(54) Title: METHOD FOR STARTING A SENSORLESS SINGLE-PHASE ELECTRIC MOTOR AND SENSORLESS SINGLE-PHASE ELECTRIC MOTOR
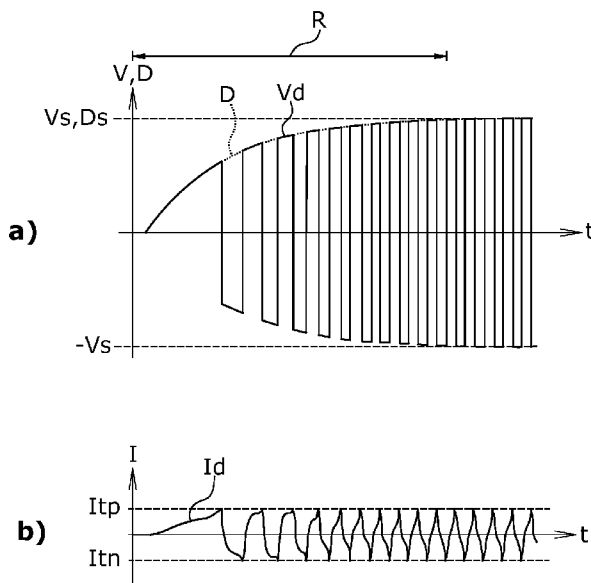
Fig.3

(57) Abstract: The invention is directed to a method for starting a sensorless single-phase electric motor (10), the electric motor comprising (10): - a permanent magnetic motor rotor (24), - an electromagnetic motor stator (12) with a stator coil (16), - a power electronics (26) for energizing the stator coil (16), - a current sensor (32) for measuring a current (I) flowing in the stator coil (16), and - a control electronics (28) for controlling the power electronics (26), the control motor electronics (28) being connected with the current sensor (32), the method comprising: - energizing the stator coil (16) with an alternating drive voltage (Vd), - monitoring a drive current (Id) being generated in the stator coil (16) by the drive voltage (Vd), and - commutating the drive voltage (Vd) each time when the drive current (Id) reaches a predefined positive current threshold value (Itp) or a predefined negative current threshold value (Itn). The method according to the invention provides a fast and reliable starting of the sensorless single-phase electric motor (10).
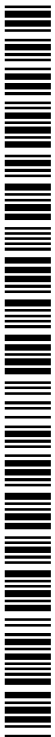
Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*

Published:
— *with international search report (Art. 21(3))*

D E S C R I P T I O N

Method for starting a sensorless single-phase electric motor and sensorless single-phase electric motor

The invention is directed to a method for starting a sensorless single-phase electric motor and to a sensorless single-phase electric motor.

Sensorless single-phase electric motors do not comprise any position sensor, as for example a Hall sensor, for detecting a present motor rotor position. Therefore, the present rotor position has to be indirectly detected, for example, by analyzing transitions in the polarity of a counter-electromotive force (CEMF) caused by a rotating permanent-magnetic motor rotor. However, indirect sensorless rotor position detection methods known in the art typically require the motor rotor to rotate at least with a minimum speed to allow a reliable rotor position detection. Therefore, a specific acceleration procedure is required to accelerate the motor rotor up to this minimum speed.

US 2014/0111127 A1 discloses a method for starting a sensorless single-phase electric motor wherein the motor rotor is initially moved into a defined rotor rest position by energizing the stator coil with a defined positioning current. Subsequently, the motor rotor is accelerated in an acceleration drive mode, wherein the stator coil is energized with a pulsed alternating current provided with a predefined duty cycle so that the CEMF can be analyzed in the OFF-phase of the pulsed current, i.e. when the stator coil is not energized. However, the necessary off-phases of the pulsed drive current limit the effective drive energy provided to the stator coil so that the pulsed drive current allows only a relatively slow motor

rotor acceleration. The relatively slow initial positioning of the motor rotor additionally slows down the starting of the electric motor.

It is an object of the invention to provide a fast and reliable starting of a sensorless single-phase electric motor.

This object is achieved with a method for starting a sensorless single-phase electric motor with the features of claim 1, and with a sensorless single-phase electric motor with the features of claim 6.

The sensorless single-phase electric motor according to the invention is provided with a permanent magnetic motor rotor. The motor rotor can be either a monolithic rotor body being permanently magnetized or, alternatively, can be a typical ferromagnetic rotor body with at least one attached permanent magnet. Typically, the motor rotor of the single-phase electric motor is provided with exactly two opposite magnetic poles.

The sensorless single-phase electric motor according to the invention is also provided with a motor stator with a stator coil. Preferably, the motor stator comprises a substantially U-shaped ferromagnetic stator body defining two opposite magnetic poles. Typically, the single-phase electric motor is provided with a single stator coil being located opposite to the open end of the U-shaped stator body. Preferably, the motor stator is provided with a laminated stator body, i.e. the stator body is made of a stack of ferromagnetic metal sheets.

Caused by the interaction of the permanent-magnetic motor rotor and the ferromagnetic stator, the motor rotor moves into one of two defined static rest positions if the motor stator is not energized. If the stator coil is energized with a defined voltage, the motor rotor is accelerated toward one of two drive positions, dependent on the magnetic orientation of the

electromagnetic stator field and, as a result, dependent on the polarity of the provided voltage.

The motor stator and the motor rotor according to the invention are designed in that way that the two rest positions of the motor rotor, are located at different rotational positions than the two drive positions. This allows a reliable starting of the resting motor rotor.

The sensorless single-phase electric motor according to the invention is also provided with a power electronics for energizing the stator coil with a defined feed voltage. Typically, the power electronics comprises several semiconductor switches for commutating the feed voltage.

The sensorless single-phase electric motor according to the invention is also provided with current sensor for measuring a current flowing in the stator coil. Preferably, the current sensor comprises a simple sense resistor being electrically connected in series with the stator coil. However, the current sensor can be any means that allows to measure the present electrical current flowing in the stator coil.

The sensorless single-phase electric motor according to the invention is also provided with a control electronics for controlling the power electronics. The control electronics is electrically connected with the current sensor so that the control electronics can evaluate the current being measured by the current sensor. The control electronics typically comprises a microcontroller.

The method for starting a sensorless single-phase electric motor according to the invention comprises the following steps:
- energizing the stator coil with an alternating drive voltage,

- monitoring a drive current being generated in the stator coil by the drive voltage, and

- commutating the drive voltage each time when the drive current reaches a predefined positive current threshold value or a predefined negative current threshold value.

The stator coil is energized with the alternating drive voltage being provided with a defined effective voltage amplitude. The energized stator coil generates an electromagnetic stator field which – depending on the present electrical polarity of the drive voltage – accelerates the motor rotor out of its static rest position and toward one of the two drive positions in which the permanent-magnetic rotor field is parallel to the electromagnetic stator field, i.e. the motor rotor north pole is located adjacent to the motor stator south pole and the motor rotor south pole is located adjacent to the motor stator north pole.

The drive current generated in the stator coil depends on the magnetic orientation of the motor rotor – i.e. the orientation of the permanent-magnetic rotor field – with respect to the electromagnetic stator field. If the motor rotor north pole is located adjacent to the motor stator south pole and the motor rotor south pole is located adjacent to the motor stator north pole, the permanent-magnetic rotor field is parallel to the electromagnetic stator field so that the permanent-magnetic rotor field enhances the total effective stator field. This causes a relatively high drive current, wherein the stator field enhancement and, as a result, the drive current is maximum at the drive position. Therefore, the stator current continuously increases if the motor rotor is moved toward the drive position.

According to the invention, the drive voltage is commutated – i.e. the electrical polarity of the drive voltage is inversed – each time when the

drive current reaches a predefined positive or negative current threshold value, wherein both current threshold values are defined lower than a maximum drive current generated in the stator coil when the motor rotor is located in one of the two drive positions. As a result, the drive voltage is always commutated before the motor rotor reaches the drive position, wherein the specific orientation of the motor at the commutation point can be defined by the current threshold values. Typically, the positive current threshold value and the negative current threshold value are equal. However, the two current threshold values can also be defined different if the motor rotor and/or motor stator are/is not perfectly symmetrical. In any case, the positive and negative current threshold values are defined in that way that the drive voltage is commutated substantially symmetrical to provide an efficient starting of the motor rotor.

The method according to the invention provides a rotor-position-controlled commutation without having a direct rotor position feedback. Furthermore, the method according to the invention allows a substantially continuous energizing of the stator coil not requiring any significant off-time for determining the present rotor position. As a result, the method according to the invention provides an efficient, fast and a reliable starting of the sensorless single-phase electric motor.

Typically, the drive voltage is generated based on a pulse-width-modulated drive signal – i.e. the drive voltage is constantly switched on and off with a defined switching frequency - wherein the effective drive voltage amplitude is defined by the duty cycle – i.e. the on-time ratio – of the pulse-width-modulated drive signal. The pulse-width-modulation provides a relatively simple adjustment of the effective drive energy fed into the stator coil. Preferably, the duty cycle of the drive signal is continuously increased up to a predefined set duty cycle during a ramp phase. As a result, the effective drive energy is continuously increased during the ramp

phase which - due to the current-threshold-based commutation – causes a continuous increase of the drive voltage alternation frequency. This ensures that the permanent-magnetic motor rotor can "follow" the generated electromagnetic stator field and, as a result, ensures a reliable starting of the electric motor.

In a preferred embodiment of the invention, the method comprises an initial magnetic orientation detection procedure with the following steps:
- energizing the stator coil with a positive detection voltage pulse with a positive electrical polarity,
- energizing the stator coil with a negative detection voltage pulse with a negative electrical polarity,
- measuring a positive detection current pulse being generated in the stator coil by the positive detection voltage pulse,
- measuring a negative detection current pulse being generated in the stator coil by the negative detection voltage pulse,
- determining a first detection parameter by evaluating the positive detection current pulse,
- determining a second detection parameter by evaluating the negative detection current pulse, and
- determining a magnetic orientation of the resting motor rotor by comparing the first detection parameter with the second detection parameter.

As already described above, the permanent-magnetic rotor field enhances the total effective stator field if the rotor field is parallel to the stator field – i.e. if each magnetic rotor pole is located adjacent to a magnetic stator pole with an opposite magnetic polarity – which causes a relatively high stator current. In contrast, the permanent-magnetic rotor field weakens the total effective stator field if the rotor field is antiparallel to the stator field – i.e. if each magnetic rotor pole is located adjacent to a magnetic

stator pole with an identical magnetic polarity. This causes a relatively low stator current.

According to the invention, the stator coil is subsequently energized with the positive detection voltage pulse and with the negative detection voltage pulse. The positive detection voltage pulse generates a positive stator field, and the negative detection voltage pulse generates a negative stator field with an opposite magnetic orientation. Both detection voltage pulses are provided that low and short that the resting motor rotor is not significantly moved by the two detection voltage pulses.

For each detection voltage pulse, the resulting detection current pulse being generated in the stator coil is measured. A first detection parameter is determined by evaluating the positive detection current pulse, and a second detection parameter is determined by evaluating the negative detection current pulse. For example, the detection parameters can be the maximum value, an average value or an integrated value of the respective detection current pulse.

If the permanent-magnetic rotor field has a component being parallel to the positive stator field, the first detection parameter is higher than the second detection parameter. If the permanent-magnetic rotor field has a component being parallel to the opposite negative stator field, the first detection parameter is higher than the second detection parameter.

As a result, the magnetic orientation of the resting motor rotor, i.e. the present rest position of the resting motor rotor, can be determined in a simple way by comparing the first detection parameter with the second detection parameter.

The magnetic orientation detection procedure according to the invention provides a reliable detection of the present magnetic orientation, even with relatively short detection voltage pulses. As a result, the magnetic orientation detection procedure according to the invention allows a very
5 fast and reliable starting of the sensorless single-phase electric motor.

The described rotor orientation detection procedure can be used to determine the present magnetic orientation of the motor rotor independent of the method used for driving the motor rotor subsequently. Therefore,
10 the described rotor orientation detection procedure represents an independent invention.

The difference between the positive detection current pulse and the negative detection current pulse is typically relatively small. Therefore, the
15 stator coil is preferably energized with at least three positive detection voltage pulses and with at least three negative detection voltage pulses. Each detection voltage pulse has substantially the same effective amplitude and duration, wherein all detection voltage pulses are that low and that short that the motor rotor is not moved significantly by the
20 generated electromagnetic stator field. Preferably, the positive and negative detection voltage pulses are provided to the stator coil alternately so that slight rotor movements caused by the positive and the negative detection voltage pulses compensate each other.

25 For each detection voltage pulse, the resulting detection current pulse is measured so that at least three positive detection current pulses and at least three negative detection current pulses are measured. The first detection parameter is determined by adding up the maximum absolute values of all positive detection current pulses, and the second detection
30 parameter is determined by adding up the maximum absolute values of all negative detection current pulses. As a result, the difference between the

first detection parameter and the second detection parameter is significantly enhanced compared to evaluating only two opposite detection voltage pulses. The same technical effect is achieved by adding up, for example, average values or integrated values of all measured detection current pulses for each detection voltage polarity. This provides a very reliable detection of the magnetic orientation of the resting motor rotor.

In a preferred embodiment of the invention, the drive voltage is provided with a defined initial electrical polarity being defined based on the determined magnetic orientation of the resting motor rotor. For example, the drive voltage is provided with a positive initial polarity if the motor rotor rests in the first rest position, and drive voltage is provided with a negative initial polarity if the motor rotor rests in the second rest position, or vice versa. In any case, the initial electrical polarity is provided in that way that the motor rotor is reliably accelerated with a defined rotational direction independent of its present magnetic orientation. This provides a reliable starting of the electric motor with a defined rotational direction.

The object of the present invention is also achieved with a sensorless single-phase electric motor as described above, wherein the control electronics is configured to execute one of the described methods according to the invention.

An embodiment of the invention is described with reference to the enclosed drawings, wherein
figure 1 shows a schematic illustration of a sensorless single-phase electric motor according to the invention, wherein a motor rotor is oriented in a first rest position,
figure 2 shows a temporal course of a) a feed voltage b) a feed current and c) a first detection parameter and second detection parameter during an initial rotor orientation detection procedure, and

figure 3 shows a temporal course of a) the feed voltage and b) the feed current during a rotor acceleration procedure.

Figure 1 shows a sensorless single-phase electric motor 10 comprising an electromagnetic motor stator 12 with a ferromagnetic stator body 14 and a single stator coil 16. The stator body is designed as a so-called laminated stator body, i.e. the stator body 14 is made of a stack of ferromagnetic metal sheets. The stator body 14 is provided substantially U-shaped, wherein a first pole leg 18 defines a first stator pole and an opposite second pole leg 20 defines a second stator pole. The stator coil 16 is arranged satellite-like at a bridge portion 22 mechanically and magnetically connecting the two pole legs 18,20.

The electric motor 10 also comprises a rotatable permanent-magnetic motor rotor 24. The motor is diametrically magnetized thereby defining a magnetic north pole N and a magnetic south pole S.

The electric motor 10 also comprises a power electronics 26 and control electronics 28. The power electronics 26 is electrically connected with the stator coil 16 via a stator connection line 30 for energizing the stator coil 16 with a defined effective feed voltage V. The power electronics 26 is controlled by the control electronics 28 via a pulse-width-modulated drive signal PWM, wherein an effective amplitude of the feed voltage V is controlled via the duty cycle D – i.e. the on-time ratio – of the drive signal PWM. The control electronics 28 is also configured to control an electrical polarity of the feed voltage V.

If the stator coil 16 is not energized, the motor rotor 24 moves into one of two static rest positions RP1,RP2 with opposite magnetic orientations of the motor rotor 24. The two rest positions RP1,RP2 of the motor rotor 24 are schematically illustrated in figure 1 by arrows representing the

orientation of the magnetic north pole N for the first rest position RP1 and the second rest position RP2, respectively. As visible in figure 1, the north pole N of the motor rotor 24 points toward the first pole leg 18 in the first rest position RP1 and points toward the second pole leg 20 in the second
5   rest position RP2.

If the stator coil 16 is energized with a positive feed voltage V, a positive electromagnetic field is generated, wherein the first pole leg 18 provides a magnetic north pole and the second pole leg 20 provides a magnetic south
10 pole. If the stator coil 16 is energized with a negative feed voltage V, a negative electromagnetic field is generated, wherein the first pole leg 18 provides a magnetic south pole and the second pole leg 20 provides a magnetic north pole.

15 The positive electromagnetic field accelerates the motor rotor 24 toward a first drive position DP1 in which the north pole N of the motor rotor 24 points toward the second pole leg 20. The negative electromagnetic field accelerates the motor rotor 24 toward a second drive position DP2 in which the north pole N of the motor rotor 24 points toward the first pole leg 18.
20 The two drive positions DP1,DP2 are schematically illustrated in figure 1 by arrows representing the orientation of the magnetic north pole N for the first drive position DP1 and the second drive position DP2 of the motor rotor 24, respectively.

25 The electric motor 10 also comprises a current sensor 32 being arranged in the stator connection line 30 to measure an electric feed current I flowing through the stator connection line 30 and, as a result, flowing through the stator coil 16. The current sensor 32 is connected with the control electronics 28 in that way that the present feed current I can be
30 evaluated by the control electronics 28.

The motor electronics 28 is configured to execute an initial rotor orientation detection procedure. In the rotor orientation detection procedure, the power electronics 26 is controlled by the control electronics 28 to alternately energize the stator coil 16 with three positive detection voltage
5 pulses Vp and with three negative detection voltage pulses Vn as schematically illustrated in figure 2a. Each positive detection voltage pulse Vp is provided with a positive electrical polarity and generates a positive electromagnetic detection field. Each negative detection voltage pulse Vn is provided with a negative electrical polarity and generates an opposite
10 negative electromagnetic detection field.

The resulting feed current I is monitored by the control electronics 28 via the current sensor 32. As schematically illustrated in figure 2b, the three positive detection voltage pulses Vp generate three positive detection
15 current pulses Ip, and the three negative detection voltage pulses Vn generate three negative detection current pulses In. Each positive detection current pulse Ip has a maximum absolute value of about I1, and each negative detection current pulse In has a maximum absolute value of about I2 being greater than I1.

20
The control electronics 28 determines a first detection parameter P1 by evaluating all positive detection current pulses Ip, in particular by adding up maximum absolute values of the three positive detection current pulses Ip. The control electronics 28 determines a second detection parameter P2
25 by evaluating all negative detection current pulses Ip, in particular by adding up maximum absolute values of the three negative detection current pulses In.

The control electronics 28 compares the determined first detection
30 parameter P1 and second detection parameter P2 to determine the present

magnetic orientation of the resting motor rotor 24, i.e. the present static rotor rest position.

If the motor rotor 24 is oriented in the first rest position RP1 – i.e. the magnetic rotor north pole N is located adjacent to the first pole leg 18 – the generated positive electromagnetic field is weakened and the generated negative electromagnetic field is enhanced by the permanent-magnetic field of the motor rotor 24. If the motor rotor 24 is oriented in the second rest position RP2 – i.e. the magnetic rotor north pole N is located adjacent to the second pole leg 20 – the generated positive electromagnetic field is enhanced and the generated negative electromagnetic field is weakened by the permanent-magnetic field of the motor rotor 24. Therefore, if the motor rotor 24 is oriented in the first rest position RP1, the determined second detection parameter P2 is higher than the determined first detection parameter P1, and if the motor rotor 24 is oriented in the second rest position RP2, the determined first detection parameter P1 is higher than the determined second detection parameter P2.

As schematically illustrated in figure 2c, the determined second detection parameter P2 is significantly higher compared to the determined first detection parameter P1. Therefore, in the described case, the resting motor rotor 24 is oriented in the first rest position RP1 as illustrated in figure 1.

The control electronics 28 is configured to subsequently execute an acceleration procedure to accelerate the resting motor rotor 24. In the acceleration procedure, the control electronics 28 controls the power electronics 26 to energize the stator coil 16 with an alternating drive voltage Vd, wherein the initial electrical polarity of the drive voltage is

defined based on the determined magnetic orientation of the resting motor rotor 24.

If the resting motor rotor 24 is oriented in the first rest position RP1, the drive voltage Vd is provided with a positive initial electrical polarity so that a positive electromagnetic field is generated initially which accelerates the resting motor rotor 24 out of the first rest position RP1 toward the first drive position DP1. If the resting motor rotor 24 is oriented in the second rest position RP2, the drive voltage Vd is provided with a negative initial electrical polarity so that a negative electromagnetic field is generated initially which accelerates the resting motor rotor 24 out of the second rest position RP2 toward the second drive position DP2. As visible in figure 3a, in the present case, the drive voltage Vd is provided with a positive initial electrical polarity because the resting motor rotor 24 is oriented in the first rest position RP1.

The control electronics 28 is configured to continuously monitor – via the current sensor 32 – a drive current Id generated in the stator coil 16 by the alternating drive voltage Vd. As visible in figure 3, the control electronics 28 is configured to commutate the drive voltage Vd each time when the measured drive current Id reaches a predetermined positive current threshold value Itp or a predetermined negative current threshold value Itn. Because the effective value of the drive current Id depends on the present rotational position of the motor rotor 24, the described commutation scheme provides an indirectly rotor-position-controlled commutation of the drive voltage Vd.

As visible in figure 3a, the control electronics 28 is also configured to continuously increase the duty cycle D of the pulse-width-modulated drive signal PWM up to a predefined set duty cycle Ds during an initial ramp phase R to thereby continuously increase the effective amplitude of the

drive voltage Vd up to a predefined set effective voltage amplitude Vs. Because of the current-threshold-controlled commutation of the drive voltage Vd, this also provides a continuously increasing alternation frequency of the drive voltage Vd.

5

Reference List

	10	sensorless single-phase electric motor
	12	motor stator
5	14	stator body
	16	stator coil
	18	first pole leg
	20	second pole leg
	22	bridge portion
10	24	motor rotor
	26	power electronics
	28	control electronics
	30	stator connection line
	32	current sensor
15		
	D	duty cycle
	DP1	first drive position
	DP2	second drive position
	Ds	set duty cycle
20	I	feed current
	In	negative detection current pulses
	Ip	positive detection current pulses
	Itn	negative current threshold value
	Itp	positive current threshold value
25	N	magnetic north pole
	P1	first detection parameter
	P2	second detection parameter
	PWM	pulse-width-modulated drive signal
	R	ramp phase
30	RP1	first rest position
	RP2	second rest position

S   magnetic south pole

t   time

V   effective feed voltage

Vd   alternating drive voltage

5 Vn   negative detection voltage pulses

Vp   positive detection voltage pulses

Vs   set effective drive voltage amplitude

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C L A I M S

1. A method for starting a sensorless single-phase electric motor (10), the electric motor comprising (10):
    - a permanent magnetic motor rotor (24),
    - an electromagnetic motor stator (12) with a stator coil (16),
    - a power electronics (26) for energizing the stator coil (16),
    - a current sensor (32) for measuring a current (I) flowing in the stator coil (16), and
    - a control electronics (28) for controlling the power electronics (26), the control electronics (28) being connected with the current sensor (32),

    the method comprising:
    - energizing the stator coil (16) with an alternating drive voltage (Vd),
    - monitoring a drive current (Id) being generated in the stator coil (16) by the drive voltage (Vd), and
    - commutating the drive voltage (Vd) each time when the drive current (Id) reaches a predefined positive current threshold value (Itp) or a predefined negative current threshold value (Itn).

2. The method according to claim 1, wherein the drive voltage (Vd) is generated based on a pulse-width-modulated drive signal (PWM), and wherein the duty cycle (D) of the drive signal (PWM) is continuously increased up to a predefined set duty cycle (Ds) during a ramp phase (R).

3. The method according to one of the preceding claims, the method comprising an initial rotor orientation detection procedure with the following steps:

    - energizing the stator coil (16) with a positive detection voltage pulse (Vp) with a positive electrical polarity,

    - energizing the stator coil (16) with a negative detection voltage pulse (Vn) with a negative electrical polarity,

    - measuring a positive detection current pulse (Ip) being generated in the stator coil (16) by the positive detection voltage pulse (Vp),

    - measuring a negative detection current pulse (In) being generated in the stator coil (16) by the negative detection voltage pulse (Vn),

    - determining a first detection parameter (P1) by evaluating the positive detection current pulse (Ip),

    - determining a second detection parameter (P2) by evaluating the negative detection current pulse (In), and

    - determining a magnetic orientation (RP1,RP2) of the resting motor rotor (24) by comparing the first detection parameter (P1) with the second detection parameter (P2).

4. The method according to claim 3, wherein the stator coil (16) is energized with at least three positive detection voltage pulses (Vp) and with at least three negative detection voltage pulses (Vn), wherein at least three positive detection current pulses (Ip) and at least three negative detection current pulses (In) are measured, wherein the first detection parameter (P1) is determined by adding up maximum absolute values of all positive detection current pulses (Ip), and wherein the second detection parameter (P2) is determined by adding up maximum absolute values of all negative detection current pulses (In).

5.   The method according to claim 3 or 4, wherein the drive voltage (Vd) is provided with an initial electrical polarity being defined based on the determined magnetic orientation (RP1,RP2) of the resting motor rotor (24).

6.   A sensorless single-phase electric motor (10) comprising:
     - a permanent magnetic motor rotor (24),
     - an electromagnetic motor stator (12) with a stator coil (16),
     - a power electronics (26) for energizing the stator coil (16),
     - a current sensor (32) for measuring a current (I) flowing in the stator coil (16), and
     - a control electronics (28) for controlling the power electronics (26), the control electronics (28) being connected with the current sensor (32),
     wherein the control electronics (28) is configured to execute the method according to one of the preceding claims.
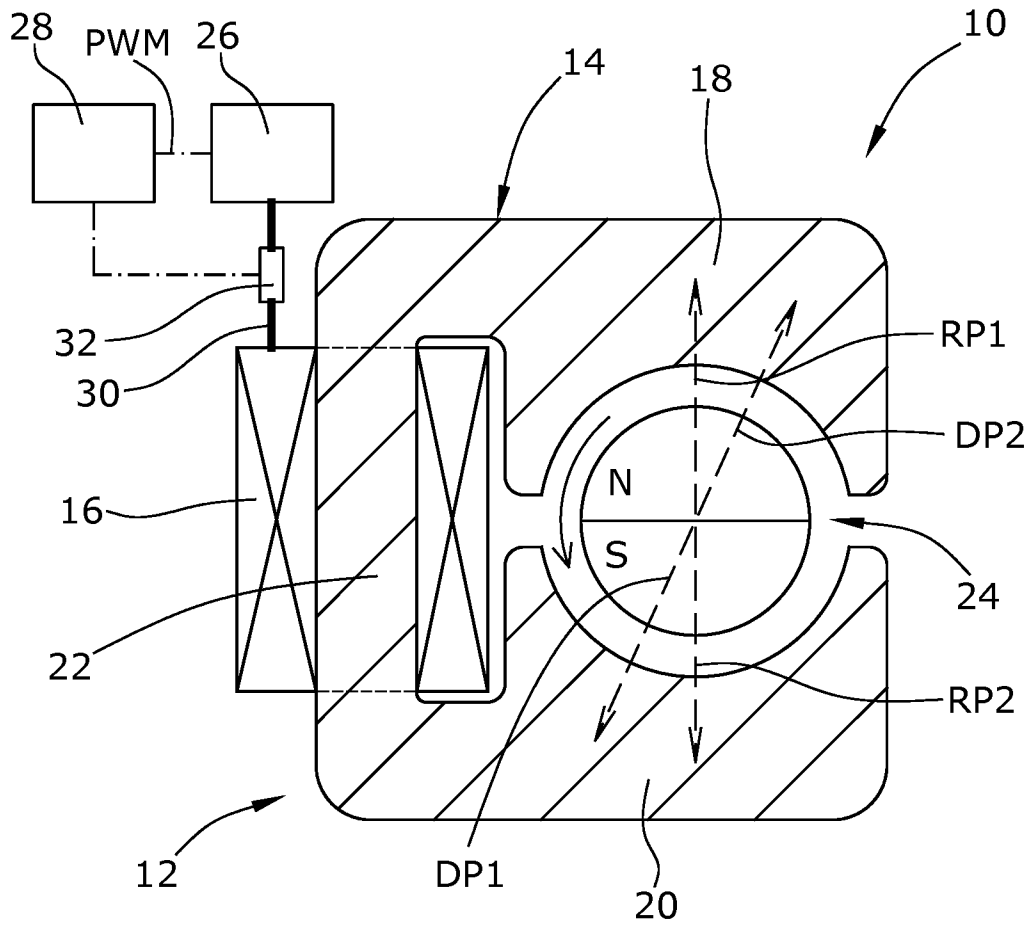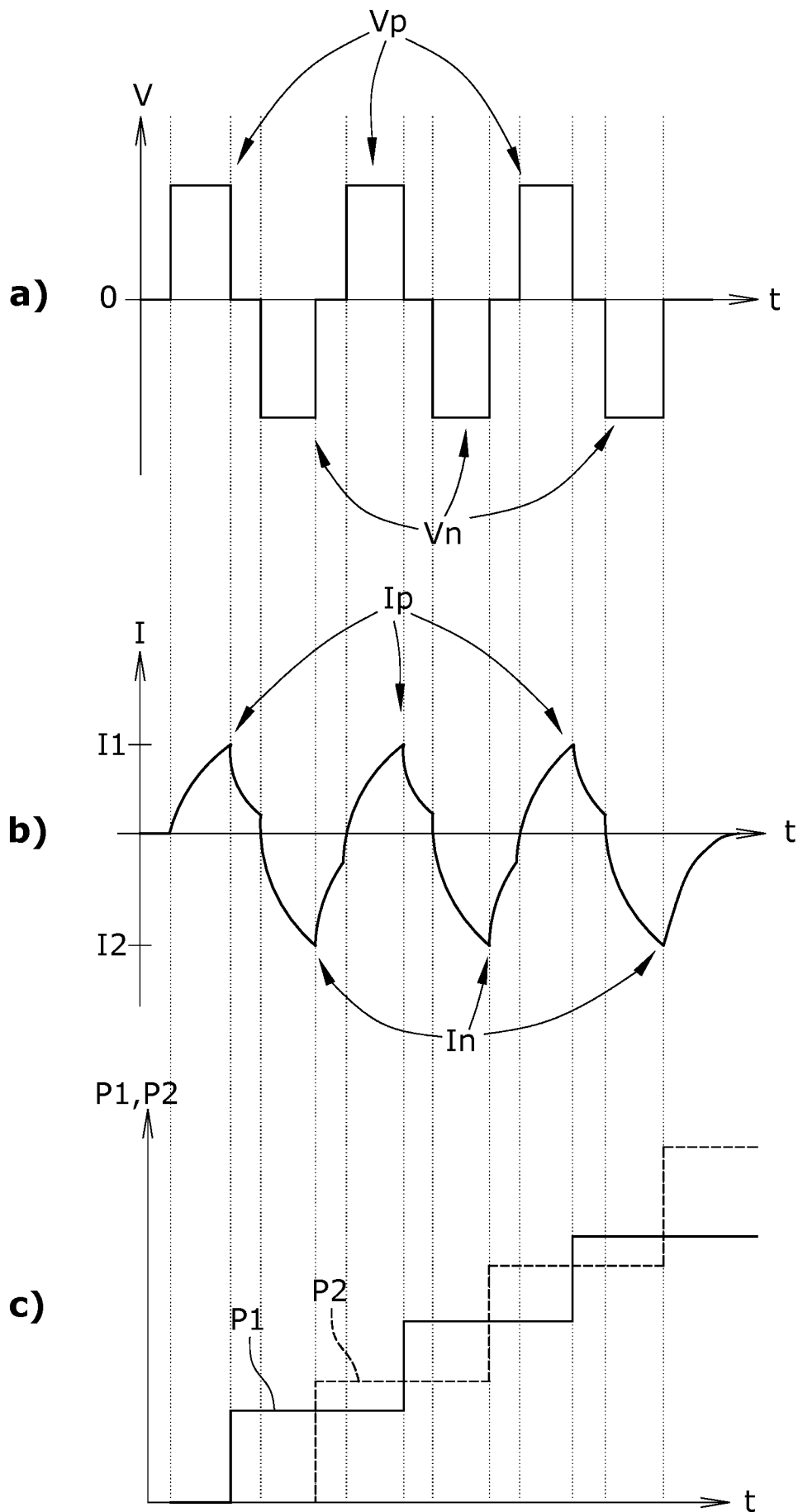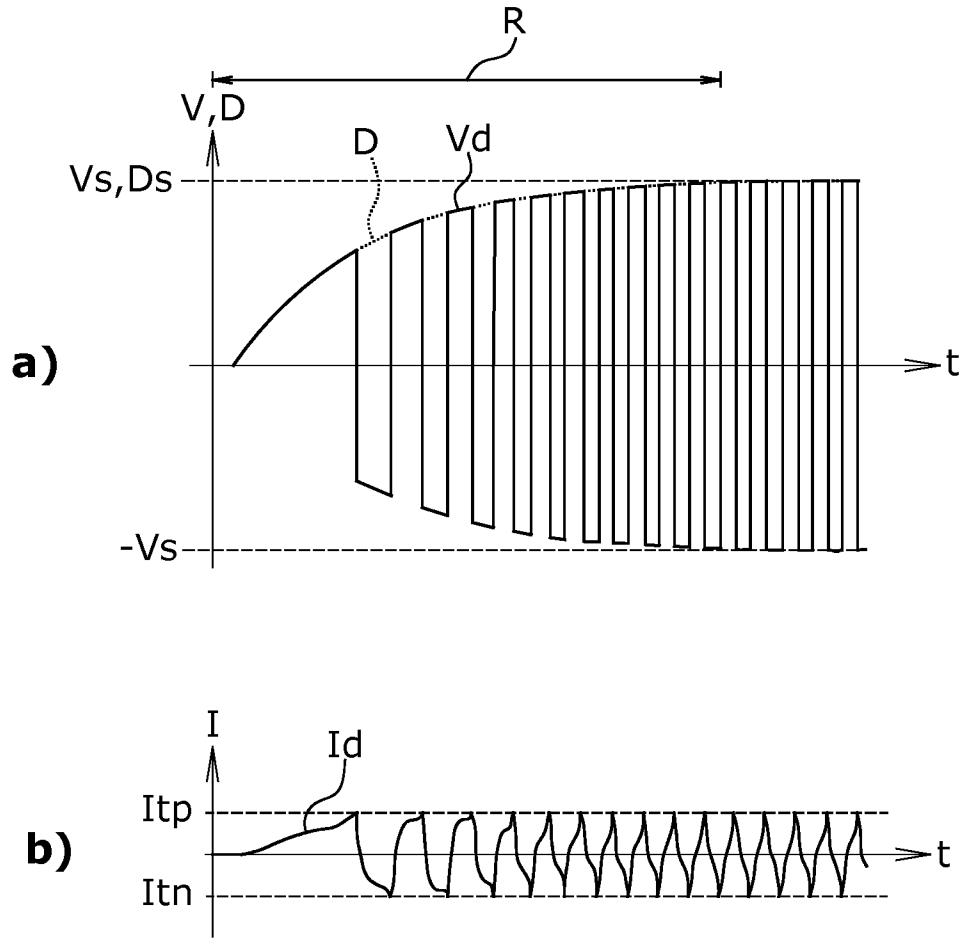
Fig.1

Fig.2

Fig.3

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02P1/46
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H02P

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	US 5 598 071 A (DUNFIELD JOHN C [US] ET AL) 28 January 1997 (1997-01-28) abstract; figure 21 column 10, line 1 - line 24 -----	1-6
A	US 2014/111127 A1 (BI LEI [CN]) 24 April 2014 (2014-04-24) cited in the application abstract -----	1-6

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
3 March 2020	16/03/2020

Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Hascher, Thierry

Form PCT/ISA/210 (second sheet) (April 2005)

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Information on patent family members

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