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D E C I S I O N
of 6 February 2004

Case Number: T 0250/01 - 3.5.2

Application Number: 95630104.8

Publication Number: 0765027

IPC: H02P 7/05

Language of the proceedings: EN

Title of invention:
Noise reduction in a switched reluctance motor by current profile

Applicant:
EMERSON ELECTRIC CO.

Opponent:
-

Headword:
-

Relevant legal provisions:
EPC Art. 56, 84

Keyword:
"Inventive step (yes)"
"Claims - clarity (yes)"

Decisions cited:
-

Catchword:
-

Case Number: T 0250/01 - 3.5.2

D E C I S I O N
of the Technical Board of Appeal 3.5.2
of 6 February 2004

Appellant: EMERSON ELECTRIC CO.
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Decision under appeal: **Decision of the Examining Division of the European Patent Office posted 6 September 2000 refusing European application No. 95630104.8 pursuant to Article 97(1) EPC.**

Composition of the Board:

Chairman: W. J. L. Wheeler
Members: F. Edlinger
B. J. Schachenmann

Summary of Facts and Submissions

I. The appeal is against the decision of the examining division refusing European patent application No. 95 630 104.8. The reasons given for the refusal were that the claims were unclear and their subject-matter lacked novelty in view of the following document:

D1: WO-A-94/28618.

II. In a communication sent with summons to oral proceedings, the Board referred to the following further documents, which are cited in the search report:

D2: US-A-5 446 359 and

D3: IEE Proceedings-B, Electrical Power Applications, vol. 140, no. 5, Part B, 1 September 1993, pages 316 to 322, XP 000403680; CHAN, S. et al "Performance enhancement of single-phase switched-reluctance motor by DC link voltage boosting".

III. Following this communication and a telephone conversation between the representative and the rapporteur, the appellant filed a new set of claims 1 to 6 and a new page 1 of the description by telefax of 26 January 2004.

IV. The Board then cancelled the oral proceedings.

V. The appellant requested that the contested decision be set aside and a patent be granted on the basis of claims 1 to 6 and page 1 of the description filed with telefax dated 26 January 2004, pages 2 to 14 of the description as indicated in the contested decision, and drawings, sheets 1/3 to 3/3 as originally filed.

VI. Claim 1 is worded as follows:

"Apparatus (10) for controlling the current profile in a single or polyphase switched reluctance motor (SRM) during the active portion of a phase comprising:
a phase winding (W);
switch means (12) for directing current flow into the winding (W) when the phase is active;
sensing means (14) for sensing operating conditions of the SRM;
signal generating means (16) providing an operating signal to the switch means (12) to control current flow to the winding (W);
control means (18) responsive to the sensing means (14) for controlling the signal generating means (16) for the signal generating means to provide operating signals having operating characteristics by which the current supply to the winding (W) is in accordance with a predetermined profile; and
the signal generating means (16) includes a PWM signal generator the pulse width, duty cycle, and frequency of which are functions of the SRM's operating characteristics, and the desired current profile to be produced when the phase is active;

characterized in that

the control means (18) is responsive to inputs from the sensing means (14) when the phase becomes active to vary, during a first time segment (T_0-T_x), the duly [*sic*] cycle and/or frequency of the PWM operating signals

produced by the signal generating means (16) so that the duty cycle is initially one length which becomes progressively shorter, and/or the initial frequency becomes progressively higher, as the current goes from zero until it reaches a peak value (Ip') of the current profile,
and to provide a constant frequency and a constant duty cycle of the PWM operating signals during a second time segment (T_x-T_c) from the time (T_x) when the current reaches the peak value (Ip') of the current profile until the phase becomes inactive so that the current flow, during the first time segment, is rapidly increased from zero to the peak value (Ip') when the phase becomes active and then allowed to decrease, during the second time segment, from the peak value (Ip') to a second and lesser value (Ip) by the time (Tc) the phase becomes inactive, the current decaying from this second value (Ip) to zero when the phase becomes inactive whereby the transition in the current profile which occurs when the phase switches from active to inactive is not an abrupt transition, this non-abrupt transition reducing the amount of ringing in the motor which normally occurs when current flow into the winding (W) ceases thereby to reduce motor noise."

Claims 2 to 5 are dependent on claim 1.

VII. Claim 6 is worded as follows:

"A method for controlling the current profile in a single or polyphase switched reluctance. [*sic*] motor (SRM) during the active portion of a phase comprising:

switching a phase winding (W) into a circuit by which current flow is directed into the winding (W) when the phase is active;
generating PWM operating signals which are used to control current flow to the winding; and,
controlling the signal characteristics of the operating signals for the operating signals to have operating characteristics by which the current supply to the winding is in accordance with a predetermined profile,

characterized in that

the initial duty cycle and/or the initial frequency, during a first time segment (T_0-T_x) becomes progressively a shorter duty cycle, respectively a higher frequency, as the current goes from zero until it reaches a peak value (Ip') of the current profile, and have a constant frequency and a constant duty cycle during a second time segment (T_x-T_c) from the time (T_x) when the current reaches the peak value (Ip') of the current profile until the phase becomes inactive,
so that the current flow is rapidly increased from zero to the peak value (Ip') when the phase becomes active and then allowed to decrease during the second time segment from the peak value (Ip') to a second and lesser value (Ip) by the time (T_c) the phase becomes inactive, the current decaying from this second value (Ip) to zero when the phase becomes inactive whereby the transition in the current profile which occurs when the phase switches from active to inactive is not an abrupt transition, this non-abrupt transition reducing the amount of ringing in the motor which normally occurs when current flow into the winding (W) ceases thereby to reduce motor noise."

VIII. The reasons for refusal given in the contested decision, as far as they are applicable to the new claims 1 and 6, may be summarised as follows:

The claims did not comply with the requirements of Article 84 EPC. The active and inactive phase periods were not clearly defined and seemed to differ from the usual meaning of these terms in that the active phase usually was the period wherein the motor inductance increased, and the inactive phase the remaining period starting at the moment where the rotor pole faced the stator pole. According to Figure 4a the active period started at time T_o and ended at time T_c set in the middle of the increasing phase inductance period. No information was given in the application for determining this point. The description (page 7, last paragraph) confirmed this lack of definition saying that "the length of time each phase is active is based on various parameters". Since after time T_c the inductance further increased and positive current still flowed through the phase winding and generated a positive torque, this period should be considered as an active period.

D1, Figure 6b, disclosed an apparatus and method with a rapid increase of the current flow from zero to a peak value when the phase became active. The current was then allowed to decrease to a second and lesser value by the time the phase became inactive. Subsequently, the current decayed to zero during the inactive portion of a phase. The average voltage was significantly higher during the initial active portion of the phase than during its inactive portion (period "T" in

Figure 6b; cf D1, page 21, lines 22 to 24). Pulse width modulation of the voltage was used to control the current profile during the inactive portion of a phase and could even continue over the whole commutation period (D1, page 21, lines 28 to 34).

IX. The appellant essentially argued as follows:

The amended claims now clearly defined that the motor current control comprised two time segments during an active portion of a phase and thereafter a time segment during an inactive portion of a phase. In the first time segment, the current was controlled to rapidly increase to a peak value when the phase became active. The current was then allowed to decrease to a second lower value during a time segment prior to the commutation point, viz a time segment during which the pole inductance was still increasing (Figure 4A). A reduced average voltage (Figure 4E) was thus applied to the winding whereby the current was decreased (Figure 4D) by the increasing phase induction to a lower value. Thereafter, the current decreased from the lower value to zero after the commutation point.

D1, Figure 6b, showed current and voltage profiles for current control of a switched reluctance motor where the average voltage and the motor current were decreased during a relatively short period T after the commutation point 17 (D1, page 15, line 17). After the period T, a negative voltage was applied to the winding which had the effect of cancelling the noise produced when zero voltage was applied during the period T. Also D2 disclosed current profiles obtained by decreasing the average voltage after the commutation point. D3 only disclosed a boost capacitor, but not a PWM controlled rapid increase when the phase became active, followed by a decreasing centre portion of the current phase.

Reasons for the Decision

1. The appeal is admissible.

2. The amended claims 1 and 6 are directly and unambiguously derivable from a combination of claims 1, 4 and 6 to 12, and claims 29 to 33 of the application as filed, respectively. Figures 4A to 4E and 7A to 7C and the passage from page 11, last paragraph to page 13, first paragraph of the application as filed further support these amendments. Claim 2 may be derived from page 3, lines 9 to 15, and page 8, paragraph 2, of the application as filed. Claims 3 to 5 substantially correspond to claims 2, 3 and 5 of the application as filed. The amended claims 1 to 6 do not infringe Article 123(2) EPC.

3. Claims 1 and 6 specify "switch means" and "switching a phase winding", respectively, for the purpose of directing current flow "into the winding (W) when the phase is active". This defines the active portion of a phase as a time period when a phase winding is energised by current from a power source, exemplified as period T_O-T_C in Figure 4 of the application (cf page 7, line 3 from below to page 8, line 2, and page 9, lines 4 to 10 of the application). The purpose of the claimed apparatus and method is "controlling the current profile … during the active portion" by

generating PWM operating signals. The active portion will thus include portions of increasing and decreasing instantaneous phase current when both switch means are on, and at least one of the switch means is turned off, respectively. But only the active portion will have portions of increasing instantaneous phase current and a net flow of energy to the motor. In switched reluctance motors, the active portion begins with, or is in advance of, the increasing portion of the inductance characteristics, and it ends at the commutation point, at or before the inductance peak, when the next phase takes over the production of motor torque in turn (page 2, lines 8 to 10; Figure 4A to 4E of the application as filed). No current is directed "into" the winding during the inactive portion of a phase after the commutation point, but phase current continues to flow, due to electromagnetic inertia, in a zero voltage loop (freewheel) or a negative voltage loop (energy recovery). The terms "active portion" and "inactive portion" thus have substantially the same meaning as in the prior art (cf D1, pages 1 and 2, bridging paragraph; page 11, line 2 from below to page 12, line 3 and page 18, paragraph 2; D2, column 2, lines 53 to 59). The choice of an appropriate advance angle for the beginning and end of the active phase is a matter of normal design. It cannot be fixed in advance without taking account of the given operating parameters of the motor, eg rotor speed and torque requirements (cf D1, page 13, paragraph 2; D2, column 3, lines 59 to 65; D3, page 317, left-hand column, paragraph 2 from below and Figure 1). The passage on page 7, last paragraph, of the present application is a reference to this variable length of time. Therefore, claims 1 and 6 clearly define the matter for which protection is sought and are supported by the description as required by Article 84 EPC.

4. Each of D1 and D2 discloses an apparatus and a method as specified by the precharacterising parts of the present claims 1 and 6, respectively. Both D1 and D2 deal with a similar problem as the present application (page 1, lines 20 to 25 and page 9, line 4 from below to page 10, line 3), namely to reduce, throughout the range of SRM operation, the noise which is caused by an abrupt change in the normal forces to which the motor is subjected.

5. D1 solves the problem by selectively producing a further vibration through a second switching step a time T later which has the effect that the two vibrations tend to at least partially cancel one another (D1, page 4, first paragraph). In a multi-step mode of operation, chopping of the phase current or a gradual reduction may be provided over at least part of the "commutation" period (D1, page 7, paragraph 2 to page 8, paragraph 2; page 21, last paragraph), ie the phase current will be reduced after the commutation point 17 when the active portion of this phase comes to an end (D1, page 15, lines 14 to 20 and Figures 6b and 6c).

6. D2 (Abstract; column 1, lines 17 to 37; column 8, lines 20 to 33; claim 2; Figure 9B) teaches to control tail current decay in order to reduce the abrupt transition in slope in the current curve between the shallow slope representing the active portion of the cycle and the steep slope where the current is falling to zero when the phase becomes inactive. To accomplish

this, the control circuit combines both hard chopping and soft chopping current decay control techniques. As in the case of D1, the resulting change in the slope of the current curve concerns time segments when the commutation has started and no more current flows from the power source into the winding.

7. None of the documents D1 to D3 cited in the search report gives a hint at progressively reducing the duty cycle and/or increasing the frequency of the operating signals during a first time segment (T_0-T_x) at the beginning of the phase's active period, and maintaining a constant duty cycle and frequency during a second time segment (T_x-T_c) until the end of the active portion of a phase. The winding current is thus raised to a high peak value (Ip') and decreases, by the application of a constant lower average voltage and by virtue of the increasing inductance, to a second and lesser value (Ip) by the time the phase becomes inactive (Figure 4D). In this way, the change in slope of the winding current may be reduced at the transitions of the time segments at time T_x and T_c. Motor noise which results from abrupt changes in winding current may thus be reduced (page 2, last paragraph; pages 4 and 5, bridging paragraph; page 12, paragraph 1 of the present application). Although D3 (Abstract and page 318, left-hand column; Figures 2 and 3) discloses a similar current profile with a rapid initial increase and a decreasing slope in the active phase, obtained by applying a high boost voltage during current pull-up, it is not concerned with reducing the motor noise and does not suggest that the winding current should be controlled by PWM operating signals to decrease from a peak value in the active portion of a phase.

8. In the judgment of the Board, the subject-matter of claims 1 and 6 is thus considered as involving an inventive step having regard to the documents D1 to D3 cited in the search report (Article 56 EPC).

9. The Board has noted an obvious clerical error in each of the claims 1 and 6 (identified by a [*sic*] in paragraphs VI and VII above). Since it is quite clear what the appellant intended to say, the Board can order correction of these errors without further ado.

Order

For these reasons it is decided that:

1. The decision under appeal is set aside.

2. The case is remitted to the department of first instance with the order to grant a patent in the following version:

   Claims 1 to 6 as filed with the telefax of 26 January 2004, with correction of the obvious errors (duly cycle should read duty cycle in claim 1, and the full stop after reluctance should be deleted in claim 6).

   Description, page 1 as filed with the telefax of 26 January 2004,
   pages 3 and 4 as filed with the letter of 1 June 1999,
   pages 2 and 5 to 14 as originally filed.

   Drawings, sheets 1/3 to 3/3 as originally filed.

The Registrar: The Chairman:

D. Sauter W. J. L. Wheeler