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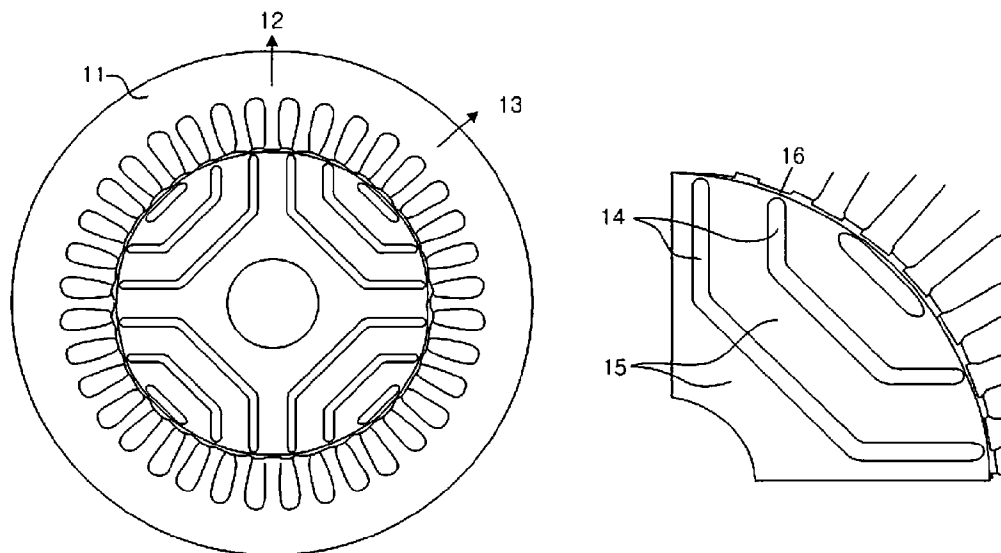
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(54) Title: ROTOR DESIGN METHOD AND ROTOR STRUCTURE INCREASING TORQUE AND MOMENT

[Fig. 1]



(57) Abstract: The present invention provides a method of designing a rotor having optimal power factor and torque, and a structure of the rotor designed and manufactured in the design method, in which in order to reduce q- axial flux leakage flux of a motor rotor and induce to flow along the polar surface of the rotor so that power factor and torque of a motor are improved when a rotor of a segment type synchronous reluctance motor is designed, the rotor is optimally designed considering the air gap formed by air, the width and number of flux barriers, and a ratio Kw of a total width of all flux barriers to a total width of all iron core regions using a finite element method and a sequential unconstrained minimization technique.

Description

ROTOR DESIGN METHOD AND ROTOR STRUCTURE INCREASING TORQUE AND MOMENT

Technical Field

- [1] The present invention relates to a method of designing a motor rotor and a structure of the rotor, in which power factor and torque are improved by optimizing the number of flux barriers and a ratio K_w of a total width of all flux barriers to a total width of all iron core regions, which should be considered when a rotor of a segment type synchronous reluctance motor is designed, using a finite element method and a sequential unconstrained minimization technique.

[2]

Background Art

- [3] In general, synchronous reluctance motors (SynRMs) are classified into an axial direction lamination type and transverse direction lamination type depending on a lamination method. In the case of the axial direction lamination type motor, although a saliency ratio is high, there is a problem in that it is much more difficult to manufacture and its manufacturing cost is relatively high as compared to the transverse direction lamination type motor, since the axial direction lamination type motor has a complex structure, and the iron core of the rotor should be fixed to the shaft.
- [4] Further, segment type synchronous reluctance motors corresponding to the transverse direction lamination type are comparatively easy to manufacture, and torque ripples generated due to slots of a stator may be improved using a skew. The segment type synchronous reluctance motors are widely used since they can be designed and manufactured to have a saliency ratio as high as that of an axial direction lamination type structure. However, the segment type synchronous reluctance motor entails a problem in that an optimized rotor is difficult to design and manufacture since torque and power factor of a motor rotor are changed depending on a variety of variables that affect characteristics of the motor, such as the number of flux barriers, width of the flux barriers, air gap, slots, ribs, and the like.

[5]

Disclosure of Invention

Technical Problem

- [6] Accordingly, the present invention has been made in order to solve the above

problems associated with the prior art, and it is an object of the invention to provide a method of designing an optimal rotor having improved power factor and torque and a structure of the rotor, in which in order to induce flux to flow along the polar surface of the rotor by reducing q-axial leakage flux of the motor rotor so that power factor and torque are improved when a segment type synchronous reluctance motor is designed, some variables among a plurality of variables that change the power factor and torque of the motor are fixed as predetermined constants, and then the number of flux barriers formed by air and a ratio K_w of a total width of all flux barriers to a total width of all iron core regions are used as variables that are optimized using a finite element method and a sequential unconstrained minimization technique to design the rotor.

- [7] Another object of the invention is to provide a graph showing the number of flux barriers determined by a radius of a motor rotor and an optimized ratio K_w of a total width of all flux barriers to a total width of all iron core regions, so that the graph can be used to determine the number of flux barriers and a ratio K_w of a total width of all flux barriers to a total width of all iron core regions when the rotor is designed, and coordinates of the flux barriers of the rotor are calculated and specifically displayed, thereby rapidly designing and manufacturing an optimal rotor.

[8]

Technical Solution

- [9] In order to accomplish the above objects of the invention, according to one aspect of the invention, there is provided a method for rapidly designing an optimal rotor of a segment type synchronous reluctance motor having improved power factor and torque, and a rotor designed and manufactured in the method, the method comprising the steps of: inputting the number of slots of a stator, an air gap, and ribs as predetermined constant values depending on a model of the segment type synchronous reluctance motor to be designed; searching for values of variables W needed to change a width and an area of the flux barriers in a 1/4 model of the rotor of the segment type synchronous reluctance motor to be designed, using the finite element method by symmetrically varying the variables with respect to a q-axis so that inductance difference L_d-L_q between a d-axis and the q-axis is maximized with the values; calculating a ratio K_w of a total width of all flux barriers to a total width of all iron core regions using the sequential unconstrained minimization technique with the values that maximize the inductance difference L_d-L_q between the d-axis and q-axis; and determining the number and width of the flux barriers of the rotor using a value of the

calculated ratio K_w of a total width of all flux barriers to a total width of all iron core regions.

[10]

Advantageous Effects

[11] The present invention is effective in that a structure of an optimal rotor having improved power factor and torque is provided in a method of easily designing the optimal rotor using a finite element method and a sequential unconstrained minimization technique, in which in order to reduce leakage flux of a motor rotor and induce q-axial flux to flow along the polar surface of the rotor so that power factor and torque of a motor are improved when a rotor of a segment type synchronous reluctance motor is designed, some variables among a plurality of variables that change the power factor and torque of the motor are fixed as constants, and then the rotor is optimally designed considering the number of flux barriers formed by air and a ratio K_w of a total width of all flux barriers to a total width of all iron core regions.

[12] Another effect of the present invention is that a graph showing the number of flux barriers determined by a radius of a motor rotor and an optimized ratio K_w of a total width of all flux barriers to a total width of all iron core regions is provided, so that the graph can be used to determine the number of flux barriers and a ratio K_w of a total width of all flux barriers to a total width of all iron core regions when the rotor is designed, and coordinates of the flux barriers of the rotor are calculated and specifically displayed, thereby rapidly designing and manufacturing an optimal rotor.

[13]

Brief Description of the Drawings

[14] FIG. 1 shows a cross-sectional view of a general segment type synchronous reluctance motor.

[15] FIG. 2 is a view showing paths of flux flow in rotor ribs of a general segment type synchronous reluctance motor.

[16] FIG. 3 is a view showing an analytical model and variables of a rotor of a segment type synchronous reluctance motor according to the present invention.

[17] FIG. 4 is a view showing variables W and changing directions for a shape change of flux barriers of a rotor of a segment type synchronous reluctance motor according to the present invention.

[18] FIG. 5 is a graph showing values of K_w changing with respect to a radius of a rotor using a finite element method and a sequential unconstrained minimization technique

according to the present invention.

[19]

Mode for the Invention

[20] The present invention relates to a method of designing a motor rotor and a structure of the rotor designed by the design method, in which power factor and torque are improved by optimizing the number of flux barriers and a ratio Kw of a total width of all flux barriers to a total width of all iron core regions, which should be considered when a segment type synchronous reluctance motor is designed, using a finite element method and a sequential unconstrained minimization technique. Constitutional means for accomplishing the present invention will be described in detail. The steps of an optimal design process for improving torque and power factor of a four-pole segment type synchronous reluctance motor (SynRM) having an output power of 1HP to 8HP according to the present invention will be described.

[21] Torque of a motor rotor is expressed as shown below.

[22] [Equation 1]

$$[23] \quad T = 3P/4(L_d - L_q)i_d \cdot i_q$$

[24] A rotor is designed in a structure of improving torque and power factor based on inductance ratio L_d/L_q and inductance difference $L_d - L_q$ between the d-axis and q-axis, which are factors that seriously affect the torque T as shown in Equation 1. A general structure of the rotor 11 of a segment type synchronous reluctance motor is as shown in FIG. 1. The rotor shown in FIG. 1 is a transverse direction lamination type having a structure that comprises a plurality of flux barriers and ribs. The present invention proposes a method for easily accomplishing an optimal design of a rotor for each capacity, considering the ratio of a total width of all flux barriers to a total width of all iron core regions and the number of flux barriers so as to increase the inductance difference $L_d - L_q$ and inductance ratio L_d/L_q between the d-axis 12 and q-axis 13 that affect the torque and power factor. In FIG. 1, slightly dark portions are iron core structures 15, and white portions are flux barriers 14 formed of air regions. In Equation 1, L_d is an inductance value of the d-axis 12, and L_q is an inductance value of the q-axis 13.

[25] Describing a stator placed outside of the rotor 11 in relation to the present invention, in slots of the stator, a saliency ratio is decreased due to the q-axis inductance L_q that is increased by flux leakage, and inductance characteristics of L_d and L_q are changed since leakage flux is determined depending on the width of openings of the slots, which should be considered in designing the rotor. Generally, although the air gap

should be maintained narrow to improve the saliency ratio L_d/L_q , it is limited due to problems in manufacturing or the like. A basic rotor model used for designing the rotor of the present invention has twenty four slots and a fixed air gap of 0.4mm.

- [26] Next, the ribs 16 placed at the outer side of the rotor to mechanically fix segments of the rotor are described. The ribs form a flux path through which q-axis flux may flow as shown in FIG. 2. As the width of the ribs is wider, L_q is increased due to leakage flux, and thus q-axis inductance is increased. Accordingly, torque is generated due to the d-axis and q-axis inductances, which affects the torque of the reluctance motor. Therefore, the width of the ribs 16 should be narrow to minimize the affect to the torque. However, there is a limit in a mechanical structure to reduce the width of the ribs, and the width of ribs 16 in a design model of the present invention is fixed to 0.5mm considering the performance and strength of the rotor 11.
- [27] Next, the number of flux barriers for restricting flow of q-axis flux is described, for which torque per unit current is increased by increasing L_d and decreasing L_q . In order to restrict the flow of q-axis flux in the flux barriers 14, the flux barriers 14 are formed as many as needed inside the rotor as an air insulation layer so that L_d is increased and L_q is decreased by differently forming magnetic potential of the iron core of the rotor. If the number of flux barriers 14 in the rotor is appropriately increased, L_d is increased and L_q is decreased, and thus the torque is increased. However, if the number of flux barriers is continuously increased, the iron core region within a limited rotor radius is comparatively decreased and saturated. Therefore, the saliency ratio is not increased any more, and the structure is not durable mechanically, so that forming an appropriate number of flux barriers 14 considering mechanical convenience in manufacturing is an important factor to obtain a maximum torque. In the present invention, considering the problem occurring in the process of manufacturing (wire cutting, etc), several models respectively having three to five flux barriers 14 are designed and analyzed to compare and review performance.
- [28] Next, among a variety of design variables affecting characteristics of torque and power factor, other than the number of flux barriers 14, K_w that is a ratio of a total width of all flux barriers 14 to a total width of all iron core regions will be considered as a major design variable when a rotor is designed. Thickness of the flux barrier 14 should be selected to maximize the inductance difference and saliency ratio, and K_w is defined as Equation 2.
- [29] [Equation 2]

$$[30] \quad kw = \sum(W_{air}) / \sum(W_{iron})$$

[31] Here,

$$\sum(W_{air})$$

denotes a total width of all flux barriers, and

$$\sum(W_{iron})$$

denotes a total width of all iron core regions.

[32] An optimal rotor of a segment type synchronous reluctance motor, which has improved power factor and torque, may be promptly designed and manufactured through the steps of: inputting the number of slots of a stator, an air gap, and ribs as predetermined constant values depending on a model of the segment type synchronous reluctance motor to be designed, considering Equations 1 and 2 and the design conditions proposed above; searching for values of variables W needed to change a width and an area of the flux barriers in a 1/4 model of the rotor of the segment type synchronous reluctance motor to be designed, using a finite element method by symmetrically varying the variables with respect to the q-axis so that inductance difference $L_d - L_q$ between the d-axis and q-axis is maximized with the searched values; calculating a ratio Kw of a total width of all flux barriers to a total width of all iron core regions using the sequential unconstrained minimization technique with the values that maximize the inductance difference $L_d - L_q$ between the d-axis and q-axis; and determining the number and width of the flux barriers of the rotor using a value of the calculated ratio Kw of a total width of all flux barriers to a total width of all iron core regions.

[33] Hereinafter, the method of designing a rotor of a segment type synchronous reluctance motor according to the present invention will be described in detail with reference to the proposed conditions and Equations 1 and 2. Among several variables needed for easily understanding and designing the rotor of a segment type synchronous reluctance motor, inductance values L_d and L_q are important factors for determining characteristics of the rotor such as current, torque, and power factor. A finite element method (FEM), which is advantageous in correctly analyzing a magnetically non-linear and complex motor, is used in the present invention to analyze the characteristics through an accurate analysis. A Equation for calculating flux of each phase using the finite element method in order to accurately extract the inductance values is shown below.

[34] [Equation 3]

$$[35] \quad \lambda = N \int B \cdot dS = N(A_1 - A_2)L_c$$

[36] Here, L_c denotes the width of lamination of the primary side, N denotes the number of turns of coil, and A_1 and A_2 denote magnetic vector potentials at a slot of the rotor shaft.

[37] After calculating linkage flux of each phase using Equation 3, fluxes of the d-axis and q-axis are calculated using a tensor transformation. In the same manner, after calculating current components of the d-axis and q-axis using the tensor transformation, inductances are calculated as shown below.

[38] [Equation 4]

$$[39] \quad L_d = \frac{\lambda_d}{I_d}, \quad L_q = \frac{\lambda_q}{I_q}$$

[40] In the curve showing changes of inductance components of the d-axis and q-axis in accordance with increase of input current, q-axis current is zero when current is applied to the d-axis, and d-axis current is also zero when current is applied to the q-axis. Mutual interference that occurs due to the d-axis current and q-axis current is ignored.

[41] Before designing the rotor of a segment type synchronous reluctance motor according to the present invention, the segment type synchronous reluctance motor comprises a winding portion of a stator through which current flows, the stator through which the main flux flows, an iron core of the rotor, and flux barriers, i.e., an insulation layer restricting flow of q-axis flux. Characteristics of torque and power factor are affected by these constitutional components. That is, the motor should be designed to flow d-axis flux along the entire polar surface in order to sufficiently obtain magnetizing inductance that can maximize generation of torque and enhance power factor and to flow less q-axis flux in order to minimize the q-axis inductance. The major purpose of designing the rotor of a segment type synchronous reluctance motor according to the present invention is that a rotor of a conventional motor can be replaced with the rotor of the present invention. A target to be compared in the basic design model according to the present invention is a motor of the same class, and accordingly, the main target of the design is the rotor of the motor since specifications of the motor, such as diameters of the stator and the rotor, air gap, length of lamination, shaft, and the like, are the same as those of a conventional motor of the same class.

- [42] Accordingly, inductance characteristics are obtained by performing a finite element method on a variety of models respectively using different number of flux barriers in the rotor of the motor and different Kw. Based on the characteristics, a method of designing an improved rotor model, which has an increased inductance difference $L_d - L_q$ and a high saliency ratio L_d/L_q between the d-axis and q-axis compared with those of the basic model, is provided together with a structure of a rotor obtained from the design method. Three to five flux barriers are used to improve the salience ratio considering limitation in manufacturing, and the models are analyzed using a variety of values of the ratio Kw of a total width of all flux barriers to a total width of all iron core regions of the rotor between 0.1 and 1.1.
- [43] Describing the magnetic saturation that occurs between the ribs of the rotor and the teeth of the stator, if the saliency ratio is high, a magnetic saturation phenomenon occurs at the yoke and teeth of the stator and the ribs of the rotor when d-axis magnetomotive force is excited in the present invention. Therefore, a value of L_d that affects torque, efficiency, and power factor of the motor may be dropped as low as 50% in some cases, which can be a cause that changes an optimal control current angle depending on driving conditions, and thus the magnetic saturation should be accurately analyzed. Accordingly, in order to consider the magnetic saturation phenomenon through a non-linear analysis, an iron core substance of the magnetic rotor is designed in consideration of the magnetic saturation using the same B-H characteristic curve of S18 as that of the basic model, and the flux barriers are regarded as an air region in the analysis.
- [44] Next, the number of flux barriers and the ratio of a total width of all flux barriers to a total width of all iron core regions, which are design variables of the rotor of the synchronous reluctance motor, are optimized using a sequential unconstrained minimization technique (hereinafter, referred to as SUMT), which is a kind of general non-linear optimization programming, as an optimal design algorithm employed for the present invention.
- [45] Generally, a problem of non-linear optimization programming is expressed as shown below.
- [46] [Equation 5]
- [47] $g_j(x) < 0 \ (j = 1, 2, \dots, m)$
- [48] Under the condition of Equation 5, $x = (x_1, x_2, \dots, x_{1n})$ that minimizes $F(x)$ is obtained.
- [49] The SUMT is also referred to as a penalty function method. In the present invention, a series of unconstrained minimization problems are solved through Equation 6, which

is another form of such an optimization problem transformed using the penalty function method, to obtain an optimized solution for the number of flux barriers and the ratio of a total width of all flux barriers to a total width of all iron core regions, which are needed to design the rotor according to the present invention.

[50] [Equation 6]

$$[51] \quad \varnothing_k = \varnothing(x, r_k) = F(x) + r_k \sum_{j=1}^m G_j[g_j(x)]$$

[52] Here, G_j denotes a function of a constraint function g_j , and r_k denotes a penalty variable of a positive integer. The second term of Equation 6 is a penalty term. If unconstrained minimization of function is repeated for a series of penalty variables r_k ($k=1, 2, \dots$), it converges on a solution of a problem expressed in Equation 5.

[53] Formulation of the penalty function for an inequality constraint problem is largely divided into an interior method and an exterior method. The interior method is employed in the present invention, and the form of G_j that is mainly used in the interior method is as shown in Equation 7.

[54] [Equation 7]

$$[55] \quad G_j = -1/g_j(x)$$

[56] Accordingly, Equation 6 may be expressed as shown below.

[57] [Equation 8]

$$[58] \quad \varnothing(x, r_k) = f(x) - r_k \sum_{j=1}^m 1/g_j(x)$$

[59] Here, all unconstrained minimum values of $\varnothing_k$ exist in a feasible region, and they converge on a solution of Equation 5 as r_k changes.

[60] On the other hand, L_d - L_q is obtained with respect to K_w by applying a Zandel function to flux barriers for each capacity in order to functionalize an objective function, and then an optimal rotor is designed.

[61] The object of a method for obtaining an optimal solution of K_w using the SUMT algorithm according to the present invention is to mathematically minimize function $F=F(X)$, where $X=(x_1, x_2, \dots, x_n)$. Function F is called as an objective function, and X denotes independent variables.

[62] Each variable should be limited to upper and/or lower bounds ($X_{li} < X_i < X_{ui}$, $i=1, 2, 3, \dots, n$).

[63] As shown in FIG. 3, the 1/4 model of the rotor shows nine independent variables. These variables are changed depending on structural constraints.

- [64] The objective function containing an unconstrained minimization function obtained using a Zandel function and the constraint conditions described above is shown below.
- [65] $F1(X)$ is for the case of 3, 3.5, and 4.5 HPs when the radius is 35.7mm, and $F2(X)$ is for the case of 5.5, 6, 7, and 8 HPs when the radius is 42.475mm.
- [66] [Equation 9]
- [67] $F1(X)=56.1(X-0.1)^2-62.1(X-1)-40.1$
- [68] [Equation 10]
- [69] $F2(X)=51.9X^2-68.2X-47.5$
- [70] FIG. 4 shows changing point variables and changing directions for a shape change of flux barriers with respect to K_w . In FIG. 4, points W1 to W10 move in the arrow directions and determine a flow path of flux. Pairs of (W1, W10), (W2, W9), (W3, W8), and the like symmetrically moves with respect to the q-axis. Points P1 to P10 move based on values considering K_w that is determined by the calculation of an element area in the finite element calculation.
- [71] In the present invention, the ratio K_w of a total width of all flux barriers to a total width of all iron core regions of the rotor of the synchronous reluctance motor is considered from 0.1 to 1.1. For the industrial application, the number of flux barriers is restricted to 3, 4, and 5 considering manufacturing conditions such as mechanical limitation and ribs.
- [72] Maximum torque is set from a view point of optimization of the rotor of the synchronous reluctance motor according to the present invention, and thus objective function $F(X)$ is used as a criterion for calculating K_w to maximize L_d-L_q or minimize (L_d-L_q) . The SUMT is a technique for searching for a local minimum of the objective function depending on changes of design of a rotor.
- [73] Clearly describing the steps of constitutional elements in the method of designing a rotor of a segment type synchronous reluctance motor according to the present invention, the method comprises the steps of: determining the number of slots of a stator, air gap, and rib values depending on a model of the segment type synchronous reluctance motor to be designed, and inputting the number of slots, air gap, and rib values as predetermined constant values; searching for values of variables {pairs of (W1, W10), (W2, W9), (W3, W8), and the like} needed to change a width and an area of the flux barriers in a 1/4 model of the rotor shown in FIG. 4, using a finite element method by symmetrically varying the variables with respect to the q-axis so that inductance difference L_d-L_q between a d-axis and a q-axis is maximized with the searched values; calculating K_w defined in Equation 2 using a sequential un-

constrained minimization technique with the values that maximize the inductance difference $L_d - L_q$; and determining the number of flux barriers and a total width of all the flux barriers of the rotor using a value of the calculated K_w .

- [74] A rotor designed and manufactured based on the W and P values calculated from the optimal K_w value, which is obtained in the method of designing a rotor of a segment type synchronous reluctance motor, is also within the range of protection of the present invention.
- [75] A specific embodiment of obtaining a ratio of a total width of all flux barriers to a total width of all iron core regions of a rotor with respect to a radius of the rotor using the finite element method and the SUMT according to the present invention is described.
- [76] Observing the specific embodiment of obtaining a ratio K_w of a total width of all flux barriers to a total width of all iron core regions of a rotor with respect to a radius of the rotor using the finite element method and the SUMT according to the present invention, ten capacities and three radiuses of the rotor are discussed. When the rotor has a radius of 33.411mm and a capacity of 1HP, with four flux barriers at a rated current, $L_d - L_q$ and L_d/L_q are observed to be further larger, and an optimal design value of K_w is shown as 0.968. When the rotor has the same radius and a capacity of 2HP, with four flux barriers, $L_d - L_q$ and L_d/L_q are observed to be further larger, and an optimal design value of K_w is shown as 0.9645. When the rotor has the same radius and a capacity of 3HP, with four flux barriers, $L_d - L_q$ and L_d/L_q are observed to be further larger, and an optimal design value of K_w is shown as 0.939. Based on the data, it is determined that the number of flux barriers is four and K_w is about 0.96 when the radius of the rotor is 33.411mm.
- [77] Next, when the rotor has a slightly increased radius of 35.7mm and a capacity of 3HP, with three flux barriers, $L_d - L_q$ and L_d/L_q are observed to be further larger, and an optimal design value of K_w is shown as 0.6867. When the rotor has the same radius and a capacity of 3.5HP, with three flux barriers, $L_d - L_q$ and L_d/L_q are observed to be further larger, and an optimal design value of K_w is shown as 0.6803. When the rotor has the same radius and a capacity of 4.5HP, with three flux barriers, $L_d - L_q$ and L_d/L_q are observed to be further larger, and an optimal design value of K_w is shown as 0.681. Based on the data, it is determined that the number of flux barriers is three and K_w is about 0.68 when the radius of the rotor is 35.7mm.
- [78] Next, when the rotor has a radius of 42.475mm and a capacity of 5.5HP, with five flux barriers, $L_d - L_q$ and L_d/L_q are observed to be further larger, and an optimal design

value of K_w is shown as 0.6985. When the rotor has the same radius and a capacity of 6HP, with five flux barriers, L_d-L_q and L_d/L_q are observed to be further larger, and an optimal design value of K_w is shown as 0.6954. When the rotor has the same radius and a capacity of 7HP, with five flux barriers, L_d-L_q and L_d/L_q are observed to be further larger, and an optimal design value of K_w is shown as 0.6903. When the rotor has the same radius and a capacity of 8HP, with five flux barriers, L_d-L_q and L_d/L_q are observed to be further larger, and an optimal design value of K_w is shown as 0.6919. Based on the data, it is determined that the number of flux barriers is five and K_w is about 0.69 when the radius of the rotor is 42.475mm.

[79] Values of L_d-L_q and L_d/L_q are obtained in the method described above based on the finite element method and sequential unconstrained minimization technique according to the present invention, and the number of flux barriers is determined for an optimal design depending on a difference of a radius of a rotor. Then, an optimal design value of K_w is determined through an operation. The optimal design value of K_w with respect to a radius of a rotor is shown in FIG. 5 as a graph. As is understood from FIG. 5, a rotor of a segment type synchronous reluctance motor is designed with a radius having a range of 33mm to 43mm. The rotor is designed to have an output power having a range of 1HP to 8HP.

[80] When K_w is obtained passing through the steps described above, in the graph shown in FIG. 5, optimal K_w approaches 0.5 as the radius of the rotor increases and approaches 1 as the radius of the rotor decreases.

[81] It is proved that K_w is abruptly decreased even with a slight difference in the radius of the rotor when the capacity is 3HP since the teeth of the stator are smaller when the radius is 35.7mm compared with those when the radius is 33.411mm.

[82]

Industrial Applicability

[83] The industrial applicability of the present invention is very high since the present invention provides a method for rapidly designing an optimal rotor having improved power factor and torque and a structure of the rotor manufactured in the design method, in which in order to induce flux to flow along the polar surface of the rotor by reducing q-axis leakage flux of the motor rotor so that power factor and torque are improved when a segment type synchronous reluctance motor is designed, some variables among a plurality of variables that change the power factor and torque of the motor are fixed as predetermined constants, and then the number of flux barriers formed by air and a ratio K_w of a total width of all flux barriers to a total width of all

iron core regions are used as variables that are optimized using a finite element method and a sequential unconstrained minimization technique to design the rotor.

[84] Although the present invention has been described with reference to several preferred embodiments, the description is illustrative of the invention and is not to be construed as limiting the invention. Various modifications and variations may occur to those skilled in the art, without departing from the scope of the invention as defined by the appended claims.

[85]

Claims

- [1] A method of designing a rotor of a segment type synchronous reluctance motor, using a finite element method and a sequential unconstrained minimization technique, the method comprising the steps of:
 inputting the number of slots of a stator, an air gap, and ribs as predetermined constant values depending on a model of the segment type synchronous reluctance motor to be designed;
 searching for values of variables W needed to change a width and an area of the flux barriers in a 1/4 model of the rotor of the segment type synchronous reluctance motor to be designed, using the finite element method by symmetrically varying the variables with respect to a q-axis so that inductance difference L_d-L_q between a d-axis and the q-axis is maximized with the values;
 calculating a ratio K_w of a total width of all flux barriers to a total width of all iron core regions using the sequential unconstrained minimization technique with the values that maximize the inductance difference L_d-L_q between the d-axis and q-axis; and
 determining the number and width of the flux barriers of the rotor using a value of the calculated ratio K_w of a total width of all flux barriers to a total width of all iron core regions.

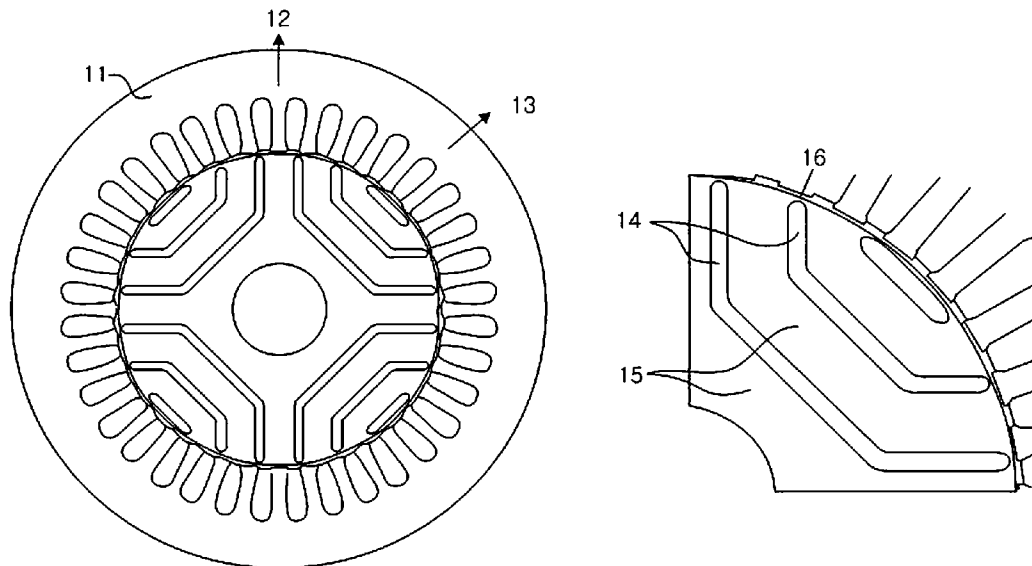
$$K_w = \sum (W_{air}) / \sum (W_{iron})$$

- [2] The method according to claim 1, wherein the variables (W, P) needed to change the width and area of the flux barriers in a 1/4 model of the rotor are respectively formed in pairs, and a solution is obtained in the sequential unconstrained minimization technique by increasing the variables (W, P) as the number of flux barriers are increased.
- [3] The method according to claim 1 or 2, wherein when the finite element method and the sequential unconstrained minimization technique are applied in the method of designing a rotor of a segment type synchronous reluctance motor, the number of flux barriers is limited to 3 to 5, the ratio K_w of a total width of all flux barriers to a total width of all iron core regions is in a range of 0.1 to 1.1.
- [4] The method according to claim 3, wherein when the finite element method and the sequential unconstrained minimization technique are applied in the method of designing a rotor of a segment type synchronous reluctance motor, a radius of the motor rotor has a value with which the ratio K_w of a total width of all flux

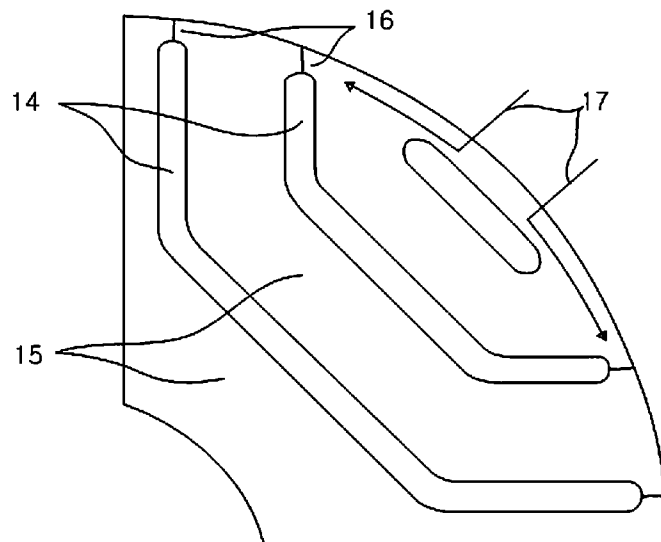
barriers to a total width of all iron core regions approaches 1 for a minimum value of the radius of the rotor, and the ratio K_w of a total width of all flux barriers to a total width of all iron core regions approaches 0.5 for a maximum value of the radius of the rotor.

- [5] A structure of a rotor of a segment type synchronous reluctance motor designed and manufactured in the method of designing a rotor of a segment type synchronous reluctance motor of claim 1 or 2.
- [6] A structure of a rotor of a segment type synchronous reluctance motor designed and manufactured in the method of designing a rotor of a segment type synchronous reluctance motor of claim 3.
- [7] A structure of a rotor of a segment type synchronous reluctance motor designed and manufactured in the method of designing a rotor of a segment type synchronous reluctance motor of claim 4.

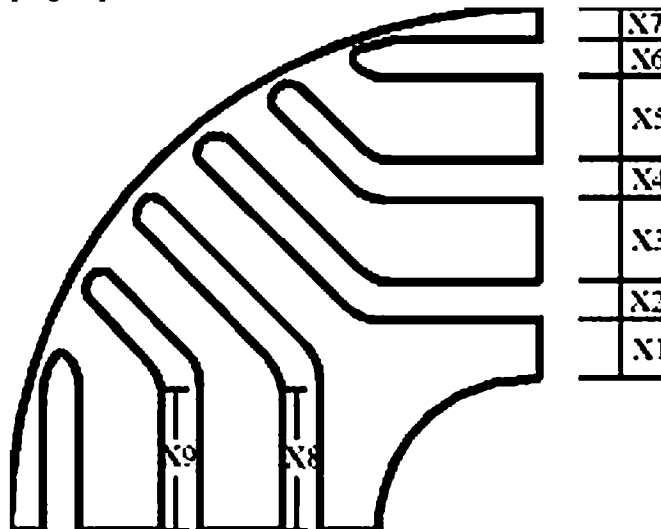
[Fig. 1]



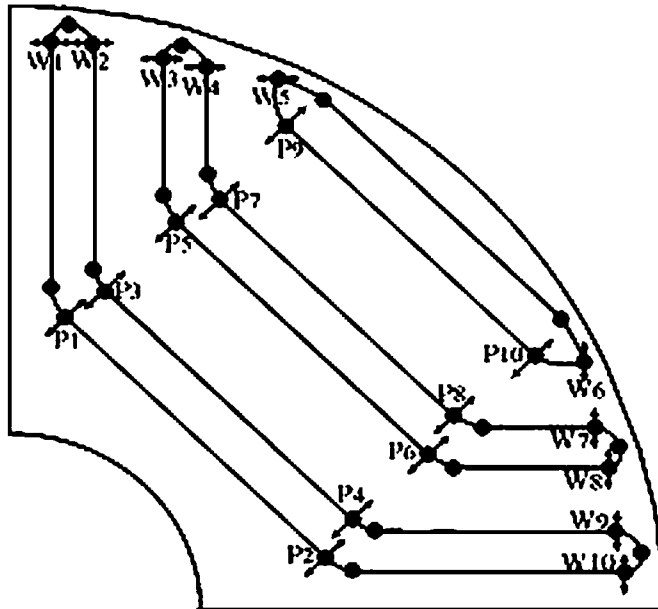
[Fig. 2]



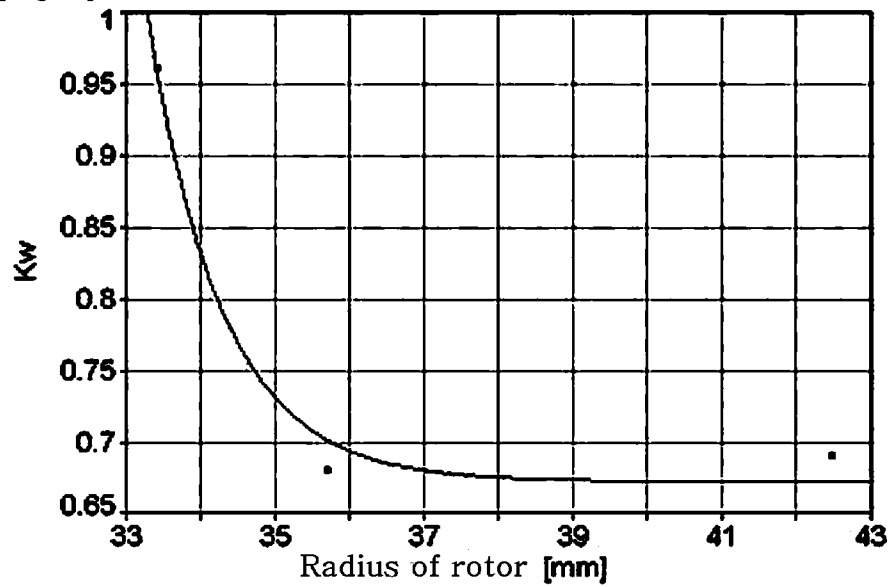
[Fig. 3]



[Fig. 4]



[Fig. 5]



A. CLASSIFICATION OF SUBJECT MATTER***H02K 15/02(2006.01)i, H02K 19/08(2006.01)i, H02K 1/22(2006.01)i***

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 8: H02K 1/22, 1/27, 15/02, 19/06, 19/08

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

Korean Utility models and applications for Utility Models since 1975

Japanese Utility models and applications for Utility Models since 1975

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

eKIPASS(KIPO internal) "motor", "rotor", "design", "FEM"

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	KR 10-2004-0019641 A (KOREA ELECTRONICS TECHNOLOGY INSTITUTE) 06 March 2004 See the abstract; figure 2	1-7
A	KR 10-2000-0028607 A (TOYODA AUTOMATIC LOOM WORKS, LTD.) 25 May 2000 See the abstract; figure 1	1-7
A	KR 10-2006-0108555 A (TOYODA AUTOMATIC LOOM WORKS, LTD.) 18 October 2006 See the abstract; figure 1	1-7

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

* Special categories of cited documents:

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

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search

08 JANUARY 2008 (08.01.2008)

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/KR2007/001710

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
KR1020040019641A	06.03.2004	None	
KR1020000028607A	25.05.2000	JP12197338	14.07.2000
		JP2000197338A2	14.07.2000
		KR2000028607A	25.05.2000
KR1020060108555A	18.10.2006	CN1855668A	01.11.2006
		EP01713156A1	18.10.2006
		EP1713156A1	18.10.2006
		JP2007300692A2	15.11.2007
		KR2006108555A	18.10.2006
		US2006250041AA	09.11.2006