



## TITLE OF THE INVENTION

STATOR OF ROTATING ELECTRIC MACHINE AND ROTATING  
ELECTRIC MACHINE USING THE SAME

## BACKGROUND OF THE INVENTION

5           The present invention relates to a stator of  
a rotating electric machine such as an electric motor,  
generator, a synchronous machine or the like, which  
is capable of decreasing vibration and noise.

          Conventionally, for example, an induction motor is  
10       known as one rotating electric machine.

          FIGS. 39A and 39B, and FIGS. 40A and 40B are views  
showing two examples of a conventional induction motor  
of this type. FIGS. 39A and 40A are partially broken  
side views thereof, and FIGS. 39B and 40B are sectional  
15       views taken along one dot chain line A-B.

          A stator 1 comprises a frame 2 and a stator core  
(iron core) 3 fixed to the frame 2. A rotor 4 is  
constituted by providing a rotor core (iron core) 7 on  
a rotation shaft 6 pivoted via a bearing 5.

20           In recent years, such induction motor is  
controlled in speed with an inverter in many cases.  
However, since the speed is changed in a speed control  
operation, there arises a problem in that a frequency  
of an electromagnetic force and the number of natural  
25       vibration of a constitution system of an induction  
motor interfere with each other to provide a resonance  
phenomenon and a large noise occurs. Then, since the



- 2 -

speed changes, the resonance point cannot be avoided.

As means for decreasing such noise resulting from such resonance phenomenon, for example, there is known one disclosed in Jpn. U.M. Publication (KOKAI)

5 No. 55-109353.

FIG. 41 is a sectional view showing a constitution example of a conventional induction motor of this type. An elastic beam 13 is provided via an elastic body 12, and the stator core 3 and the frame 2 are elastically  
10 supported on the elastic beam 13.

However, in the induction motor having the above constitution, the rigidity of the elastic beam 13 must be reduced to make it difficult to transmit the vibration of the stator core 3 to the frame 2.

15 The stator core 3 receives a torque in a circumferential direction as a reaction force of a drive torque of the rotor 7. Accordingly, the elastic beam 13 must support the weight of the stator core 3 and the force in the circumferential direction which  
20 makes it difficult to reduce the rigidity of the elastic beam 13.

Consequently, since the vibration transmission from the stator 1 to the outside cannot be sufficiently reduced, noise cannot be sufficiently reduced.

25

#### BRIEF SUMMARY OF THE INVENTION

An object of the present invention is to provide a stator of a rotating electric machine capable of

- 3 -

sufficiently decreasing vibration and noise and a rotating electric machine using the stator.

According to one aspect of the present invention, there is provided a stator of a rotating electric machine comprising a core, and a frame connected to the core, wherein the frame is configured such that an electromagnetic force vibration of the frame differs from a natural vibration mode of the frame.

According to another aspect of the present invention, there is provided a stator of a rotating electric machine of a frame-less type, comprising a core configured such that an electromagnetic force vibration of the core differs from a natural vibration mode of the core.

According to still another aspect of the present invention, there is provided a stator of a rotating electric machine comprising a core, and a frame connected to the core and having a circumference shape of a section in a direction perpendicularly to an axial direction which is selected from one of a substantial circle, substantial square, substantial trapezoid, substantial rectangle, and substantial square, wherein a central point of the core is decentered with respect to one of a central point of the frame and a cross point of a diagonal of the frame.

#### BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

The accompanying drawings, which are incorporated

- 4 -

in and constitute a part of the specification,  
illustrate embodiments of the present invention and,  
together with the general description given above and  
the detailed description of the embodiments given  
5 below, serve to explain the principles of the present  
invention in which:

FIG. 1 is a view for explaining a mechanism of  
noise generation;

10 FIG. 2A to 2F are views for explaining a circular  
mode;

FIG. 3 is a view for explaining a conventional  
noise characteristic;

FIG. 4 is a view for explaining a vibration of  
an electromagnetic force;

15 FIGS. 5A, 5B, and 5C are views for explaining  
a mechanism of the vibration generation from a relation  
between the electromagnetic force and natural vibration  
mode;

20 FIGS. 6A and 6B are views for explaining  
a vibration characteristic;

FIGS. 7A to 7C are views for explaining  
a vibration characteristic;

FIGS. 8A to 8C are views for explaining  
a vibration characteristic;

25 FIGS. 9A and 9B are a partially broken side view  
and a transverse sectional view showing a stator of  
a rotating electric machine according to a first

- 5 -

embodiment of the present invention;

FIG. 10 is a characteristic view showing  
a relation between noise and operation frequency of the  
rotating electric machine in an experiment according to  
5 the first embodiment;

FIG. 11 is a characteristic view showing  
a relation between an order  $n$  and a noise level;

FIGS. 12A and 12B are a partially broken side view  
and a transverse sectional view showing one example of  
10 a stator of a rotating electric machine according to  
a second embodiment of the present invention;

FIGS. 13A and 13B are a partially broken side view  
and a transverse sectional view showing another example  
of the stator of the rotating electric machine  
15 according to the second embodiment of the present  
invention;

FIG. 14 is a perspective view showing one example  
of a stator of a rotating electric machine according to  
a third embodiment of the present invention;

20 FIG. 15 is a perspective view showing another  
example of the stator of the rotating electric machine  
according to the third embodiment of the present  
invention;

FIG. 16 is a perspective view showing a stator  
25 of a rotating electric machine according to a fourth  
embodiment of the present invention;

FIG. 17 is a sectional view showing a stator of

- 6 -

a rotating electric machine according to a fifth embodiment of the present invention;

FIG. 18 is a sectional view showing a stator of a rotating electric machine according to a sixth embodiment of the present invention;

FIG. 19A and 19B are a sectional view and a side view showing a stator of a rotating electric machine according to a seventh embodiment of the present invention;

FIG. 20A and 20B are a sectional view and a side view showing one example of a stator of a rotating electric machine according to an eighth embodiment of the present invention;

FIGS. 21A and 21B are a sectional view and a side view showing another example of the stator of the rotating electric machine according to the eighth embodiment of the present invention;

FIG. 22 is a perspective view showing a stator of a rotating electric machine according to a ninth embodiment of the present invention;

FIG. 23 is a perspective view showing a stator of a rotating electric machine according to a tenth embodiment of the present invention;

FIG. 24 is a transverse sectional view showing one example of a stator of a rotating electric machine according to an eleventh embodiment of the present invention;

FIG. 25 is a transverse sectional view showing another example of the stator of the rotating electric machine according to the eleventh embodiment of the present invention;

5        FIG. 26 is a transverse sectional view showing another example of the stator of the rotating electric machine according to the eleventh embodiment of the present invention;

10        FIGS. 27A and 27B are a partially broken side view and a transverse sectional view showing another example of the stator of the rotating electric machine according to the eleventh embodiment of the present invention;

15        FIGS. 28A, 28B and 28C are a transverse sectional view and transverse sectional views showing still another example of the stator of the rotating electric machine according to the eleventh embodiment of the present invention;

20        FIG. 29 is a characteristic view showing a noise characteristic;

FIGS. 30A, 30B, and 30C are views showing a cross section of different  $h_2/h_1$ ;

25        FIG. 31 is a transverse sectional view showing a stator of a rotating electric machine according to a twelfth embodiment of the present invention;

FIG. 32 is a characteristic view showing a noise characteristic;

FIG. 33 is a transverse sectional view showing a stator of a rotating electric machine according to a fourteenth embodiment of the present invention;

5 FIG. 34 is a transverse sectional view showing a stator of a rotating electric machine according to a fifteenth embodiment of the present invention;

FIG. 35 is a perspective view showing the stator of the rotating electric machine according to the fifteenth embodiment of the present invention;

10 FIG. 36 is a transverse sectional view showing a stator of a rotating electric machine according to sixteenth and seventeenth embodiments of the present invention;

15 FIGS. 37A and 37B are transverse sectional views showing a stator of a rotating electric machine according to an eighteenth embodiment of the present invention;

20 FIG. 38 is a transverse sectional view showing a stator of a rotating electric machine according to a nineteenth embodiment of the present invention;

FIGS. 39A and 39B are a partially broken side view and a sectional view showing one constitution example of a conventional induction motor;

25 FIGS. 40A and 40B are a partially broken side view and a sectional view showing another constitution example of a conventional induction motor; and

FIG. 41 is a partially broken side view showing

another constitution example of the conventional induction motor.

#### DETAILED DESCRIPTION OF THE INVENTION

An embodiment of a rotating electric machine including a rotor according to the present invention will now be described with reference to the accompanying drawings.

In the beginning, there will be explained a mechanism of noise generation which forms a pre-suppositional idea of the present invention.

FIG. 1 is a view for explaining a mechanism of noise generation. When a frequency of an electromagnetic force which acts on an air gap between a rotor core 102 and a stator core 104 is resonated with the number of natural vibration of the stator core 104, a frame 106 is remarkably vibrated so that the vibration is radiated to the air to generated as a noise.

A mode of deformation of the frame 106 caused by the electromagnetic force is generally an ellipse mode (order  $n = 2$ ) in a circular vibration mode.

The circular vibration mode refers to a mode in which an external configuration is changed in a radial direction as shown in FIGS. 2A to 2F. The mode includes an expansion-shrinkage mode (order  $n = 0$ ), a translation mode (order  $n = 1$ ), an ellipse mode (order  $n = 2$ ), a triangle mode (order  $n = 3$ ), a square mode (order  $n = 4$ ), a pentagon mode (order  $n = 5$ ), and

the like.

Conventionally, a transversal cross section (perpendicularly to a rotation axis) of the stator core 3 and the frame 2 is circular or square as shown in  
5 FIGS. 39B and 40B in many cases. The measurement result of the noise is shown in FIG. 3. A horizontal axis shows an operation frequency (Hz) while a vertical axis shows a noise level (dB). There can be seen  
10 a large peak between 40 Hz to 60 Hz of the operation frequency of the induction motor. This is the noise generated under the influence of the resonance.

Now, the principle of noise generation will be specifically explained.

Since an electromagnetic force is a rotating  
15 magnetic field, there can be generated a mode in which the electromagnetic force is rotated and changed with the lapse of time as a forced vibration toward an inner diameter of the stator core primarily in an ellipse  
mode ( $n = 2$ ) seen from a given point in the stator  
20 core.

Vibration by the above electromagnetic force is represented in equation (1):

$$f_M = A \cdot \sin(\omega t - M\theta) \quad (1)$$

where  $f_M$  denotes a vibration caused by the  
25 electromagnetic force,  $A$  denotes an amplitude of the electromagnetic force,  $\omega$  denotes a number of angular vibrations of the electromagnetic force,  $M$  denotes

an order of electromagnetic force vibration,  $\theta$  denotes a mechanical angle, and  $t$  denotes time.

A natural vibration  $\phi_N$  is represented in equation (2) when only a surface vibration of a circle is considered as shown in FIGS. 2A to 2F:

$$\phi_N = \phi_N \cdot \sin N\theta \quad (2)$$

where  $\phi_N$  denotes a natural vibration of a circle,  $\phi_N$  denotes an amplitude of the natural vibration, and  $N$  denotes an order of the natural vibration.

Since the noise due to vibration is caused by a resonance of the electromagnetic vibration and the natural vibration as shown in FIG. 1, a vibration amplitude  $z$  caused by an electromagnetic force which acts on an induction motor are represented by equation (3) according to the present invention.

$$z = f_M \cdot \phi_N \quad (3)$$

Since the vibration amplitude  $z$  represents a vibration at a certain angle  $\theta$ , an amplitude  $Z$  of a whole circle can be obtained from equation (4) by integrating the amplitude  $z$  over the whole circumference with respect to  $\phi$ .

From equation (4), it is found that the vibration amplitude  $Z$  of the whole circle can be determined from the product of the electromagnetic force and the natural vibration.

$$Z = \int_0^{2\pi} z d\theta = \int_0^{2\pi} f_M \cdot \phi_N d\theta \quad (4)$$

Next, detailed explanation is made by substituting

specific values.

The vibration amplitude  $Z$  generated by the electromagnetic force mode (order  $M = 2$ ) and the natural vibration mode (order  $N = 2$ ) can be determined from a vector product as shown in FIG. 5A.

An outward direction of the radius direction represents a plus while an inward direction thereof represents a minus.

Points to be calculated are eight points on a circumference as representative points in an approximate calculation.

In FIG. 5A, in the case of the electromagnetic force mode (order  $M = 2$ ) and the natural vibration mode (order  $N = 2$ ), the calculation of the vector product is expressed as equation (5).

The numeric values of the determinant are represented in a vector amount of the respective eight points shown in FIG. 5A.

$$[1 \ 0 \ -1 \ 0 \ 1 \ 0 \ -1 \ 0] \begin{bmatrix} 1 \\ 0 \\ -1 \\ 0 \\ 1 \\ 0 \\ -1 \\ 0 \end{bmatrix} = 4 \quad (5)$$

Thus, in a combination of the electromagnetic force mode (order  $M = 2$ ) and the natural vibration mode (order  $N = 2$ ), a vibration amplitude is generated which has a magnitude such that the value of the vector product becomes  $Z = 4$ .

Next, the vibration amplitude  $Z$  generated in a combination of the electromagnetic force mode (order  $M = 2$ ) and the natural vibration mode (order  $N = 3$ ) can be determined in a calculation of a vector product as shown in FIG. 5B.

$$\begin{bmatrix} 1 & 0 & -1 & 0 & 1 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ -0.71 \\ 0 \\ 0.71 \\ -1 \\ 0.71 \\ 0 \\ -0.71 \end{bmatrix} = 0 \quad (6)$$

In the combination of the electromagnetic force mode (order  $M = 2$ ) and the natural vibration mode (order  $N = 3$ ),  $Z = 0$  and no vibration is generated.

Next, the vibration amplitude  $Z$  generated in a combination of the electromagnetic force mode (order  $M = 2$ ) and the natural vibration mode (order  $N = 5$ ) can be determined in a calculation of a vector product as shown in FIG. 5C.

$$\begin{bmatrix} 1 & 0 & -1 & 0 & 1 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} 1 \\ -0.71 \\ 0 \\ 0.71 \\ -1 \\ 0.71 \\ 0 \\ -0.71 \end{bmatrix} = 0 \quad \dots(7)$$

In the combination of the electromagnetic force mode (order  $M = 2$ ) and the natural vibration mode (order  $N = 5$ ),  $Z = 0$  and no vibration is generated.

From the above relation, it can be seen that setting the order  $N$  of the natural vibration mode to 3

and 5 with respect to the electromagnetic force mode (order  $M = 2$ ) is a condition for preventing the vibration. Similarly, the order  $N = 7, \dots$  (odd number) of the natural vibration mode with respect to the electromagnetic force mode (order  $M = 2$ ) can preventing the vibration.

This means that even when the stator core is resonated due to the induced electromagnetic force, the vibration can be securely decreased.

The natural vibration mode is mainly based on the cross section of the structure so that it is desirable to set the order  $n$  of the circular vibration mode to an odd number, e.g., 3, 5, 7,  $\dots$ .

Since the order  $M$  of the electromagnetic force induced to the stator core is usually even number, for example two, it is possible to cancel the vibration due to the electromagnetic force and the natural vibration by setting the shape of the cross section (perpendicularly to the rotation shaft) of the stator frame in accordance with the circular vibration mode (the order  $n = 3, 5, 7, \dots$  (odd number)).

In order to verify the principle, the external configuration of the frame is changed and the verification is conducted during the experiment.

In an actual induction motor, it is difficult to grasp an order  $M$  of an electromagnetic force. Then, a vibrator is attached on an inner diameter of the stator

core, and the verification is conducted in a multiple point excitation experiment method.

Twelve vibrators for generating the same vibration force are arranged with equal intervals and a phase of adjacent vibrators is shifted by 45 degrees so that it is possible to generate the vibration mode of order  $M = 2$  at the circumferential surface of the inner diameter of the stator core.

A frequency of the vibrator is changed to 0 to 2500 Hz to be evaluated at a vibration acceleration.

FIG. 6A is a view showing an acceleration when the cross section (perpendicularly to the rotation shaft) of the stator frame is circular. The acceleration is particularly large for  $n = 2$ . The acceleration is the second largest for  $n = 4$  and 6. The acceleration is small for  $n = 3$  and 5 as compared with the acceleration for  $n = 2, 4$  and 6.

FIG. 6B is a view showing an acceleration when the cross section (perpendicularly to the rotation shaft) of the stator frame is square. The acceleration is particularly large for  $n = 2$  and 4. The acceleration is the second largest for  $n = 6$ . The acceleration is small for  $n = 3$  and 5 as compared with the acceleration for  $n = 2, 4$  and 6.

FIG. 7A is a view showing an acceleration when the outer circumference of a cross section (perpendicularly to the rotation shaft) of the stator frame has a shape

defined by the circular vibration mode of order  $n = 2$  (ellipse mode). The acceleration is particularly large for  $n = 2$ . The acceleration is the second largest for  $n = 4$  and 6. The acceleration is small for  $n = 3$  and 5 as compared with the acceleration for  $n = 2, 4$  and 6.

FIG. 7B is a view showing an acceleration when the outer circumference of a cross section (perpendicularly to the rotation shaft) of the stator frame has a shape defined by the circular vibration mode of order  $n = 4$  (square mode). The acceleration is particularly large for  $n = 4$ . The acceleration is the second largest for  $n = 2$  and 6. The acceleration is small for  $n = 3$  and 5 as compared with the acceleration for  $n = 2, 4$  and 6.

FIG. 7C is a view showing an acceleration when the outer circumference of a cross section (perpendicularly to the rotation shaft) of the stator frame has a shape defined by the circular vibration mode of order  $n = 6$  (hexagon mode). The acceleration is particularly large for  $n = 6$ . The acceleration is the second largest for  $n = 2, 3$  and 4. The acceleration is small for  $n = 5$ .

FIG. 8A is a view showing an acceleration when the outer circumference of a cross section (perpendicularly to the rotation shaft) of the stator frame has a shape defined by the circular vibration mode of order  $n = 3$  (triangle mode). It is recognized that the acceleration is small on the whole.

FIG. 8B is a view showing an acceleration when the

outer circumference of a cross section (perpendicularly to the rotation shaft) of the stator frame has a shape defined by the circular vibration mode of order  $n = 5$  (pentagon mode). It is recognized that the acceleration is small on the whole.

FIG. 8C is a view showing an acceleration when the outer circumference of a cross section (perpendicularly to the rotation shaft) of the stator frame has a shape defined by the circular vibration mode of order  $n = 7$  (heptagon mode). It is recognized that the acceleration is small on the whole though it is rather large as compared with FIGS. 8A and 8B. This is because the shape of the outer circumference of the cross section comes close to the circle with an increase in an order. Therefore, the upper limit of the order  $n$  of the circular vibration mode is preferably set to 7.

As can be recognized from the experiment result, the vibration is not generated if the order  $n$  of the circular vibration mode defining the shape of the outer circumference of the cross section of the stator core is odd number such that the order  $N$  of the natural vibration mode of the outer circumference of the cross section of the stator core is not equal to the order  $M$  ( $= 2$ ) of the electromagnetic force.

Even if the shape of the outer circumference of the cross section of the stator core is any shape, there is generated a natural vibration mode.

However, the vibration amplitude of the natural vibration mode (order  $N = 2$ ) is suppressed and ceased to be generated by setting the order  $n$  of the circular vibration mode defining the shape of the outer circumference of the cross section of the stator core to 3.

On the contrary, the vibration amplitude of the natural vibration mode (order  $N = 3$ ) is enlarged by setting the order  $n$  of the circular vibration mode defining the shape of the outer circumference of the cross section of the stator core to 3.

That is, the magnitude of the vibration is determined by the relation between the order  $M$  of the electromagnetic force mode and the order  $N$  of the natural vibration mode. In order to effectively reduce the vibration, it becomes essential to prevent the both orders from agreeing with each other.

From such a viewpoint, the shape of the outer circumference of the cross section in a direction perpendicularly to an axial direction of the stator frame is set to a shape defined by a sine curve of an odd number order (excluding 1, preferably, any one of 3, 5 and 7 appropriately selected in accordance with the number of poles in the rotating electric machine). A substantial same effect is obtained even if the shape is merely a polygon having odd-number (excluding 1) sides (preferably, any one of substantial triangle,

substantial pentagon, and substantial heptagon).

Further, if the stator frame is not provided, i.e., in the case of frame-less type stator, the shape of the outer circumference of the cross section in a direction  
5 perpendicularly to an axial direction of the stator core is set to a shape defined by a sine curve of an odd number order (excluding 1, preferably, any one of 3, 5 and 7 appropriately selected in accordance with the number of poles in the rotating electric machine),  
10 order or a substantial polygon having odd-number (excluding 1) sides (preferably, any one of substantial triangle, substantial pentagon, and substantial heptagon).

Hereinafter, embodiments of the present invention  
15 will be explained in detail by referring to the drawings. Since the overall structure of the rotating electric machine is the same as the conventional examples shown in FIGS. 39A to 40B, the same portions as those of the conventional examples will be indicated  
20 in the same reference numerals and their detailed description will be omitted.

#### First Embodiment

FIG. 9A is a partially broken side view showing a constitution example of a stator core of a rotating  
25 electric machine according to the first embodiment, and FIG. 9B is a transverse sectional view thereof (a cross section in a direction perpendicularly to an axial

direction of the frame).

The stator 1 comprises the frame 2 and the stator core 3 fit into and fixed to the frame 2. Assuming that a ratio of an average radius  $r$  of an outer circumference of the frame 2 and a deformation amount  $A$  from the average radius  $r$  is in the range of  $0.05 \leq A/r \leq 0.5$ , and a mechanical angle is denoted by  $\theta$ , an outer circumference  $D$  of a cross section of the frame 2 in a direction perpendicularly to an axial direction is set to a substantial sine waveform as expressed as follows:

$$D \approx A \cdot \sin n\theta$$

where an order  $n$  of the substantial sine waveform is set to an odd number excluding 1.

As the odd number order  $n$  excluding 1, preferably, any one of orders 3, 5 and 7 appropriately selected in accordance with the number of poles in the rotating electric machine is set as the order.

An operation of the stator 1 of the rotating electric machine will be explained.

When an operation of the rotating electric machine is started, the rotation shaft 6 is rotated.

At this time, with an electromagnetic force generated between a gap between the stator core 3 and the rotor core 7, the stator core 3 is deformed and vibrated in a radial direction, and the vibration is transmitted to the frame 2. When they are resonated,

large vibration and noise are generated which causes a problem.

In the embodiment, an order M of an electro-magnetic force vibration and an order N of a natural vibration are different from each other ( $M \neq N$ ), the vibration generated on an external configuration of the frame 2 is cancelled even in a resonance state, so that the vibration and the noise generated in the stator 1 can be effectively reduced.

The values of 0.05 and 0.5 in  $0.05 \leq A/r \leq 0.5$  show the minimum and the maximum limit of the cross section defining a sine waveform.

An order of a sine wave defining the shape of the stator frame of the rotating electric machine is denoted by n (= 3, 5 and 7) so that the order M (= 2) of the electromagnetic force vibration and the order N (= 3, 5 and 7) of the natural vibration do not agree with each other. Consequently, the deformation of a circular vibration mode (an ellipse mode of order n = 2) is hardly generated in the frame 2. Accordingly, the vibration generated on the external configuration of the stator 1 cancel each other which enables reducing the vibration and the noise of the stator 1.

FIG. 10 is a characteristic view showing a relation between an operation frequency and a noise of the rotating electric machine in an experiment for n = 3 and 5.

When a cross section in a direction perpendicu-  
larly to an axial direction of a conventional frame  
1 is circular, as shown in FIG. 3, two peaks are  
generated at a resonance point. However, as shown in  
5 FIG. 10, a peak disappears.

With such constitution, the electromagnetic force  
vibration order and the natural vibration order are  
different from each other, so that the two orders  
cancel each other which enables sufficiently reducing  
10 the vibration and the noise.

FIG. 11 is a characteristic view showing  
a relation between the order  $n$  and a noise level.

In FIG. 11, the orders  $n$  are shown from the  
third to the twenty-fifth on a horizontal axis while  
15 the maximum values of the noise level are shown on  
a vertical axis.

FIG. 11 is a view showing a summary of what is  
obtained from a relation between the operation  
frequency of the rotating electric machine and the  
noise shown in FIGS. 10 and 3 and FIG. 11 is a graph  
20 formed by illustrating the maximum peak values of the  
noise level.

As apparent from FIG. 11, it is found that the  
noise is low under the condition of the order of  $n = 3$ ,  
25 5 and 7. Consequently, in the embodiment, the order  $n$   
which is effective for the noise reduction is set to 3,  
5 and 7.

As described above, in the first embodiment, the outer circumference of the cross section in a direction perpendicularly to the axial direction of the frame 2 is a shape defined by a sine waveform with the odd  
5 number order of  $n = 3, 5$  and  $7$ , so that the electromagnetic force vibration order and the natural vibration order are different from each other to cancel each other which enables effectively reducing the vibration and the noise generated in the stator 1.

10 Other embodiments of the rotating electric machine according to the present invention will be described. The same portions as those of the first embodiment will be indicated in the same reference numerals and their detailed description will be omitted.

15 Second Embodiment

FIG. 12A is a partially broken side view showing a constitution example of the stator of the rotating electric machine according to the second embodiment and FIG. 12B is a transverse sectional view (a cross  
20 section in a direction perpendicularly to an axial direction of a frame).

The stator 1 comprises the frame 2 and the stator core 3 fit into and fixed to the frame 2. A cross section in a direction perpendicularly to an axial  
25 direction of the frame 2 is substantially odd-number (excluding 1) sided polygonal.

As the substantial odd-number (excluding 1) sided

polygon, preferably, any one of a substantial triangle, a substantial pentagon and a substantial heptagon is appropriately selected in accordance with the number of poles in the rotating electric machine.

5           The term "substantial" here means that the angle may be rounded, the side may be curved or as shown in FIGS. 13A and 13B, a star configuration may be adopted.

          In the stator 1 according to the second embodiment, the cross section of the frame 2 is  
10       odd-number sided polygonal such as substantially triangular, substantially pentagonal and substantially heptagonal. Consequently, even in a resonance state an order N of a natural vibration becomes an odd number and is different from an order M (which is an even  
15       number) of an electromagnetic force vibration. Accordingly, the vibration generated on the frame 2 is cancelled which enables effectively reducing the vibration and the noise generated in the stator 1.

          That is, when an electromagnetic force vibration  
20       of mode 2 (ellipse mode) on a circumference is represented in one straight-line, it is expressed by two sine waves. Consequently, in order to cancel the electromagnetic force vibration, the cross section of the frame 2 is preferably defined by three sine waves  
25       of the circular vibration mode as shown in the first embodiment.

          However, in view of the facility in the actual

manufacture, a straight-line polygon is more favorable than a curved surface (sine wave). Furthermore, the stability at the time of installation is improved.

5 In order to compare with the first embodiment, it can be confirmed in the experiment that the vibration is increased by 5% in the second embodiment as compared with the first embodiment in the vibration in a radial direction of the frame 2 while the noise level increased by only 2dB (A).

10 In such constitution, in the polygon as well, in the same manner as the first embodiment, an operation and an effect of canceling the electromagnetic force vibration and the natural vibration each other can be obtained because of a difference in the order of two  
15 modes which enables sufficiently reducing the vibration and the noise.

As has been described above, in the stator of the rotating electric machine according to the second embodiment, the cross section in a direction  
20 perpendicularly to the axial direction of the frame 2 is set to substantially triangular, substantially pentagonal and substantially heptagonal. Accordingly, the electromagnetic force vibration order and the natural vibration order are different from each other  
25 to cancel two vibrations each other which enables effectively reducing the vibration and the noise generated in the stator 1.

### Third Embodiment

FIGS. 14 and 15 are perspective views showing constitution examples of the stator of the rotating electric machine according to the third embodiment.

5       The frame 2 is divided two parts which are attached on both end portions in an axial direction of the stator core 3.

As in the first or second embodiment, the frame 2 is not entirely fit into and fixed to the whole stator core 3, so that the force magnitude of the electro-  
10       magnetic force is uniform in an axial direction. Therefore, it is possible to effectively reduce the vibration and the noise generated in the stator 1.

When only both end portions have rigidity in a  
15       radial direction with two frames 2, the electromagnetic force can be sufficiently cancelled.

Two frames 2 are attached only on both end portions, so that the overall weight of the rotating electric machine can be reduced in weight by about 10%.

20       The deformation of a circular vibration mode of order 2 (ellipse mode) is hardly generated on the external configuration of the frame 2. Accordingly, the vibration generated on the external configuration of the stator 1 is cancelled which enables reducing  
25       the vibration and the noise of the stator 1.

As described above, in the stator 1 according to the third embodiment, since the frame 2 is divided and

attached on both end portions in an axial direction of the stator core 3, the vibration and the noise generated in the stator 1 can be effectively reduced.

Though FIGS. 14 and 15 indicate the frame 2 having a polygon cross section, the third embodiment can be applied to the frame 2 having a shape defined by a sine wave of odd number order as described in the first embodiment.

#### Fourth Embodiment

FIG. 16 is a perspective view showing a constitution example of the stator of the rotating electric machine according to the fourth embodiment.

The frame 2 is divided into three parts which are attached on both end portions and a substantial central portion in an axial direction of the stator core 3.

Attaching the frames 2 on both end portions and on the central portion in an axial direction of the stator core 3 becomes effective when the stator core 3 is long in an axial direction with respect to the third embodiment.

For example, when an external dimension of the stator core 3 is denoted by  $\phi D$  and a thickness length of the stator core in an axial direction is denoted by  $L$ , it is effective when applied under the condition of  $\phi D < L$ .

Depending on the rotating electric machine, when the length of the stator core 3 is long, the

deformation of the stator core 3 cannot be cancelled only with the frames 2 on both end portions.

5 In the embodiment, three frames 2 are attached on both end portions and the central portion of the long stator core 3 which has a force in capable of canceling by only two frames 2 on both end portions. Therefore, the rigidity thereof can be balanced.

10 Consequently, the deformation of a circular vibration of order 2 (ellipse mode) is hardly generated on the external configuration of the frame 2. Accordingly, the vibration generated on the external configuration of the stator 1 cancels each other which enables reducing the vibration and the noise of the stator 1.

15 As described above, in the stator 1 according to the fourth embodiment, three frames 2 are attached on both end portions and a substantial central portion in an axial direction of the stator core 3 frame which enables effectively reducing the vibration and the noise generated in the stator 1.

20 Though FIG. 16 indicates the frame 2 having a polygon cross section, the fourth embodiment can be applied to the frame 2 having a shape defined by a sine wave of odd number order as described in the first embodiment.

25

#### Fifth Embodiment

FIG. 17 is a sectional view showing a constitution

example of the stator of the rotating electric machine according to the fifth embodiment.

The fifth embodiment is a modification of the third embodiment. Two frames are not aligned in a circumferential direction and one frame is rotated with respect to the other frame by degree of  $(360^\circ / 2n)$ . If  $n = 5$ , one frame is rotated with respect to the other frame by  $36^\circ$ .

The frames are attached such that the corners of the polygon or the vertexes of the sine wave defining the circular mode do not agree with each other as seen from the axial direction. Therefore, the distribution of the electromagnetic force is a uniform ellipse in a thickness direction (axial direction) of the stator core 3. Accordingly, the frames 2 on both end portions of the stator core 3 changes the rigidity in a twist circumferential direction thereby resulting in the scattering of the vibration with further electromagnetic force. Thus, it is possible to reduce the vibration and the noise.

Consequently, the deformation of a circular vibration of order 2 (ellipse mode) is hardly generated on the external configuration of the frame 2, so that the vibration generated on the external configuration of the stator 1 is cancelled, thereby enabling reducing the vibration and the noise of the stator 1.

As described above, in the stator 1 according to

the fifth embodiment, the vibration of an outer circumference of the cross section in a direction perpendicularly to the axial direction of the frame 2 is set to a substantial n sided polygon and by  
5 referencing to one frame 2, the other frame 2 is rotated an order of  $(360^\circ / 2n)$  in a circumferential direction which enables effectively reducing the vibration and the noise generated in the stator 1.

#### Sixth Embodiment

10 FIG. 18 is a sectional view showing a constitution example of the stator of the rotating electric machine according to the sixth embodiment.

The frame 2 is constituted as a polygon in which a portion other than angles comes on an extension line for connecting an angle of a cross section of the frame  
15 2 and a center O of the stator core 3. Therefore, the frame 2 is constituted as a non-equilateral polygon which can reduce the vibration and the noise as a result of an action for scattering the ellipse mode  
20 of the electromagnetic force in a circumferential direction.

Consequently, the deformation of a circular vibration of order 2 (ellipse mode) is hardly generated on the external configuration of the frame 2 and the  
25 vibration generated on the external configuration of the stator 1 which enables reducing the vibration and the noise of the stator 1.

As described above, in the stator 1 according to the sixth embodiment, the cross section of the stator is a non-equilateral polygon in which a portion other than the angle comes on an extension line for  
5 connecting the angle of the frame and the central point O of the stator core 3. Thus, it is possible to effectively reduce the vibration and the noise generated in the stator 1.

As in the third to fifth embodiments, the sixth  
10 embodiment can also be applied to the case in which the shape of the cross section of the frame is defined by a sine wave of odd number order.

#### Seventh Embodiment

FIGS. 19A and 19B are a sectional view and a side  
15 view showing a constitution example of the stator of the rotating electric machine according to the seventh embodiment.

As in the third and fourth embodiments, the frames 2 are attached either only on both end portions or on  
20 both end portions and the central portion of the core 3 and are connected with each other by ribs 8 in axial direction.

In the stator 1 according to the seventh embodiment, the mechanical rigidity of the frame 2  
25 at both end portions is increased and strengthened. Accordingly, even when the thickness of the core 3 in the axial direction is lengthened, rigidity which

surpasses the electromagnetic force can be secured.  
Therefore, the vibration generated on the external  
configuration of the stator 1 is cancelled which  
enables effectively reducing the vibration and the  
noise generated in the stator 1.

5 Since the rigidity of the frames 2 on both ends  
is increased and strengthened with the connection  
with the ribs 8 for connecting the respective frames  
2 as compared with the third embodiment or fourth  
10 embodiment, the rigidity which surpasses the electro-  
magnetic force can be secured even when the thickness  
of the stator core 3 in an axial direction in  
lengthened.

Consequently, the deformation of a circular  
15 vibration of order 2 (ellipse mode) is hardly generated  
on the external configuration of the frame 2, and the  
vibration generated on the external configuration of  
the stator 1 is cancelled which enables reducing the  
vibration and the noise of the stator 1.

20 As described above, since the rib 8 connects  
the respective frames 2 in an axial direction, the  
vibration and the noise generated in the stator 1 can  
be effectively reduced.

#### Eighth Embodiment

25 FIGS. 20A and 20B are a sectional view and a side  
view showing a constitution example of the stator of  
the rotating electric machine according to the eighth

embodiment.

The eighth Embodiment is a modification of the seventh embodiment and in which the ribs 8 are connected to an outer circumference of the stator core 3 with mechanical connection means such as welding,  
5 bonding, bolts or the like. Accordingly, the vibration of the stator core 3 is transmitted to the frame 2 via the ribs 8 and the rigidity of the structure system which surpasses the electromagnetic force can be  
10 secured even when the thickness of the stator core 3 in the axial direction is lengthened.

Furthermore, as shown in FIGS. 21A and 21B, if positions of the ribs 8 are located at the angles of the frame 2 and the centers of the sides thereof,  
15 the deformation of the stator core 3 is transmitted to the frame 2 via the ribs 8. Accordingly, the rigidity of the structure system which surpasses the electromagnetic force can be secured even when the thickness of the stator core 3 in the axial direction is  
20 lengthened.

Consequently, the deformation of a circular vibration of order 2 (ellipse mode) is hardly generated on the external configuration of the frame 2, and the vibration generated on the external configuration of  
25 the stator 1 is cancelled which enables reducing the vibration and the noise of the stator 1.

As described above, in the stator 1 according to

the eighth embodiment, the ribs 8 and the stator core 3 are connected with mechanical connection means such as welding, bonding, bolts or the like. Accordingly, the vibration and the noise generated in the stator 1 can be effectively reduced.

#### Ninth Embodiment

FIG. 22 is a perspective view showing a constitution example of the stator of the rotating electric machine according to the ninth embodiment.

The above embodiments comprise a frame of the stator, however, the ninth embodiment does not and is called frame-less type stator.

Assuming that a ratio of an average radius  $r$  of an outer circumference of the stator core 3 and a deformation amount  $B$  from the average radius  $r$  is in the range of  $0.05 \leq B/r \leq 0.5$ , and a mechanical angle is denoted by  $\theta$ , an outer circumference  $E$  of a cross section of the stator core 3 in a direction perpendicularly to an axial direction is set to a substantial sine waveform as expressed as follows:

$$E \approx B \cdot \sin n\theta$$

where an order  $n$  of the substantial sine waveform is set to an odd number excluding 1.

As the odd number order  $n$  excluding 1, preferably, any one of orders 3, 5 and 7 appropriately selected in accordance with the number of poles in the rotating electric machine is set as the order.

An operation of the stator 1 of the rotating electric machine will be explained.

When an operation of the rotating electric machine is started, the rotation shaft 6 is rotated.

5           At this time, with an electromagnetic force generated between a gap between the stator core 3 and the rotor core 7, the stator core 3 is deformed and vibrated in a radial direction, and the vibration is transmitted to the frame 2. When they are resonated,  
10           large vibration and noise are generated which causes a problem.

          In the embodiment, an order M of an electromagnetic force vibration and an order N of a natural vibration are different from each other ( $M \neq N$ ), the  
15           vibration generated on an external configuration of the frame 2 is cancelled even in a resonance state, so that the vibration and the noise generated in the stator 1 can be effectively reduced.

          The values of 0.05 and 0.5 in  $0.05 \leq B/r \leq 0.5$   
20           show the minimum and the maximum limit of the cross section defining a sine waveform.

          An order of a sine wave defining the shape of the stator core 3 of the rotating electric machine is denoted by n (= 3, 5 and 7) so that the order M (= 2)  
25           of the electromagnetic force vibration and the order N (= 3, 5 and 7) of the natural vibration do not agree with each other. Consequently, the deformation of

a circular vibration mode (an ellipse mode of order  $n = 2$ ) is hardly generated in the frame 2. Accordingly, the vibration generated on the external configuration of the stator 1 cancel each other which enables  
5 reducing the vibration and the noise of the stator 1.

As described above, in the ninth embodiment, the outer circumference of the cross section in a direction perpendicularly to the axial direction of the stator core 3 is a shape defined by a sine waveform with  
10 the odd number order of  $n = 3, 5$  and  $7$ , so that the electromagnetic force vibration order and the natural vibration order are different from each other to cancel each other which enables effectively reducing the vibration and the noise generated in the stator 1.

#### 15 Tenth Embodiment

FIG. 23 is a perspective view showing a constitution example of the stator of the rotating electric machine according to the tenth embodiment.

A cross section in a direction perpendicularly to an axial direction of the stator core 3 is  
20 substantially odd-number (excluding 1) sided polygonal.

As the substantial odd-number (excluding 1) sided polygon, preferably, any one of a substantial triangle, a substantial pentagon and a substantial heptagon is  
25 appropriately selected in accordance with the number of poles in the rotating electric machine.

In the stator 1 according to the tenth embodiment,

the cross section of the stator core 3 is odd-number sided polygonal such as substantially triangular, substantially pentagonal and substantial heptagonal. Consequently, even in a resonance state an order N of  
5 a natural vibration becomes an odd number and is different from an order M (which is an even number) of an electromagnetic force vibration. Accordingly, the vibration generated on the stator core 3 is cancelled which enables effectively reducing the vibration and  
10 the noise generated in the stator 1.

As has been described above, in the stator core of the rotating electric machine according to the tenth embodiment, the cross section in a direction perpendicularly to the axial direction of the stator core 3  
15 is substantially triangular, substantially pentagonal and substantial heptagonal. Accordingly, the electromagnetic force vibration order and the natural vibration order are different from each other to cancel two vibrations each other which enables effectively  
20 reducing the vibration and the noise generated in the stator 1.

#### Eleventh Embodiment

FIGS. 24, 25 and 26 are transverse sectional views respectively showing constitution examples of the  
25 stator of the rotating electric machine according to the eleventh embodiment.

A thickness of the frame 2 at an angle portion

of a cross section (a substantial triangle or a substantial pentagon) in a direction perpendicularly to an axial direction is set to  $h_2$  and a thickness of the frame 2 at an extension line for connecting the angle portion and a central point of the stator core 3 is set to  $h_1$ . A ratio of  $h_2$  and  $h_1$  is set in a range of  $h_2/h_1 = 2.5$  to  $4.5$ .

The ratio of  $h_2$  and  $h_1$  is preferably set to a range of  $h_2/h_1 = 3.0$  to  $4.0$ , and is more preferably set to  $h_2/h_1 = 3.5$ .

In the stator 1 according to the eleventh embodiment, the electromagnetic force hardly acts due to a balance of the rigidity ratio  $h_2/h_1$ . Accordingly, the vibration generated on the frame 2 even in a resonance state is cancelled which enables effectively reducing the noise generated on the whole rotating electric machine.

Hereinafter, the details of the eleventh embodiment will be described.

When the cross section of the frame 2 is a substantial triangle, the installation area is large in a practical usage aspect in an actual product. When the cross section of the frame is a substantial heptagon which comes close to a circle, the effect of reducing noises is slightly small as compared with the substantial pentagon.

Consequently, preferably, the cross section of the

frame 2 is set to a substantial pentagon and the angles are rounded.

In order to determine the thickness of the frame 2, the stress which works on the frame 2 is judged for the stator core 3 and the frame 2 which are formed as shown in FIGS. 27A and 27B with an interference  $2\delta$  in the pressure-in or shrinkage fit process.

Assuming that a longitudinal elastic coefficient and a Poisson ratio of respective materials of the stator core 3 and the stator frame 2 are denoted by  $E_1$ ,  $E_2$  and  $\nu_1$ ,  $\nu_2$ , a surface pressure  $P_m$  of a contact surface is given in the following equation (8).

$$P_m = \frac{2\delta / 2b}{\left\{ \frac{1 - \nu_1}{E_1} + \frac{1 - \nu_2}{E_2} \right\} + 2 \left\{ \frac{1}{E_1} \left( \frac{c^2}{b^2 - c^2} \right) + \frac{1}{E_2} \left( \frac{a^2}{a^2 - b^2} \right) \right\}} \quad (8)$$

Symbol  $a$  denotes a radius of an external configuration of the frame 2, symbol  $b$  denotes a radius of an inner diameter of the frame 2, and symbol  $c$  denotes a radius of a slot bottom of the stator core 3.

The stress in a direction of a contact line of each circle generated with these interferences is set a thickness of the frame 3 less than a stress yield point in the maximum interference  $2\delta$ .

From equation (3), the vibration can be determined with a product of the electromagnetic force vibration and the natural vibration.

With respect to the natural vibration, as shown in the following equations (9) and (10), from equation

(3), the number of natural vibrations is calculated as the stator 1 in which the frame 2 and the stator core 3 are connected.

$$f_n = \frac{1}{2\pi} \sqrt{\frac{EI}{A\rho R^4} \frac{n^2(1-n^2)^2}{n^2+1}} \quad (9)$$

Symbol R denotes a radius of a circle, symbol  $\rho$  denotes a weight of a unit length, symbol E denotes a longitudinal elastic coefficient, and symbol I denotes a secondary moment of a cross section.

Symbol n denotes an order of a circular vibration mode ( $n = 2$  in the case of an ellipse mode).

Symbol E1 denotes a bending rigidity, and is an index showing a facility of the deformation at the time when the bent moment acts.

Symbol E denotes a facility of the deformation of a material, and symbol I denotes a facility of the deformation of a cross section.

As shown in FIGS. 28A, 28B and 28C showing a transverse sectional view and sectional views on line A-B, the secondary moment of the cross section passes through the centers G1 and G2 of gravity of respective circles of the stator core 3 and the frame 2. The secondary moment I of the cross section can be represented in the following equation (10).

$$I = \frac{1}{12} \{B_1(h_1)^3 + B_2(h_2)^3\} \quad (10)$$

Since symbols B1 and B2 denote lengths in an axial

direction, the lengths are the same.

It is found that the bending rigidity acts in a cube of the plate thicknesses  $h_1$  and  $h_2$  of the frame 2 from equation (9).

5        From this fact, it is considered that the deformation of the frame 2 and the stator core 3 can be suppressed by setting the ratio of the  $h_2$  and  $h_1$  to an optimal level with the bending rigidity, so that the following experiment is attempted.

10        As a consequence, the optimal value of the ratio of  $h_2/h_1$  of the thickness of the frame 2 has been detected with respect to the substantial pentagon.

FIG. 29 is a noise characteristic view showing a summary of a result of the noise measurement by using as a parameter a ratio of  $h_2/h_1$ .  
15

FIGS. 30A, 30B, and 30C are views showing a cross section in respective cases of  $h_2/h_1 = 2.5$ ,  $h_2/h_1 = 3.0$ , and  $h_2/h_1 = 4.5$ .

In FIG. 29, a circular cross section denotes a conventional rotating electric machine shown in FIGS. 39A and 39B and represents the weight same as the frame having the substantial pentagon.  
20

In a zone A ( $h_2/h_1 > 4.5$ ), a film plate vibration is generated because the plate thickness of  $h_1$  is thin.

25        In a zone B ( $h_2/h_1 < 2.5$ ), the rigidity ratio of the  $h_2$  and  $h_1$  is small and comes close to the frame having a circular configuration, and it can be said

that this is the mass effect by the plate thickness of the frame.

As described above, in the stator of the rotating electric machine according to the eleventh invention, since the ratio of  $h_2$  and  $h_1$  is in a range of  $h_2/h_1 = 2.5$  to  $4.5$ , the electromagnetic force hardly acts due to a balance of the rigidity ratio of  $h_2/h_1$  by the thickness of the frame 2. Accordingly, the vibration generated on the frame 2 is cancelled even in a resonance state which enables effectively reducing the noise generated on the whole rotating electric machine.

Twelfth Embodiment

FIG. 31 is a transverse sectional view showing a constitution example of the stator of the rotating electric machine according to the twelfth embodiment.

A thickness of the frame 2 at an angle portion of the cross section of a substantial pentagon is set to  $h_2$ , a thickness of a yoke of the stator core 3 is set to  $h_3$ , and a ratio of  $h_3$  and  $h_2$  is in a range of  $h_3/h_2 \leq 0.8$ .

Preferably, the ratio of  $h_3$  and  $h_2$  is in a range of  $0.2 \leq h_3/h_2 \leq 0.4$ .

In the stator 1 according to the twelfth embodiment, the electromagnetic force hardly acts on the frame 2 due to a balance of a rigidity ratio with respect to  $h_3/h_2$  for an order  $M$  of an electromagnetic force vibration even in a resonance state.

Accordingly, the vibration generated on the external configuration of the stator 2 is cancelled which enables effectively reducing the noise generated on the whole rotating electric machine.

5           The thickness  $h_3$  of the yoke of the stator core 3 differs depending on the number of poles. The thickness  $h_3$  decreases with an increase in the number of poles.

10           The electromagnetic force acts on an inner diameter of the stator core 3, so that the vibration is transmitted to the frame 2 from the stator core 3. Then, the bending rigidity requires the rigidity of the frame 2 which counters the deformation of the stator core 3.

15           FIG. 32 is a noise characteristic view in which a ratio of  $h_3/h_2$  is shown as a parameter when the thickness of the yoke of the stator core 3 is set to  $h_3$ .

20           As shown in FIG. 32, by setting  $h_3/h_2 = 0.8$  or more, the electromagnetic force hardly acts due to a balance of the rigidity ratio of the stator core 3 and the frame 2. Accordingly, the vibration generated on the frame 2 is cancelled which enables effectively reducing the noise generated on the whole rotating electric machine.

25

As described above, in the stator of the rotating electric machine according to the embodiment, the

ratio of  $h_3$  and  $h_2$  is in a range of  $h_3/h_2 \leq 0.8$ .

Accordingly, the electromagnetic force hardly acts due to a balance of the rigidity ratio of the stator core 3 and the frame 2 so that the vibration generated on the frame 2 is cancelled which enables effectively reducing the noise generated on the whole rotating electric machine.

#### Thirteenth Embodiment

According to the thirteenth embodiment, a ratio of  $E_2$  and  $E_1$  in any one of the above embodiments, e.g., the first or second embodiment, is in a range of  $E_1/E_2 = 2.5$  to 80 where a longitudinal elastic coefficient which is a mechanical constant of a material forming the frame 2 is denoted by  $E_2$ , and a longitudinal elastic coefficient of an electric iron plate constituting the stator core 3 is denoted by  $E_1$ .

In the stator 1 according to the thirteenth embodiment, when the material of the frame 2 is a material having a longitudinal elastic ratio equal to or more than a longitudinal elastic ratio corresponding to an aluminum material, a mold material of a polymer material and the like, the vibration generated on the external configuration of the stator core 3 and the frame 2 is cancelled which enables effectively reducing the noise generated on the whole rotating electric machine.

When the ratio of the longitudinal elastic

- 45 -

coefficient  $E_2$  which is a mechanical characteristic of a material forming the frame 2 and the longitudinal elastic coefficient  $E_1 = 21000 \text{ kg/mm}^2$  of the electric iron plate of the stator core 3 is  $E_1/E_2 = 2.5$  to 80, for example, if the material of the frame 3 is the aluminum material having a longitudinal elastic coefficient  $E_2 = 7000 \text{ kg/mm}^2$  ( $E_1/E_2 = 3$ ) and the mold material of the polymer material having a longitudinal elastic coefficient of  $E_2 = 300 \text{ kg/mm}^2$  ( $E_1/E_2 = 80$ ), the vibration generated on the configuration of the stator core 3 and the frame 2 is cancelled, which enables effectively reducing the noise generated on the whole rotating electric machine.

When the material of the frame 2 has a longitudinal elastic coefficient  $E_2 = 100 \text{ kg/mm}^2$  ( $E_1/E_2 = 210$ ) of, for example, resin or rubber material, the deformation of the frame 2 cannot surpass the deformation force of the stator core 3 which generates a small noise reduction effect of the noise generated on the whole rotating electric machine.

As described above, in the stator of the rotating electric machine according to the embodiment, the ratio of  $E_2$  and  $E_1$  is in a range of  $E_1/E_2 = 2.5$  to 80. Accordingly, the vibration generated on the external configuration of the stator core 3 and the frame 2 is cancelled which enables effectively reducing the noise generated on the whole rotating electric machine.

## Fourteenth Embodiment

FIG. 33 is a transverse sectional view showing a constitution example of the stator of the rotating electric machine according to the fourteenth embodiment.

There is provided a cooling fin 9 in addition to the stator 1 of any one of the above embodiments, e.g., the first or second embodiment. The cooling fin 9 is arranged at an outer circumference of the frame 2 excluding an angle portion. The outer configuration of the cooling fin 9 is a substantially circular configuration with a radius  $r$  of  $j$  at a vertex  $g$ .

According to the fourteenth embodiment, the cooling fin 9 does not affect the bending rigidity of the stator 2 but serves as an additional weight.

A weight balance becomes even on a circumference by adjusting the height of the cooling fin 9 at a thin portion of the frame 2. When the weight balance becomes uniform, a vibration component by a twist rotation caused by a mechanical imbalance of the rotor is decreased, and the vibration generated on the whole frame 2 is cancelled which enables effectively reducing the noise generated on the whole rotating electric machine.

Furthermore, an installation area can be further made small by arranging the outer configuration of the cooling fin 9 in a circular configuration.

Incidentally, in the embodiment, the cooling fin 9 is arranged in perpendicular to the sides of the polygon. However, it is possible to arrange the cooling fin 9 in along with the radius direction.

5           As described above, in the stator of the rotating electric machine according to the fourteenth embodiment, the vibration generated on the whole frame 2 is cancelled which enables effectively reducing the whole rotating electric machine.

10       Fifteenth Embodiment

FIGS. 34 and 35 are a transverse sectional view and a perspective view showing a constitution example of the stator of the rotating electric machine according to the fifteenth embodiment.

15           The fifteenth embodiment is a modification of the second embodiment in which one end of the frame 2 is rotated by  $(360^\circ / 2n)$  with reference to the other end of the frame 2. If  $n = 5$ , one frame is rotated with respect to the other frame by  $36^\circ$ .

20           Accordingly, the stator 2 on both ends of the stator core 3 changes the mechanical rigidity in a circumferential direction so that the vibration caused by the electromagnetic force is scattered. As a consequence, the deformation of a circular vibration of order 2 (ellipse mode) is hardly generated on the frame  
25       2, and the vibration generated on the frame 2 is cancelled which enables reducing the vibration

and the noise of the whole rotating electric machine. The vibration generated on the frame 2 which enables reducing the vibration and the noise on the whole rotating electric machine.

5 Sixteenth Embodiment

FIG. 36 is a transverse sectional view (a cross section in a direction perpendicularly to an axial direction of a frame) showing a constitution example of the stator of the rotating electric machine according to the sixteenth embodiment.

The stator 1 comprises the frame 2 and stator core 3 fit into and fixed to the frame 2. A cross section in a direction perpendicularly to an axial direction of the frame 2 is substantially circular, square, trapezoidal, and rectangular. A central point of the frame 2 is decentered with respect to a central point of the stator core 3. Since the ratio  $h_2/h_1$  of the thickness of the frame 2 changes based on the decentering amount  $\varepsilon_1$ , the electromagnetic force hardly acts.

Accordingly, the vibration generated on the frame 2 is cancelled even in a resonance state which enables effectively reducing the noise generated on the whole rotating electric machine.

25 Seventeenth Embodiment

The subject matter of the seventeenth embodiment is a specific value of the decentering amount  $\varepsilon_1$ .

The decentering amount  $\epsilon_1$  is set to a value between  $(0.25 \text{ to } 0.8)(D-d)/2$  where an outer diameter of the stator core 3 is denoted by  $d$ , an outer diameter of the frame 2 having a substantial circular configuration is denoted by  $D$ . The decentering amount  $\epsilon_1$  is preferably set to a value between  $(0.7 \text{ to } 0.8)(D-d)/2$ . More preferably, the decentering amount  $\epsilon_1$  is preferably set to  $0.8(D-d)/2$ .

#### Eighteenth Embodiment

FIGS. 37A and 37B are transverse sectional views showing constitution examples of the stator of the rotating electric machine according to the eighteenth embodiment. The cross sectional of the frame 2 of the stator is substantially rectangular or square, an outer diameter of the stator core 3 is denoted by  $d$  and a length of a short side of the frame 2 having a substantial rectangular configuration or a length of one side of the frame 2 having a substantial square configuration is denoted by  $x$ , and a decentering amount is denoted by  $\epsilon_2$ , a center of the stator core 3 is decentered from a cross point of a diagonal of the frame 2 having a substantial rectangular or square configuration in a range of  $\epsilon_2 = (x - d)/2.5$  to  $(x - d)/8$ .

The whole weight is not increased and the electromagnetic force hardly acts due to a balance of the rigidity ratio of  $h_2/h_1$  of the thickness of the

frame 2 having a substantial rectangular or square configuration. Accordingly, the vibration generated on the frame 2 is cancelled in a resonance state which enables effectively reducing the noise generated on the whole rotating electric machine.

#### Nineteenth Embodiment

FIG. 38 is a transverse sectional view showing a constitution example of the stator of the rotating electric machine according to the nineteenth embodiment.

A cross section in a direction perpendicularly to an axial direction of the frame 2 is substantially trapezoidal. An outer diameter of the stator core 3 is denoted by  $d$ , a height of the frame 2 having a substantial trapezoidal configuration is denoted by  $h$ , and a decentering amount is denoted by  $\epsilon_3$ , a center of the stator core 3 from the height of  $h/2$  of the frame 2 having a substantial trapezoidal configuration is decentered in a range of  $\epsilon_3 = (h - d)/2.5$  to  $(h - d)/8$ .

A trapezoidal configuration may only use a configuration effect in a height direction. Decentering is in a range of  $(h - d)/2.5$  to  $(h - d)/8$ , so that the electromagnetic force hardly acts due to a balance of the rigidity ratio  $h_2/h_1$  associated with the thickness of the frame 2. Accordingly, the vibration generated on the frame 2 is cancelled in a resonance state which enables effectively reducing the

noise generated on the whole rotating electric machine.

#### Twentieth Embodiment

According to a twentieth embodiment, there is provided a rotating electric machine comprising the  
5 rotor 4 and the stator 1 according to any one of the first to nineteenth embodiments.

As a consequence, it becomes possible to effectively reduce the vibration and the noise generated on the whole rotating electric machine.

10 Additional advantages and deformations will readily occur to those skilled in the art. Therefore, the present invention in its broader aspects is not limited to the specific details, representative devices, and illustrated examples shown and described  
15 herein. Accordingly, various deformations may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents. For example, each of the embodiments can be appropriately combined as much as  
20 possible. In such a case, a combined operation and effect can be obtained. Furthermore, each of the embodiments includes inventions at various stages, so that various inventions can be extracted from an appropriate combination in a plurality of constituent  
25 elements which are disclosed.

## WHAT IS CLAIMED IS:

1. A stator of a rotating electric machine comprising:

a core; and

5 a frame connected to the core, wherein the frame is configured such that an electromagnetic force vibration of the frame differs from a natural vibration mode of the frame; wherein  
10 a circumference shape of a section of the frame in a direction perpendicularly to an axial direction of the frame is a substantial odd-number sided polygon.

2. The stator according to claim 1, wherein  
15 a circumference shape of a section of the frame in a direction perpendicularly to an axial direction of the frame is substantially defined by  $A \cdot \sin n\theta$ ,

where  $A$  is a deformation from an average radius  $r$  of the cross section, a ratio  $A/r$  being set to a range of  $0.05 \leq A/r \leq 0.5$ ,

20  $\theta$  is a mechanical angle, and

$n$  is an odd number excluding 1.

3. The stator according to claim 2, wherein the  
25  $n$  is any one of 3, 5 and 7 which is selected in accordance with the number of poles in the rotating electric machine.

4. The stator according to claim 1, wherein said substantial odd-number sided polygon is any one of

a substantial triangle, a substantial pentagon and a substantial heptagon which is selected in accordance with the number of poles in the rotating electric machine.

5           5. The stator according to claim 1 or 4, wherein  $h2/h1$  is set to a range of 2.5 to 4.5,

where  $h2$  is a thickness of the frame at an angle of the polygon, and

10            $h1$  is a thickness of the frame at an extension line for connecting an angle and a central point of the section of the stator.

6. The stator according to claim 1 or 4, wherein  $h2/h1$  is set to a range of 3 to 4,

15           where  $h2$  is a thickness of the frame at an angle of the polygon, and

$h1$  is a thickness of the frame at an extension line for connecting an angle and a central point of the section of the stator.

20           7. The stator according to claim 1 or 4, wherein  $h2/h1$  is set to 3.5,

where  $h2$  is a thickness of the frame at an angle of the polygon, and

25            $h1$  is a thickness of the frame at an extension line for connecting an angle and a central point of the section of the stator.

8. The stator according to claim 1 or 4, wherein  $h3/h2$  is set to a range of 0.2 to 0.8,

where  $h_2$  is a thickness of the frame at an angle of the polygon, and

$h_3$  is a thickness of a yoke of the core.

9. The stator according to claim 1 or 4, wherein  
5  $h_3/h_2$  is set to a range of 0.2 to 0.4,

where  $h_2$  is a thickness of the frame at an angle of the polygon, and

$h_3$  is a thickness of a yoke of the core.

10. The stator according to claim 1 or 4, wherein  
10  $E_2/E_1$  is set to a range of 2.5 to 80,

where  $E_2$  is a longitudinal elastic coefficient of the frame, and

$E_1$  is a longitudinal elastic coefficient of the core.

15 11. The stator according to any one of claims 1 to 3, wherein said frame comprises two parts which are connected to said core at end portions in an axial direction of said core.

12. The stator according to claim 11, wherein said  
20 frame further comprises a part which is connected to said core between said two parts.

13. The stator according to claim 11, wherein one of said two parts is rotated  $(360/2n)$  degrees in a circumferential direction with reference to the other  
25 of said two pairs.

14. The stator according to claim 1 or 4, wherein a portion other than an angle is on an extension line

for connecting the angle and a central point of the polygon.

15. The stator according to claim 11, wherein said two parts are connected to each other by a rib.

5 16. The stator according to claim 15, wherein said rib is connected to said two parts by means of at least one of welding means, bonding means and bolt means.

10 17. The stator according to any of claims 1 to 3, wherein a cooling fin is connected to the frame at a portion other than an angle portion, an outer circumference of the cooling fin being a circular shape.

15 18. A stator of a rotating electric machine of a frame-less type, comprising:

a core configured such that an electromagnetic force vibration of the core differs from a natural vibration mode of the core; wherein

20 a circumference of a section of the core in a direction perpendicularly to an axial direction of the core is a substantial odd-number sided polygon.

25 19. The stator according to claim 18, wherein a circumference of a section of the core in a direction perpendicularly to an axial direction of the core is substantially defined by  $A \cdot \sin n\theta$ ,

where  $A$  is a deformation from an average radius  $r$

of the cross section, a ratio  $A/r$  being set to a range of  $0.05 \leq A/r \leq 0.5$ ,

$\theta$  is a mechanical angle, and

$n$  is an odd number excluding 1.

5        20. The stator according to claim 19, wherein the  $n$  is any one of 3, 5 and 7 which is selected in accordance with the number of poles in the rotating electric machine.

10        21. The stator according to claim 18, wherein said substantial odd-number sided polygon is any one of a substantial triangle, a substantial pentagon and a substantial heptagon which is selected in accordance with the number of poles in the rotating electric machine.

15        22. A stator of a rotating electric machine comprising:

        a core; and

        a frame connected to the core and having a circumference shape of a section in a direction  
20        perpendicularly to an axial direction which is selected from one of a substantial circle, substantial square, substantial trapezoid, substantial rectangle, and substantial square, wherein a central point of the core is decentered with respect to one of a central point of  
25        the frame and a cross point of a diagonal of the frame.

        23. The stator according to claim 22, wherein the circumference shape is a substantial circle and

a decentering amount is set to a range of  $0.25(D-d)/2$  to  $0.8(D-d)/2$ ,

where  $d$  is a diameter of the core, and

$D$  is a diameter of the frame.

5        24 . The stator according to claim 22, wherein the circumference shape is a substantial circle and a decentering amount is set to a range of  $0.7(D-d)/2$  to  $0.8(D-d)/2$ ,

where  $d$  is a diameter of the core, and

10         $D$  is a diameter of the frame.

25 . The stator according to claim 22, wherein the circumference shape is a substantial circle and a decentering amount is set to  $0.8(D-d)/2$ ,

where  $d$  is a diameter of the core, and

15         $D$  is a diameter of the frame.

26 . The stator according to claim 22, wherein the circumference shape is one of a substantial rectangular and a substantial square, and a decentering amount is set to a range of  $(x-d)/2.5$  to  $(x-d)/8$ ,

20        where  $d$  is a diameter of the core, and

$x$  is a length of a short side of the substantial rectangle or a length of a side of the substantial square.

25        27 . The stator according to claim 22, wherein the circumference shape is a substantial trapezoid, and a decentering amount is set to a range of  $(h-d)/2.5$  to  $(h-d)/8$ ,

13 APR 2005

- 58 -

where  $d$  is a diameter of the core, and  
 $h$  is a height of a substantial trapezoid.