switching element during an input of the stop signal from the comparing means.

5. The motor as defined in claim 4, wherein the current sensing means comprises a current sensing resistor coupled to minus(-) terminal of the driving circuit for the SRM, which serves to output a voltage signal proportional to a driving current value.

6. The circuit as defined in claim 5, wherein the comparing means consists of a variable resistor for determining a reference voltage Vref, a capacitor for eliminating noise components contained in the voltage signal output from the current sensing resistor, and an OP-amp which outputs a low level signal when a voltage value of a voltage signal applied through the capacitor is larger than that of the reference voltage Vref, and outputs a high level signal when a voltage value of a voltage signal applied through the capacitor is smaller than that of the reference voltage.

7. The circuit as defined in claim 6, wherein the signal selecting means consists of a first logic product gate which performs logic product of the output signal from the comparing means and the rotor position signal and then produces a signal for controlling the gate of the upper switching element, and a second logic product gate which performs logic product of the output signal from the first logic product gate and the PWM signal and then produces a signal for controlling the gate of the upper switching element.

8. A driving circuit for a switched reluctance motor substantially as hereinbefore described with reference to Figures 5 and 6 of the accompanying drawings.

Application No: GB 9713251.8 **Examiner:** David Brunt
Claims searched: 1 to 8 **Date of search:** 15 September 1997

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H2K (KSD1A, KSD1X), H2J (JEP)

Int Cl (Ed.6): H02H (7/08, 7/085), H02P (1/16, 3/06, 5/05, 7/05)

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	EP 0635931 A2	(SWITCHED RELUCTANCE DRIVES) see column 9 lines 4-9 & Fig 7(a)	1,2
X	EP 0577843 A1	(SEKOGIKEN) see column 22 lines 17-33 & Fig 5	1,2
X	EP 0512121 A1	(SEKOGIKEN) see column 5 lines 5-48 & Fig 4	1,2
X	EP 0429659 A1	(SEKOGIKEN) see column 16 lines 4-14 & Fig 7	1,2
X	EP 0399146 A1	(GE) see column 10 lines 8-58 & Figs 1B & 10	1,2
X	EP 0397514 A2	(GE) see whole document	1,2
X	US 4896089	(KLIMAN) see column 5 line 67 to column 6 line 17	1,2

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