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METHOD AND APPARATUS FOR DETERMINING A
ROTATIONAL ANGLE OF A ROTARY BODY

BACKGROUND OF THE INVENTION

1. Field of the Invention:

This invention relates to a method and apparatus for determining a rotational angle of a rotary body, and more particularly to an improved method for determining a rotational angle of a rotor of an AC motor or a DC motor which drives a door in an automatic door system in order to control the rotation of the motor.

2. Description of the Prior Art:

In an automatic door system, a belt is wound around a drive pulley that is driven by an AC motor or a DC motor and a driven pulley, a door is connected to this belt, and opening and closing operations of the door are effected by normally or reversely rotating the motor.

In order to control opening and closing of a door in such an automatic door system according to a desired

operation mode, provision must be made such that the position and speed (positive or negative) of the door can be always detected. In a heretofore known automatic door system, in accordance with rotation of an encoder mounted to a rotor of a motor, sensing pulses are generated at a predetermined rotational angle interval, and by a count up or count down of the number of these sensing pulses depending upon the direction of rotation, the distance moved of the door and hence the position of the door with reference to a given position (for instance, a closing-stop position of the door) could be determined, and the moving speed of the door could be detected on the basis of a repetition cycle of these sensing pulses.

However, in such a method, there is a possibility of malfunction such that in a pulse series of sensing pulses generated by rotation of an encoder upon rotation of the motor for driving the door, one pulse may drop out or one pulse may be excessively added due to electrical or mechanical faults. In such cases, errors would arise in the detected position or moving speed of the door, and so it becomes impossible to precisely control opening and closing of a door in an automatic door system according to a desired operation mode.

This is not limited to an automatic door system, but

the situation is also the same in operation control of other instruments driven by a motor, and more generally, this is a problem common to methods for detecting a rotational angle or a rotational speed of a rotary body by means of sensing pulses as described above.

SUMMARY OF THE INVENTION

The present invention has been made in view of the foregoing circumstances, and its aim is to provide an improved method and apparatus for determining a rotational angle of a rotary body, in which errors would not occur in detection of a rotational angular position or a rotational speed of a rotary body in the case where a surplus pulse has been added or drop-out of a pulse has occurred in a series of sensing pulses generated according to rotation of an encoder.

According to one aspect of the present invention, there is provided a method of determining a rotational angle of a rotary body, comprising the steps of: -

(a) generating, according to an encoding pattern on an encoder rotating synchronously with the rotary body, rotational angular position signals in the form of n trains of n-phase square waves, and generating sensing

pulses at predetermined rotational angular intervals of $360/(2\underline{m})^\circ$, where $\underline{m}$ is an integer larger than $\underline{n}$ and where $\underline{n}$ is an integer larger than unity and is an integral divisor of $\underline{m}$; wherein the angular intervals between successive changes of level of each square wave are $\underline{n}(360/2\underline{m})^\circ$; there being a phase-shift, between each said train of square waves and at least one other said train of square waves, of $\pm (p \cdot 360/2\underline{m})^\circ$ respectively, where p is an integer between 1 and $(\underline{n}-1)$ inclusive; each said sensing pulse being generated immediately after a change of level of one or other of said trains of square waves;

(b) detecting a set of levels, consisting of the respective instantaneous levels of said $\underline{n}$ trains of square waves, in response to each successive sensing pulse;

(c) for each pair of successive sensing pulses, comparing the set of levels of said $\underline{n}$ trains of square waves obtained in response to the first sensing pulse with a reference pattern and deriving two alternative expected sets of levels of said $\underline{n}$ trains of square waves for a forward rotational step and a backward rotational step respectively;

(d) for each pair of successive sensing pulses, comparing the set of levels of said $\underline{n}$ trains of square

waves obtained in response to the second sensing pulse with said two alternative expected sets of levels of said n trains of square waves;

(e) if the comparison indicates an abnormality, in that the set of levels of said n trains of square waves obtained in response to the second sensing pulse accords with neither of said two alternative expected sets of levels of said n trains of square waves, generating an abnormality alarm signal; and

(f) in the event of no abnormality, adding (+1) or (-1) to a rotational step counter for each forward or backward rotational step indicated by the comparison to have occurred.

Preferably, since the sensing pulses generated according to an encoding pattern on an encoder are not simply accumulated as is the case with the prior art, but the accumulation of the sensing pulses for evaluating a rotational angle is effected only in the case where it has been checked by means of n-phase rotational angular position signals whether or not the sensing pulses are pulses generated correctly at a predetermined rotational angle interval and they have been proved to be correct sensing pulses, errors would not arise in the detected rotational angle and

rotational speed of the rotary body.

In the event that a faulty sensing pulse has been detected or drop-out of a sensing pulse has been detected, an abnormal alarm signal is generated and control is interrupted so as to avoid malfunction. But even in such cases, if necessary, it is possible to add a subsequent sensing pulse or eliminate a subsequent sensing pulse in response to the abnormal alarm signal for continuing correct control.

According to another aspect of the present invention, there is provided an apparatus for determining a rotational angle of a rotary body, comprising: -

(a) an encoder adapted and arranged to rotate synchronously with the rotating body for generating, according to an encoding pattern on said encoder, rotational angular position signals in the form of n trains of n -phase square waves, and for generating sensing pulses at predetermined rotational angular intervals of $360/(2m)^\circ$, where m is an integer larger than n and where n is an integer larger than unity and is an integral divisor of m ; wherein the angular intervals between successive changes of level of each square wave are $n(360/2m)^\circ$; there being a phase-shift,

between each said train of square waves and at least one other said train of square waves, of $\pm (p.360/2m)$ respectively, where p is an integer between 1 and $(n-1)$ inclusive; each said sensing pulse being generated immediately after a change of level of one or other of said trains of square waves;

(b) detection means for detecting a set of levels, consisting of the respective instantaneous levels of said n trains of square waves, in response to each successive sensing pulse;

(c) identification means for identifying the expected sets of levels of said n trains of square waves by, for each pair of successive sensing pulses, comparing the set of levels of said n trains of square waves obtained in response to the first sensing pulse with a reference pattern, and deriving two alternative said expected sets of levels of said n trains of square waves for a forward rotational step and a backward rotational step respectively;

(d) comparison means for comparing the set of levels of said n trains of square waves obtained in response to the second sensing pulse with said two alternative expected sets of levels of said n trains of square waves;

(e) signal means for generating an abnormality alarm

signal if the comparison indicates an abnormality in that the set of levels of said n trains of square waves obtained in response to the second sensing pulse accords with neither of said two alternative expected sets of levels of said n trains of square waves; and

(f) a rotational step counter to which, in the event of no abnormality, (+1) or (-1) is added for each forward or backward rotational step respectively indicated by the comparison means to have occurred.

Preferably said comparing means further comprises means for comparing a variation pattern of a combination of detected n levels with a previously stored variation pattern of a combination of last detected n levels and, if they are identical with each other, generating an abnormal alarm signal.

Preferably said generating means is adapted to generate said sensing pulses at an interval of 30 degrees ($m=6$) of the rotation of said encoder, and 3-phase rectangular wave signals which alternately take a high level and a low level at an interval of 90 degrees that is three times 30 degrees and which are phase-shifted by 60 or 30 degrees with respect to one another, are generated as rotational angular position signals.

The invention will be described by way of example with reference to the accompanying drawings, wherein like references refer to like parts unless the context requires otherwise.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

Fig. 1 is a block diagram of an apparatus for performing determination of a rotational angle of a motor by practicing the method according to the present invention;

Fig. 2 is a diagram showing, as a function of a rotational angle, sensing pulses and 3-phase rotational angular position signals, 60° out of phase at a predetermined rotational angle to one another, which are generated by a signal generator according to an encoding pattern of an encoder; and

Fig. 3 is a flow chart representing logical operations executed for the sensing pulses and the 3-phase rotational angular position signals in a controller shown in Fig. 1.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In Fig. 1, a known encoder 4 which is, for example, disc-shaped is integrally mounted to and synchronously rotated with a rotor of an AC motor or a DC motor 1 serving as a drive source for performing, for instance, opening and closing operations of a door in an automatic door system, and when the rotor rotates, 3-phase rotational angular position signals P1, P2 and P3 (See Fig. 2), out of phase at a predetermined rotational angle to one another and sensing pulse series SP are generated by an optical or magnetic signal generator 2 opposed to a circumferential portion of an encoder 4 according to an optical or magnetic encoding pattern preset along the circumference of the encoder. These three-phase rotational angular position signals P1, P2 and P3 and sensing pulse series SP are transmitted from the signal generator 2 to a controller 3, where the pulse series and the signals are subjected to logical operations as will be explained in the following.

As shown in Fig. 2 in the form of a waveform diagram taking a rotational angle of the encoder 4 along an abscissa, the 3-phase rotational angular position signals P1, P2 and P3 consist of 3-phase rectangular waves, which alternately repeat a high level (hereinafter called simply H-level) and a low level (hereinafter called simply L-level) at an interval of 90° that is equal to three times 30° corresponding

to the rotational angle interval of the sensing pulses, and which are phase-shifted by 60° with respect to one another. Of course, a repetition frequency of these rectangular waves also becomes high as the rotational of the encoder 4 is increased, but the relationship between the rotational angular position of the encoder and the output levels of the three signals is always fixed independently of the rotational speed, as indicated in Fig. 2.

In more particular, in one revolution ($=360^\circ$) of the encoder 4, the first phase rotational angular position signal P1 is a rectangular wave signal which takes H-level in the intervals of 90° - 180° and 270° - 360° and L-level in the intervals of 0° - 90° and 180° - 270° , the second phase rotational angular position signal P2 is a rectangular wave signal which takes H-level in the intervals of 150° - 240° and 330° - 60° and L-level in the intervals of 60° - 150° and 240° - 330° , and the third phase rotational angular position signal P3 is a rectangular wave signal which takes H-level in the interval of 30° - 120° and 210° - 300° and L-level in the intervals of 120° - 210° and 300° - 30° .

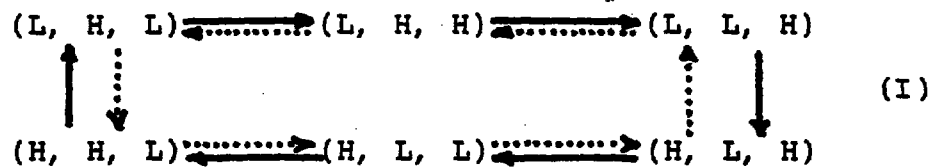
On the other hand, the sensing pulse series SP is a

pulse series consisting of narrow sensing pulses SP1, SP2, SP3,.....generated, in the case of the illustrated embodiment, at an interval of 30° which is one 12-th of one revolution ($=360^{\circ}$) of the encoder 4, and a repetition frequency of this pulse series becomes high as the rotational speed of the rotor, and hence, of the encoder 4 is increased.

Now, the logical operations for precisely determining the rotational angular position of the encoder 4 by means of the above described sensing pulse series SP and the 3-phase rotational angular position signals P1, P2 and P3 in the controller 3, will be explained with reference to the flow chart in Fig. 3.

At first, the sensing pulses SP1, SP2, SP3,.....are generated, in turn, just behind the respective level changes of the 3-phase rotational angular position signals P1, P2 and P3 so that the levels of the respective ones of the 3-phase rotational angular position signals P1, P2 and P3 can be detected (Fig. 3:10). If the signal generator 2 correctly generates these rotational angle position signals P1, P2 and P3 and the sensing pulse series SP according to an encoding pattern preset on the encoder 4, and if they are not disturbed during the period when they are transmitted to the controller 3, then as indicated at

the bottom of Fig. 2, the combination of the levels of the rotational angular position signals P1, P2 and P3 detected in response to each of the sensing pulses SP1, SP2, SP3.....must be cyclically varied according to the following variation pattern (I) (this being called "reference variation pattern"):



(wherein it is a matter of course that if the motor is reversed in rotation and the encoder 4 rotates in the reversed direction, the level combination would be cyclically varied according to a reversed pattern as indicated by dotted line arrows).

As a first step of checking whether or not these signals P1, P2 and P3 and the sensing pulse series SP are correct ones, a combination of signal levels detected by the last sensing pulse and a combination of signal levels detected by the present sensing pulse are compared with each other, and it is determined whether or not they are identical to each other (Fig. 3: 11, 12). As will be apparent from the above-mentioned reference variation pattern, naturally these two level combinations should be different from each other, and if

they are identical, it should be determined that malfunction has occurred due to any fault. For instance if it is assumed that the last sensing pulse was SP2, then the combination of the signal levels detected in response to that sensing pulse is (L, H, H). In the event that the pulse deemed as the present sensing pulse is not correctly the next sensing pulse SP2 but a pulse SP' (indicated by a dotted line in Fig. 2) mixed as result of noise, the combination of the signal levels now detected in response to this noise pulse SP' is also (L, H, H), and so, as a result of comparison, it is determined that the both level combinations are identical. Therefore, in the event that it is determined that they are identical, an abnormal alarm signal is generated (Fig. 3: 13), and consequently a buzzer is made to sound (Fig. 3: 14).

In the event that it has been determined that the present combination of the detected levels and the last combination of the detected levels are different from each other, the checking operation proceeds to a second step. In the second checking step, a level combination derived by shifting the last detected level combination (Fig. 3: 16c) by one predetermined rotational angle (30°) forwards according to the reference variation pattern (Fig. 3: 16a), that is, (L, L, H), if the last combination is (L, H, H), and a level combination

derived by shifting the last detected level combination (Fig. 3: 16c) by one predetermined rotational angle (30°) backwards according to the reference variation pattern (Fig. 3: 16b), that is, (L, H, L), if the last combination is (L, H, H), are respectively compared with the now detected level combination (Fig. 3: 15). As a result, if the now detected level combination coincides with either one of the above-described two combinations (L, L, H) and (L, H, L), it is known that the sensing pulse series SP and the 3-phase rotational angular position signals P1, P2 and P3 are being correctly transmitted to the controller 3. On the contrary, if the now detected level combination does not coincide with either one of the above-mentioned two combinations, it should be determined that malfunction has occurred due to any fault. For instance, in the case where the last sensing pulse was SP2 and the combination of the signal levels detected in response to that sensing pulse is (L, H, H), if it is assumed that the next sensing pulse SP3 has dropped out due to any circuit fault, then the now observed sensing pulse corresponds to the sensing pulse SP4 that is located one pulse interval beyond the sensing pulse SP3, and according, the combination of the signal levels detected in response to that sensing pulse would be (H, L, H). This level combination is determined not to coincide with either one of the above-described contrasts of comparison (L, L, H) and (L, H, L).

Therefore, in the event that a presently detected level combination does not coincide with either one of the above-mentioned two combinations (L, L, H) and (L, H, L) and hence it has been determined that the detected level combination does not coincide with the reference variation pattern, an abnormal alarm signal is generated (Fig. 3: 13), and consequently, a buzzer is made to sound (Fig. 3: 14).

Further, in a third step of the checking for the combination of the detected levels of the rotational angular-position signals P1, P2 and P3, in the event that the presently detected level combination coincides with the reference variation pattern, it is determined whether the presently detected level combination is identical to a level combination (L, L, H) derived by shifting the last detected level combination (L, H, H) by one predetermined rotational angle (30°) forwards according to the reference variation pattern or a level combination (L, H, L) derived by shifting the same by one predetermined rotational angle (30°) backwards (Fig. 3: 17). In the former case, since the combination of the signal levels is varying according to the reference variation pattern of forward travelling (solid line arrows shown in the foregoing pattern (I)), it is determined that the encoder 4 (motor 1) is rotating in the normal direction, and so, (+1) is added to a

rotational angle counter equipped in the controller 3 so as to count up by one predetermined rotational angle (30°). In the latter case, it is determined that the encoder 4 (motor 1) is rotating in the reverse direction, and so, (-1) is added to the rotational angle counter so as to count down by one predetermined rotational angle (30°).

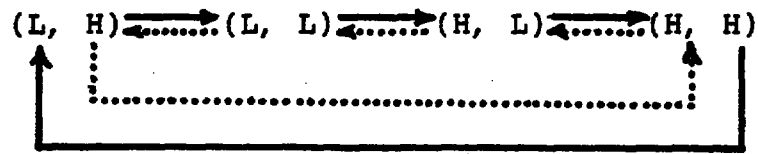
If the above-mentioned operations are effected, in the rotational angle counter is always reserved an accumulated value of a rotational angle taking 30° as one unit, and a positive or negative rotational speed of the encoder 4 can be also known from the repetition frequency of the count pulses for counting up or counting down in this rotational angle counter.

It is to be noted that while the sensing pulses are generated, by way of example, at an interval of 30° that is equal to one 12-th of one revolution ($=360^{\circ}$), and as the rotational angular position signals, 3-phase rectangular wave signals which alternately repeat H-level and L-level at an interval of 90° that is three times the predetermined rotational angular interval of the sensing pulses and which are phase-shifted by 60° with respect to one another are generated in the above-described preferred embodiment, generally, if the predetermined rotational angular

interval of the sensing pulses is selected to be an even number ($2m$) fraction of 360° , and as the rotational angular position signals, n -phase rectangular wave signals which alternately repeat H-level and L-level at an interval equal to n times the predetermined rotational angular interval $(360/2m)^\circ$ of the sensing pulses (n being a divisor, larger than unity, of m) and which are phase-shifted by $(p \cdot 360/2m)^\circ$ with respect to one another (where $1 \leq p \leq (n-1)$) are generated, then determination of a rotational angle and a rotational speed of the encoder 4 can be effected in a similar manner to the above-described embodiment, as will be obvious for those skilled in the art. It is, therefore, possible for the rectangular wave signals to be phase-shifted by 30° . It will be also apparent that as the predetermined rotational angular interval of the sensing pulses is decreased by selecting the above-referred integer m larger, finer determination and control of the angular position can be achieved.

If the case where the predetermined rotational angular interval of the sensing pulse is 30° , in another more simplified embodiment, 2-phase rectangular wave signals which alternately repeat H-level and L-level at an interval of 60° and which are phase-shifted by 30° can be employed as the rotational angular position signals by selected $n=2$. In this case, a reference variation pattern for the combination of the signal

levels is as follows:



While a principle of the present invention has been described above in connection to one preferred embodiment of the invention, all matter contained in the above description and shown in the accompanying drawings shall be interpreted to be illustrative and not in a limiting sense.



Claims:

1. A method of determining a rotational angle of a rotary body, comprising the steps of:-

(a) generating, according to an encoding pattern on an encoder rotating synchronously with the rotary body, rotational angular position signals in the form of $\underline{n}$ trains of $\underline{n}$ -phase square waves, and generating sensing pulses at predetermined rotational angular intervals of $360/(2\underline{m})^\circ$, where $\underline{m}$ is an integer larger than $\underline{n}$ and where $\underline{n}$ is an integer larger than unity and is an integral divisor of $\underline{m}$; wherein the angular intervals between successive changes of level of each square wave are $\underline{n}(360/2\underline{m})^\circ$; there being a phase-shift, between each said train of square waves and at least one other said train of square waves, of $\pm (p.360/2\underline{m})^\circ$ respectively, where p is an integer between 1 and $(\underline{n}-1)$ inclusive; each said sensing pulse being generated immediately after a change of level of one or other of said trains of square waves;

(b) detecting a set of levels, consisting of the respective instantaneous levels of said $\underline{n}$ trains of square waves, in response to each successive sensing pulse;

(c) for each pair of successive sensing pulses,



comparing the set of levels of said n trains of square waves obtained in response to the first sensing pulse with a reference pattern and deriving two alternative expected sets of levels of said n trains of square waves for a forward rotational step and a backward rotational step respectively;

(d) for each pair of successive sensing pulses, comparing the set of levels of said n trains of square waves obtained in response to the second sensing pulse with said two alternative expected sets of levels of said n trains of square waves;

(e) if the comparison indicates an abnormality, in that the set of levels of said n trains of square waves obtained in response to the second sensing pulse accords with neither of said two alternative expected sets of levels of said n trains of square waves, generating an abnormality alarm signal; and

(f) in the event of no abnormality, adding (+1) or (-1) to a rotational step counter for each forward or backward rotational step indicated by the comparison to have occurred.

2. A method of determining a rotational angle of a rotary body, comprising the steps of: -



(a) generating, according to an encoding pattern on an encoder rotating synchronously with the rotary body, rotational angular position signals in the form of n trains of n-phase square waves, and generating sensing pulses at predetermined rotational angular intervals of $360/(2\underline{m})^\circ$, where m is an integer larger than n and where n is an integer larger than unity and is an integral divisor of m; wherein the angular intervals between successive changes of level of each square wave are $\underline{n}(360/2\underline{m})^\circ$; there being a phase-shift, between each said train of square waves and at least one other said train of square waves, of $\pm(360/2\underline{m})^\circ$ respectively; each said sensing pulse being generated immediately after a change of level of one or other of said trains of square waves;

(b) detecting a set of levels, consisting of the respective instantaneous levels of said n trains of square waves, in response to each successive sensing pulse;

(c) for each pair of successive sensing pulses, comparing the set of levels of said n trains of square waves obtained in response to the first sensing pulse with a reference pattern and deriving two alternative expected sets of levels of said n trains of square waves for a forward rotational step and a backward rotational



step respectively;

(d) for each pair of successive sensing pulses, comparing the set of levels of said n trains of square waves obtained in response to the second sensing pulse with said two alternative expected sets of levels of said n trains of square waves;

(e) if the comparison indicates an abnormality, in that the set of levels of said n trains of square waves obtained in response to the second sensing pulse accords with neither of said two alternative expected sets of levels of said n trains of square waves, generating an abnormality alarm signal; and

(f) in the event of no abnormality, adding (+1) or (-1) to a rotational step counter for each forward or backward rotational step indicated by the comparison to have occurred.

3. A method of determining a rotational angle of a rotary body, comprising the steps of: -

(a) generating, according to an encoding pattern on an encoder rotating synchronously with the rotary body, rotational angular position signals in the form of n trains of n-phase square waves, and generating sensing

pulses at predetermined rotational angular intervals of $360/(2\underline{m})^\circ$, where $\underline{m}$ is an integer larger than $\underline{n}$ and where $\underline{n}$ is an integer larger than unity and is an integral divisor of $\underline{m}$; wherein the angular intervals between successive changes of level of each square wave are $\underline{n}(360/2\underline{m})^\circ$; there being a phase-shift, between each said train of square waves and at least one other said train of square waves, of $\pm 2 (360/2\underline{m})^\circ$; each said sensing pulse being generated immediately after a change of level of one or other of said trains of square waves;

(b) detecting a set of levels, consisting of the respective instantaneous levels of said $\underline{n}$ trains of square waves, in response to each successive sensing pulse;

(c) for each pair of successive sensing pulses, comparing the set of levels of said $\underline{n}$ trains of square waves obtained in response to the first sensing pulse with a reference pattern and deriving two alternative expected sets of levels of said $\underline{n}$ trains of square waves for a forward rotational step and a backward rotational step respectively;

(d) for each pair of successive sensing pulses, comparing the set of levels of said $\underline{n}$ trains of square waves obtained in response to the second sensing pulse



with said two alternative expected sets of levels of said n trains of square waves;

(e) if the comparison indicates an abnormality, in that the set of levels of said n trains of square waves obtained in response to the second sensing pulse accords with neither of said two alternative expected sets of levels of said n trains of square waves, generating an abnormality alarm signal; and

(f) in the event of no abnormality, adding (+1) or (-1) to a rotational step counter for each forward or backward rotational step indicated by the comparison to have occurred.

4. A method of determining a rotational angle of a rotary body as claimed in any preceding claim, wherein said comparing step further comprises a step of comparing a variation pattern of a combination of detected n levels with a previously stored variation pattern of a combination of last detected n levels and, if they are identical with each other, generating an abnormal alarm signal.

5. A method of determining a rotational angle of a rotary body as claimed in claim 1, 2, or claim 4 dependent upon claim 1 or 2; wherein said sensing pulses



are generated at an interval of 30 degrees ($m=6$) of the rotation of said encoder, and 3-phase rectangular wave signals which alternately take a high level and a low level at an interval of 90 degrees that is three times 30 degrees and which are phase-shifted by 30 degrees with respect to one another, are generated as rotational angular position signals.

6. A method of determining a rotational angle of a rotary body as claimed in claim 1, 3, or claim 4 dependent upon claim 1 or 3; wherein said sensing pulses are generated at an interval of 30 degrees ($m=6$) of the rotation of said encoder, and 3-phase rectangular wave signals which alternately take a high level and a low level at an interval of 90 degrees that is three times 30 degrees and which are phase-shifted by 60 degrees with respect to one another, are generated as rotational angular position signals.

7. An apparatus for determining a rotational angle of a rotary body, comprising: -

(a) an encoder adapted and arranged to rotate synchronously with the rotating body for generating, according to an encoding pattern on said encoder, rotational angular position signals in the form of n trains of n -phase square waves, and for generating



sensing pulses at predetermined rotational angular intervals of $360/(2\underline{m})^\circ$, where $\underline{m}$ is an integer larger than $\underline{n}$ and where $\underline{n}$ is an integer larger than unity and is an integral divisor of $\underline{m}$; wherein the angular intervals between successive changes of level of each square wave are $\underline{n}(360/2\underline{m})^\circ$; there being a phase-shift, between each said train of square waves and at least one other said train of square waves, of $\pm (p \cdot 360/2\underline{m})^\circ$ respectively, where p is an integer between 1 and $(\underline{n}-1)$ inclusive; each said sensing pulse being generated immediately after a change of level of one or other of said trains of square waves;

(b) detection means for detecting a set of levels, consisting of the respective instantaneous levels of said $\underline{n}$ trains of square waves, in response to each successive sensing pulse;

(c) identification means for identifying the expected sets of levels of said $\underline{n}$ trains of square waves by, for each pair of successive sensing pulses, comparing the set of levels of said $\underline{n}$ trains of square waves obtained in response to the first sensing pulse with a reference pattern, and deriving two alternative said expected sets of levels of said $\underline{n}$ trains of square waves for a forward rotational step and a backward rotational step respectively;



(d) comparing means for comparing the set of levels of said n trains of square waves obtained in response to the second sensing pulse with said two alternative expected sets of levels of said n trains of square waves;

(e) signal means for generating an abnormality alarm signal if the comparison indicates an abnormality in that the set of levels of said n trains of square waves obtained in response to the second sensing pulse accords with neither of said two alternative expected sets of levels of said n trains of square waves; and

(f) a rotational step counter to which, in the event of no abnormality, (+1) or (-1) is added for each forward or backward rotational step respectively indicated by the comparison means to have occurred.

8. An apparatus for determining a rotational angle of a rotary body, comprising: -

(a) an encoder adapted and arranged to rotate synchronously with the rotating body for generating, according to an encoding pattern on said encoder, rotational angular position signals in the form of n trains of n-phase square waves, and for generating sensing pulses at predetermined rotational angular intervals of $360/(2\underline{m})^\circ$, where m is an integer larger



than $\underline{n}$ and where $\underline{n}$ is an integer larger than unity and is an integral divisor of $\underline{m}$; wherein the angular intervals between successive changes of level of each square wave are $\underline{n}(360/2\underline{m})^\circ$; there being a phase-shift, between each said train of square waves and at least one other said train of square waves, of $\pm (360/2\underline{m})^\circ$ respectively; each said sensing pulse being generated immediately after a change of level of one or other of said trains of square waves;

(b) detection means for detecting a set of levels, consisting of the respective instantaneous levels of said $\underline{n}$ trains of square waves, in response to each successive sensing pulse;

(c) identification means for identifying the expected sets of levels of said $\underline{n}$ trains of square waves by, for each pair of successive sensing pulses, comparing the set of levels of said $\underline{n}$ trains of square waves obtained in response to the first sensing pulse with a reference pattern, and deriving two alternative said expected sets of levels of said $\underline{n}$ trains of square waves for a forward rotational step and a backward rotational step respectively;

(d) comparing means for comparing the set of levels



of said n trains of square waves obtained in response to the second sensing pulse with said two alternative expected sets of levels of said n trains of square waves;

(e) signal means for generating an abnormality alarm signal if the comparison indicates an abnormality in that the set of levels of said n trains of square waves obtained in response to the second sensing pulse accords with neither of said two alternative expected sets of levels of said n trains of square waves; and

(f) a rotational step counter to which, in the event of no abnormality, (+1) or (-1) is added for each forward or backward rotational step respectively indicated by the comparison means to have occurred.

9. An apparatus for determining a rotational angle of a rotary body, comprising: -

(a) an encoder adapted and arranged to rotate synchronously with the rotating body for generating, according to an encoding pattern on said encoder, rotational angular position signals in the form of n trains of n-phase square waves, and for generating sensing pulses at predetermined rotational angular intervals of $360/(2\underline{m})^\circ$, where m is an integer larger than n and where n is an integer larger than unity and



is an integral divisor of m ; wherein the angular intervals between successive changes of level of each square wave are $\frac{n(360/2m)}{p}$; there being a phase-shift, between each said train of square waves and at least one other said train of square waves, of $\pm 2(360/2m)$; where p is an integer between 1 and $(n-1)$ inclusive; each said sensing pulse being generated immediately after a change of level of one or other of said trains of square waves;

(b) detection means for detecting a set of levels, consisting of the respective instantaneous levels of said n trains of square waves, in response to each successive sensing pulse;

(c) identification means for identifying the expected sets of levels of said n trains of square waves by, for each pair of successive sensing pulses, comparing the set of levels of said n trains of square waves obtained in response to the first sensing pulse with a reference pattern, and deriving two alternative said expected sets of levels of said n trains of square waves for a forward rotational step and a backward rotational step respectively;

(d) comparing means for comparing the set of levels of said n trains of square waves obtained in response to



the second sensing pulse with said two alternative expected sets of levels of said n trains of square waves;

(e) signal means for generating an abnormality alarm signal if the comparison indicates an abnormality in that the set of levels of said n trains of square waves obtained in response to the second sensing pulse accords with neither of said two alternative expected sets of levels of said n trains of square waves; and

(f) a rotational step counter to which, in the event of no abnormality, (+1) or (-1) is added for each forward or backward rotational step respectively indicated by the comparison means to have occurred.

10. Apparatus for determining a rotational angle of a rotary body as claimed in claim 7, 8 or 9; wherein said comparing means further comprises means for comparing a variation pattern of a combination of detected n levels with a previously stored variation pattern of a combination of last detected n levels and, if they are identical with each other, generating an abnormal alarm signal.

11. Apparatus for determining a rotational angle of a rotary body as claimed in claim 7, 8, or claim 10 dependent upon claim 7 or 8; wherein said generating



means is adapted to generate said sensing pulses at an interval of 30 degrees ($m=6$) of the rotation of said encoder, and 3-phase rectangular wave signals which alternately take a high level and low level at an interval of 90 degrees that is three times 30 degrees and which are phase-shifted by 30 degrees with respect to one another, are generated as rotational angular position signals.

12. Apparatus for determining a rotational angle of a rotary body as claimed in claim 7 or 9, or claim 10 dependent upon claim 7 or 9; wherein said generating means is adapted to generate said sensing pulses at an interval of 30 degree ($m=6$) of the rotation of said encoder, and 3-phase rectangular wave signals which alternately take a high level and low level at an interval of 90 degrees that is three times 30 degrees and which are phase-shifted by 60 degrees with respect to one another, are generated as rotational angular position signals.

13. A method of determining a rotational angle of a rotary body substantially as described herein with reference to the accompanying drawings.

14. Apparatus for determining a rotational angle of a rotary body substantially as described herein with reference to the accompanying drawings.
