

DESCRIPTION

TITLE OF INVENTION: PROCESSING DEVICE, PROCESSING METHOD, PROGRAM, AND CORE

TECHNICAL FIELD

[0001] The present disclosure relates to a processing device, a processing method, a program, and a core, and is particularly suitable for being used for designing cores. This application is based upon and claims the benefit of priority of the prior Japanese Patent Application No. 2024-018904, filed on February 9, 2024, the entire contents of which are incorporated herein by reference.

BACKGROUND ART

[0002] In an apparatus including a core, the design of the core may have a significant influence on the performance of the apparatus (hereinafter, the apparatus including the core is also simply referred to as the apparatus). Examples of the core included in the apparatus include a core provided with magnetic flux obstructing parts. The magnetic flux obstructing part is a part through which magnetic flux has more difficulty passing than other parts of the core, or a part through which magnetic flux does not pass. Therefore, the flow of magnetic flux within and around the core changes depending on the number, position, shape, and size of the magnetic flux obstructing parts. Examples of such a magnetic flux obstructing part include a void, for example. Hereinafter, the magnetic flux obstructing part that

is a void is also referred to as a flux barrier.

[0003] As techniques for designing the magnetic flux obstructing part such as a flux barrier, there are methods described in Patent Literature 1 and Non Patent Literature 1.

Patent Literature 1 has described setting a region of a basic shape of a flux barrier within a design region, and calculating an optimal solution for a mapping to be applied to the region of the basic shape. Specifically, in Patent Literature 1, a mapping that maximizes or minimizes a characteristic value of an apparatus (a value of an objective function) when the apparatus is operated is calculated as an optimal solution. Then, the mapping, which is the optimal solution, is applied to the basic shape of the flux barrier, thereby generating a flux barrier. As described above, in the technique described in Patent Literature 1, a matrix representing the mapping to be applied to the region of the basic shape of the flux barrier is used as a design variable, and the optimal solution for the matrix is calculated.

[0004] Further, Non Patent Literature 1 has described generating flux barriers of an IPM motor by a method obtained by improving an On-Off method. In the On-Off method, it is calculated whether each of a plurality of meshes obtained by dividing a design region is in an on state or an off state. For example, the on state is made to correspond to a

magnetic material, and the off state is made to correspond to air. In the On-Off method, a state of each cell (the on state or the off state) that minimizes or maximizes a value of an objective function within a range in which a constraint condition is satisfied is explored as an optimal solution. In a general On-Off method, the state of each cell is calculated as being independent of the states of other cells. In contrast, Non Patent Literature 1 calculates the state of each cell according to an output of a Normalized Gaussian Network (NGnet) in each cell. The output of the NGnet is represented by a weighted sum of normalized Gaussian functions whose values vary spatially smoothly. In the technique described in Non Patent Literature 1, a weighting coefficient for the normalized Gaussian function is used as a design variable, and the optimal solution for the weighting coefficient is calculated.

CITATION LIST

PATENT LITERATURE

[0005] Patent Literature 1: Japanese Laid-open Patent Publication No. 2021-114099

NON PATENT LITERATURE

[0006] Non Patent Literature 1: Takahiro Sato and five others, "Shape Optimization of Rotor in Interior Permanent Magnet Motor Based on Topology Optimization Method Using Normalized Gaussian Network," IEEJ Transactions on Industry Applications, Vol. 135, No.

3, pp. 291-298, 2015

SUMMARY OF INVENTION

TECHNICAL PROBLEM

[0007] However, in the techniques described in Patent Literature 1 and Non Patent Literature 1, the ease with which a candidate solution is selected (and the difficulty with which a candidate solution is selected) do not change depending on the position of the magnetic flux obstructing part, as long as the position is one where the magnetic flux obstructing part can exist. Therefore, in the process of exploration of solutions, the possibility increases that a flux barrier having a small degree of contribution to the improvement of the characteristics of the core will be generated. Accordingly, it may take a long time for the solutions to converge to an optimal solution. This may lead to an increase in calculation load. On the other hand, when a convergence condition is relaxed to inhibit the increase in the calculation load, the possibility increases that a flux barrier having a small degree of contribution to the improvement of the characteristics of the core will be generated based on the optimal solution.

[0008] The present disclosure has been made in view of the above problems, and an object thereof is to generate a magnetic flux obstructing part that improves the characteristics of a core without imposing a significant calculation load.

SOLUTION TO PROBLEM

[0009] The processing device of the present disclosure is a processing device for performing processing for designing a core provided with a magnetic flux obstructing part, the processing device including: an index calculation unit configured to calculate, based on a distribution of magnetic properties in a design region of an original core that serves as a prototype of a designed core, a distribution of a generation index for evaluating the ease with which the magnetic flux obstructing part is generated in the design region; and a determination unit configured to determine a region of the magnetic flux obstructing part in the design region based on the distribution of the generation index, in which the design region is a region in a cut surface of the original core, and the cut surface of the original core is a cut surface in a direction perpendicular to a direction in which the magnetic flux obstructing part is viewed in a plan view.

[0010] The processing method of the present disclosure is a processing method for performing processing for designing a core provided with a magnetic flux obstructing part, the processing method including: an index calculation step of calculating, based on a distribution of magnetic properties in a design region of an original core that serves as a prototype of a designed core, a distribution of a generation index for evaluating the ease with which

the magnetic flux obstructing part is generated in the design region; and a determination step of determining a region of the magnetic flux obstructing part in the design region based on the distribution of the generation index, in which the design region is a region in a cut surface of the original core, and the cut surface of the original core is a cut surface in a direction perpendicular to a direction in which the magnetic flux obstructing part is viewed in a plan view.

[0011] The program of the present disclosure causes a computer to function as each unit of the processing device.

[0012] The core of the present disclosure is provided with the magnetic flux obstructing part in the whole or a portion of at least one of the regions determined by the determination unit included in the processing device.

ADVANTAGEOUS EFFECTS OF INVENTION

[0013] According to the present disclosure, it is possible to generate a magnetic flux obstructing part that improves the characteristics of a core without imposing a significant calculation load.

BRIEF DESCRIPTION OF DRAWINGS

[0014] [Fig. 1A] Fig. 1A is a view illustrating a first example of a flow of magnetic flux in a region having a relatively low magnetic flux density of a region of a rotor core.

[Fig. 1B] Fig. 1B is a view illustrating a

second example of the flow of magnetic flux in a region having a relatively low magnetic flux density of a region of a rotor core.

[Fig. 2A] Fig. 2A is a view illustrating a first example of a flow of magnetic flux in a region having a relatively high magnetic flux density of a region of a rotor core.

[Fig. 2B] Fig. 2B is a view illustrating a second example of the flow of magnetic flux in a region having a relatively high magnetic flux density of a region of a rotor core.

[Fig. 3] Fig. 3 is a view illustrating an example of a configuration of an IPMSM.

[Fig. 4] Fig. 4 is a diagram illustrating an example of a functional configuration of a processing device.

[Fig. 5] Fig. 5 is a flowchart illustrating an example of a processing method.

[Fig. 6] Fig. 6 is a view illustrating an example of a result of sampling.

[Fig. 7] Fig. 7 is a view explaining an example of a method of determining a region of a magnetic flux obstructing part.

[Fig. 8] Fig. 8 is a diagram illustrating an example of a hardware configuration of the processing device.

[Fig. 9A] Fig. 9A is a view illustrating an example of a result of generating flux barriers in a method of this embodiment.

[Fig. 9B] Fig. 9B is a view illustrating an example of a result of generating flux barriers in a method described in Patent Literature 1.

DESCRIPTION OF EMBODIMENTS

[0015] One embodiment of the present disclosure will be explained below with reference to the drawings. Incidentally, the fact that objects to be compared such as lengths, positions, sizes, and intervals, are the same includes the case where they are strictly the same, as well as the case where they are different within a range that does not depart from the gist of the present disclosure (for example, the case where they are different within a tolerance range defined at the time of design). Further, in each of the drawings, the x-y-z coordinates are used to indicate a relationship of orientations in each drawing. In the x-y-z coordinates, the symbol with a black circle (●) within a white circle (○) is a symbol indicating an arrow line indicating that the direction from a far side toward a near side of the paper sheet is a positive direction.

[0016] (Findings and Ideas)

First, findings and ideas obtained by the present disclosers when reaching this embodiment are explained. In the methods described in Patent Literature 1 and Non Patent Literature 1, a flux barrier can be generated such that a characteristic value of an apparatus (a value of an objective function) is maximized or minimized. However, for

example, when performing an optimization calculation, it is necessary to repeatedly perform an exploration of solutions until the solutions converge to an optimal solution. In addition, for example, when calculating the characteristic value of the apparatus by performing an electromagnetic field analysis, it is necessary to perform the electromagnetic field analysis in each iteration. Therefore, as the number of iterations in the optimization calculation (convergence calculation) increases, there is a concern that the calculation load will increase. Accordingly, in order to inhibit the increase in the calculation load, it is considered to relax a convergence condition. However, when the convergence condition is relaxed, even in the case where a better optimal solution actually exists, there is an increased possibility that that better optimal solution is not calculated. For example, there is an increased possibility that a flux barrier having a relatively small degree of contribution to the improvement of the characteristics of the core is generated based on the optimal solution. Incidentally, generating a magnetic flux obstructing part such as a flux barrier corresponds to calculating information capable of specifying a region occupied by the magnetic flux obstructing part in the core. This information may be, for example, information indicating each position (coordinates) of a boundary line between the magnetic flux obstructing

part and an outside.

[0017] Fig. 1A and Fig. 1B are views illustrating, as an example, a flow of magnetic flux in a region having a relatively low magnetic flux density, of regions of rotor cores 101 and 102. Fig. 1A is a view illustrating the case where a flux barrier 111 exists. Fig. 1B is a view illustrating the case where the flux barrier 111 does not exist. Further, Fig. 2A and Fig. 2B are views illustrating, as an example, a flow of magnetic flux in a region having a relatively high magnetic flux density, of regions of rotor cores 201 and 202. Fig. 2A is a view illustrating the case where a flux barrier 211 enlarged to a region 221 on an outer peripheral surface side of the rotor core 201 exists. Fig. 2B is a view illustrating the case where the flux barrier enlarged to a region on an outer peripheral surface side of the rotor core 202 does not exist (the case where a flux barrier 212 not enlarged to the region on the outer peripheral surface side of the rotor core 202 exists). In Figs. 1A, 1B, 2A, and 2B, arrow lines represent magnetic flux. Further, in Figs. 1A, 1B, 2A, and 2B, a higher density of the arrow lines indicates a higher magnetic flux density. Further, although not necessarily clear due to limitations of the representation, in Figs. 1A, 1B, 2A, and 2B, a higher darkness of the arrow lines indicates a higher magnetic flux density.

[0018] As can be seen from the comparison between

Fig. 1A and Fig. 1B, even if the flux barrier 111 is generated in a region having a low magnetic flux density of the rotor core 101, the magnetic flux directed toward a stator core does not significantly change. In addition, the amount of magnetic flux bypassing the flux barrier 111 is small. That is, the characteristics of the motor do not significantly change between the case where the flux barrier 111 exists and the case where the flux barrier 111 does not exist.

[0019] In contrast, as can be seen from the comparison between Fig. 2A and Fig. 2B, a region 222 of a soft magnetic material illustrated in Fig. 2B is replaced with the region 221 of the flux barrier 211 in Fig. 2A. In Fig. 2A, due to the existence of the region 221 of the flux barrier 211 replaced from the region 222 of the soft magnetic material, the magnetic flux directed from the rotor core 201 toward stator cores 231 and 232 is bent more significantly than the magnetic flux directed from the rotor core 202 toward stator cores 233 and 234 illustrated in Fig. 2B. Therefore, by the flux barrier 212 being changed to the flux barrier 211, the characteristics of the motor significantly change.

[0020] From the above, the present disclosers considered that, by calculating a region of a core where the influence on the characteristics of a motor is relatively large due to the existence of a magnetic flux obstructing part such as a flux barrier

(a void) more intensively (preferentially) than a region of the core where the influence is relatively small, a region of the magnetic flux obstructing part can be determined so as to further improve the characteristics of the core while shortening calculation time. That is, the present disclosers considered it preferable to make it difficult for the magnetic flux obstructing part to exist in a region of an original core where the influence on the characteristics of an apparatus (for example, a motor) is relatively small even with the existence of the magnetic flux obstructing part (that is, a region having a relatively low magnetic flux density). Conversely, the present disclosers considered it preferable to make it easy for the magnetic flux obstructing part to exist in a region of the original core where the influence on the characteristics of the apparatus (for example, the motor) becomes relatively large with the existence of the magnetic flux obstructing part (that is, a region having a relatively high magnetic flux density).

[0021] Here, the original core is a core that serves as a prototype for the designed core. In other words, the original core is a core that serves as a reference when designing the core provided with a magnetic flux obstructing part. For example, in the case where the magnetic flux obstructing part is determined by performing an optimization calculation, the shape and position of the magnetic flux

obstructing part provided in the original core are optimized, with the shape of the original core serving as a reference shape when evaluating the designed core. In Fig. 1A and Fig. 1B, the original core is the rotor core 102 illustrated in Fig. 1B. In Fig. 2A and Fig. 2B, the original core is the rotor core 202 illustrated in Fig. 2B.

[0022] Incidentally, optimization is, for example, exploring a solution that satisfies a condition to be adopted as an optimal solution in an algorithm for performing an optimization calculation. In this case, the solution that satisfies the condition may be set as the optimal solution. The original core may be modified such that the designed core can be provided with the magnetic flux obstructing part based on the optimal solution. Further, the original core may be modified such that the designed core can be provided with the magnetic flux obstructing part based on a solution at a point in the middle of the optimization, even if the condition is not satisfied, for example.

[0023] Based on the above findings, the present disclosers conceived of calculating, based on a distribution of magnetic properties (for example, magnetic flux density) in a design region of an original core, a distribution of an index for determining the ease with which a magnetic flux obstructing part is generated in the design region, and determining a region of the magnetic flux obstructing part based on the distribution of the

generation index. Hereinafter, the design region of the original core is also referred to simply as the design region. In addition, the index for determining the ease with which a magnetic flux obstructing part is generated in the design region is also referred to as the generation index.

[0024] In this way, based on the distribution of the magnetic properties of the original core, it is possible to quantify, as positions in the core, positions where it is easy for the magnetic flux obstructing part to be generated and positions where it is difficult for the magnetic flux obstructing part to be generated. Therefore, for example, in the case where the region of a magnetic flux obstructing part is determined by exploring an optimal solution for the magnetic flux obstructing part, it is possible to intensively explore, as positions for generating the magnetic flux obstructing part, positions where a change in the characteristics of the apparatus (for example, the motor) becomes large depending on whether or not the magnetic flux obstructing part is generated. Therefore, it is possible to determine the magnetic flux obstructing part that improves the characteristics of the core without imposing a significant calculation load.

[0025] Here, the design region is a design target region of the core. Further, the design region is a region in a cut surface of the original core. The cut surface of the original core is a cut surface in

a direction perpendicular to a direction in which the magnetic flux obstructing part is viewed in a plan view. Hereinafter, such a cut surface of the original core is also referred to simply as the cut surface of the original core. Further, viewing the magnetic flux obstructing part in a plan view refers to viewing the magnetic flux obstructing part such that the entire flow of magnetic flux can be visualized at once by magnetic flux lines, assuming that the magnetic flux flows from an N-pole (a first pole) of a magnet installed in the core (the original core) to an S-pole (a second pole) of the magnet. In this case, the magnetic flux may be a portion of the magnetic flux flowing from the N-pole (the first pole) to the S-pole (the second pole) (the magnetic flux within a range viewed when the magnetic flux obstructing part is viewed). Also, in this case, it is preferable to view the magnetic flux obstructing part from a position directly facing the magnetic flux obstructing part. For example, in the case where the apparatus is a radial-gap type rotary electric machine, the direction in which the magnetic flux obstructing part is viewed in a plan view is a direction parallel to the rotation axis of the rotary electric machine. In addition, in the case where the apparatus is an axial-gap type rotary electric machine, the direction in which the magnetic flux obstructing part is viewed in a plan view is a direction perpendicular to the rotation axis of the

rotary electric machine (a radial direction of the rotary electric machine). In the case where the apparatus is a linear motor, the direction in which the magnetic flux obstructing part is viewed in a plan view is a direction perpendicular to both a direction in which the linear motor travels (a direction of a travelling magnetic field) and a normal direction to a surface that is a travel path of an object including the linear motor. In addition, in the case where the core is a laminated core, the direction in which the magnetic flux obstructing part is viewed in a plan view is a direction parallel to a lamination direction of soft magnetic sheets. Incidentally, the magnet installed in the core may be a permanent magnet or an electromagnet.

[0026] The embodiment to be explained below has been made based on the above findings and ideas.

Incidentally, in the following explanation, the case where the aforementioned generation index is a generation probability of the magnetic flux obstructing part is explained as an example. However, the generation index is not limited to the generation probability of the magnetic flux obstructing part. For example, the generation index may be represented by a numerical value other than the generation probability. For example, the generation index may be represented by an integer value corresponding to the ease with which a magnetic flux obstructing part is generated. For example, the generation index may

be represented by an integer value from 1 to 10. In this case, for example, the value of the generation index may be determined such that a smaller value of the generation index indicates that it is more difficult for the magnetic flux obstructing part to be generated.

[0027] (Core)

Here, in the embodiment to be explained below, the case where the core provided with the magnetic flux obstructing part is a rotor core included in an IPMSM (Interior Permanent Magnet Synchronous Motor) is explained. Thus, an outline of the IPMSM is described.

[0028] Fig. 3 is a view illustrating an example of a configuration of an IPMSM 300. Fig. 3 illustrates, as an example, a so-called V-shaped IPMSM in which permanent magnets as magnetic poles of a rotor are arranged in a V shape. Further, Fig. 3 illustrates, as an example, the case where the number of poles of the IPMSM 300 (a rotor 310) is eight poles (incidentally, the number of poles of the IPMSM 300 is not limited). In Fig. 3, a range PR indicated by a double-headed arrow line is a portion that constitutes one pole of the IPMSM 300. Incidentally, when the number of poles of the IPMSM 300 (the rotor 310) is n , the IPMSM 300 has a relationship of n -fold rotational symmetry with a rotation axis 0 of the IPMSM 300 set as a rotational symmetry axis. n is an integer of 2 or more. In the example illustrated in

Fig. 3, n is 8 ($n = 8$). Fig. 3 illustrates one of the four regions obtained by equally dividing a cut surface, which is obtained when the IPMSM 300 is cut perpendicular to the rotation axis 0 of the IPMSM 300, into four parts. That is, Fig. 3 illustrates, of the regions of the IPMSM 300, the region that constitutes two poles of the rotor 310. These four regions have a 4-fold ($= 8 \text{ poles} \div 2$) symmetrical relationship with the rotation axis 0 of the IPMSM 300 set as the rotational symmetry axis. Thus, in Fig. 3, by rotating the region illustrated in Fig. 3 by 90° at a time with the center line of the IPMSM 300 set as the rotation axis 0, the entire configuration of the cut surface of the IPMSM 300, when cut perpendicular to the rotation axis 0 of a motor such as the IPMSM 300, can be obtained. The cut surface is also referred to as a motor cross section below. The motor cross section is an example of the cut surface in a direction perpendicular to the direction in which the magnetic flux obstructing part is viewed in a plan view.

[0029] In Fig. 3, the IPMSM 300 includes the rotor 310 and a stator 320.

The stator 320 includes a stator core 321 and not-illustrated stator coils. The stator 320 generates a rotating magnetic field. Incidentally, in Fig. 3, the illustration of the stator coils included in the stator 320 is omitted. The not-illustrated stator coils are each arranged in each slot 322 of the

stator core 321 (for convenience of notation, only one slot is marked with a reference numeral in Fig. 3). The winding method of the stator coil is not limited. The winding method of the stator coil may be distributed winding or concentrated winding.

[0030] The rotor 310 rotates with the rotation axis 0 of the IPMSM 300 set as its rotation axis.

Therefore, a rotation axis 0 of the rotor 310 and the rotation axis 0 of the IPMSM 300 coincide.

The rotor 310 includes a rotor core 311 and a plurality of permanent magnets per pole.

Incidentally, Fig. 3 illustrates, as an example, the case where the number of permanent magnets per pole is two (see permanent magnets 312a to 312b). However, the number of permanent magnets per pole is not limited.

The rotor core 311 is formed using a soft magnetic material. For example, the rotor core 311 is formed by stacking a plurality of electrical steel sheets.

[0031] As described above, Fig. 3 illustrates, as an example, the case where the plural permanent magnets 312a to 312b per pole are installed in the rotor core 311. Therefore, in the rotor core 311, a plurality of magnet holes per pole are formed along a direction parallel to a rotation axis 0 of the rotor core 311.

In the following, the direction parallel to the rotation axis 0 of the rotor core 311 is also referred to as the z-axis direction. The magnet holes are through holes penetrating in the z-axis

direction. The plural permanent magnets 312a to 312b are installed (embedded) in the rotor core 311 by being inserted into the aforementioned magnet holes formed in the rotor core 311 respectively. As described above, Fig. 3 illustrates, of the regions of the IPMSM 300, the region that constitutes two poles of the rotor 310. Fig. 3 illustrates, as an example, the case where the two permanent magnets 312a to 312b per pole are embedded. Therefore, Fig. 3 illustrates, as an example, the case where 16 permanent magnets in total are embedded in the rotor core 311. Incidentally, in Fig. 3, for convenience of notation, only the portion constituting one pole of the rotor 310 is marked with reference numerals and symbols, and the reference numerals and symbols for portions constituting the other seven poles of the rotor 310 are omitted.

[0032] In the aforementioned magnet holes formed in the rotor core 311, the spaces where the permanent magnets 312a to 312b do not exist are flux barriers 313a to 313d. The flux barriers 313a to 313d are regions through which magnetic flux does not pass, or regions through which magnetic flux has more difficulty passing than the regions around the flux barriers 313a to 313d. Here, the case where no tangible object exists in the flux barriers 313a to 313d is explained as an example (namely, the case where the flux barriers 313a to 313d are voids (air regions) is explained as an example). However, the

magnetic flux obstructing part is not limited to the flux barrier (the void). For example, a nonmagnetic material may be installed in the flux barriers 313a to 313d, which are voids. In this case, a nonmagnetic part (a region of nonmagnetic material) is included in the magnetic flux obstructing part. When a nonmagnetic material is installed in a portion of the region of one flux barrier, a nonmagnetic part and a void exist in that one flux barrier. In this case, the nonmagnetic part and the void are magnetic flux obstructing parts. Incidentally, the nonmagnetic part and the void may be treated as one magnetic flux obstructing part, or may be treated as separate magnetic flux obstructing parts. Further, the magnetic flux obstructing part may be, besides the void, a part capable of obstructing the flow of magnetic flux more than other parts, such as a part where the thickness of a steel sheet is made thinner than that of other parts by pressing.

Incidentally, the IPMSM itself may be a well-known IPMSM, and is not limited to the IPMSM 300 illustrated in Fig. 3 as an example.

[0033] Further, the core provided with the magnetic flux obstructing part is not limited to the rotor core of the IPMSM. For example, the core provided with the magnetic flux obstructing part may be a rotor core of a motor other than the IPMSM. For example, the permanent magnets do not have to be embedded in the rotor core. Further, for example,

the core provided with the magnetic flux obstructing part may be a stator core. In this way, the core provided with the magnetic flux obstructing part may be at least one of a rotor core and a stator core of a rotary electric machine. The rotary electric machine may be a motor or a generator. Further, the rotary electric machine may be a radial-gap type rotary electric machine or an axial-gap type rotary electric machine. Incidentally, in the radial-gap type rotary electric machine, a rotor and a stator face each other in the radial direction of the rotary electric machine. In the axial-gap type rotary electric machine, a rotor and a stator face each other in a direction parallel to the rotation axis of the rotary electric machine. Further, the core provided with the magnetic flux obstructing part may be a core included in an apparatus other than the rotary electric machine. The apparatus other than the rotary electric machine may be, for example, a linear motor.

[0034] Further, this embodiment explains, as an example, the case where the magnetic flux obstructing part is a flux barrier (a void). However, the magnetic flux obstructing part is not limited to the flux barrier (the void). For example, as described above, a nonmagnetic material may be installed in the flux barriers 313a to 313d. That is, the magnetic flux obstructing part may be a nonmagnetic material installed in a hollow portion of the core. In this

way, the magnetic flux obstructing part may be a nonmagnetic part provided in the core. The nonmagnetic part is, for example, a region occupied by at least one of air and a nonmagnetic material. Further, the magnetic flux obstructing part may be, for example, a region of a soft magnetic material to which compressive residual stress is applied. For example, when the core is formed by bonding a plurality of soft magnetic material sheets with an adhesive, the adhesive is applied onto sheet surfaces of the soft magnetic material sheets. Compressive residual stress is applied to the region immediately below the adhesive-applied region and its periphery. Further, when a plurality of soft magnetic material sheets are joined by caulking, compressive residual stress is applied to the caulked region and its peripheral region. These regions may be magnetic flux obstructing parts.

[0035] As described above, the magnetic flux obstructing part may be configured, for example, by making a portion of the region of the core (a portion of the region of the soft magnetic material) a nonmagnetic region. The nonmagnetic region is, for example, a region occupied by at least one of air and a nonmagnetic material. Further, the magnetic flux obstructing part may be configured, for example, by applying residual stress to a portion of the region of the core (a portion of the region of the soft magnetic material).

[0036] (Processing device and Processing Method)

Fig. 4 is a diagram illustrating an example of a functional configuration of a processing device 410. Fig. 5 is a flowchart illustrating an example of a processing method performed using the processing device 410. The processing device 410 includes, as hardware, for example, one or more hardware processors and one or more memories. The processing device 410 executes various calculations by executing one or more programs stored in the memory using the one or more hardware processors. The hardware processor may be, for example, a CPU (Central Processing Unit) or a GPU (Graphics Processing Unit). Further, the processing device 410 may include a CPU and a GPU. Further, the memory may be, for example, a RAM (Random Access Memory) or a ROM (Read Only Memory). Further, the processing device 410 may include a RAM and a ROM. Further, the processing device 410 may also include a storage medium other than RAM and ROM. Further, the processing device 410 may be implemented by dedicated hardware such as an ASIC (Application Specific Integrated Circuit), for example.

[0037] An input processing device 420 is a device for inputting various types of information into the processing device 410. For example, the input processing device 420 may include a user interface. In this case, the input processing device 420 includes, for example, a keyboard and a mouse.

Further, the input processing device 420 may include an information processing device (a computer) separate from the processing device 410. The number of input processing devices 420 may be one, or two or more. Further, at least one of the input processing devices 420 may be a device internal to the processing device 410.

[0038] An output processing device 430 is a device that performs processing based on information output from the processing device 410. For example, the output processing device 430 may include a computer display. Further, the output processing device 430 may include an information processing device (a computer) separate from the processing device 410. Further, the output processing device 430 may be a device used for manufacturing the core. The number of output processing devices 430 may be one, or two or more. Further, at least one of the output processing devices 430 may be a device internal to the processing device 410.

Communication between the processing device 410 and the input processing device 420, as well as between the processing device 410 and the output processing device 430, may be wired communication or wireless communication.

[0039] Next, an example of pieces of processing performed by the processing device 410 is explained. This embodiment explains, as an example, the case where the processing device 410 performs processing

for designing a rotor core provided with flux barriers.

In Fig. 4, this embodiment explains, as an example, the case where the processing device 410 includes an acquisition unit 411, a distribution calculation unit 412, an index calculation unit 413, a determination unit 414, and an output unit 415.

[0040] <Acquisition unit 411, Steps S501, S504>

The acquisition unit 411 acquires prerequisite information PI (Steps S501, S504). The prerequisite information PI is information indicating prerequisite conditions when the processing device 410 generates a magnetic flux obstructing part (a flux barrier in this embodiment). In other words, the prerequisite information PI is information that needs to be set in the processing device 410 in advance for the processing device 410 to generate a magnetic flux obstructing part. The content of the prerequisite information PI is determined, for example, by a designer of the apparatus (the IPMSM in this embodiment). In the following explanation, the designer of the apparatus is also simply referred to as the designer. Incidentally, in the following explanation, the designer may be replaced with an operator of the processing device 410. The prerequisite information PI includes, for example, operating condition information, configuration condition information, analysis condition information, and region condition information. This embodiment

explains, as an example, the case where the acquisition unit 411 acquires the operating condition information, the configuration condition information, and the analysis condition information at Step S501, and acquires the region condition information at Step S504.

[0041] The operating condition information is information indicating conditions regarding the operation of the apparatus to be designed. As described above, this embodiment explains, as an example, the case where the apparatus is an IPMSM. In this case, the operating condition information includes, for example, the amplitude of a stator current (excitation current), the lead angle of the IPMSM, and the rotational speed of the IPMSM.

Further, this embodiment explains, as an example, the case where the processing device 410 performs an electromagnetic field analysis. The acquisition unit 411 sets conditions regarding the operation of the apparatus when performing the electromagnetic field analysis based on the operating condition information. Incidentally, the setting by the acquisition unit 411 is implemented, for example, by storing information to be set in a storage medium.

[0042] The configuration condition information is information for specifying conditions regarding the configuration of the apparatus including the original core. The configuration condition information includes, for example, the number, position, size,

shape, and material (physical property values, and so on) of the component parts. In this embodiment, the component parts include, for example, a rotor core, a permanent magnet, a stator core, and a stator coil. Further, a specific example of the original core is the rotor core 311 illustrated in Fig. 3.

Incidentally, as described above, Fig. 3 illustrates, as an example, the case where the rotor core 311 is provided with the flux barriers 313a to 313d. As above, the original core may be provided with the magnetic flux obstructing parts. However, the original core does not have to be provided with the magnetic flux obstructing parts.

[0043] This embodiment explains, as an example, the case where the configuration of the motor cross section does not change in the height direction (z-axis direction) in the IPMSM. Therefore, this embodiment explains, as an example, the case where a two-dimensional analysis of the motor cross section is performed as the electromagnetic field analysis. Thus, the configuration condition information includes, for example, information indicating the region (coordinate region) occupied by each component part of the IPMSM in the coordinate plane. However, as the electromagnetic field analysis, a three-dimensional analysis including the height direction (z-axis direction) may be performed. In this case, the aforementioned configuration condition information includes, for example, information

indicating the region (coordinate region) occupied by each component part of the IPMSM in the coordinate space. This embodiment explains, as an example, the case where the region where the electromagnetic field analysis is performed is the design region. The design region is a design target region of the core. Specifically, this embodiment explains, as an example, the case where the design region is the region of the motor cross section of the IPMSM 300. The design region may be, for example, the entire motor cross section of the IPMSM 300. However, as described above, this embodiment explains, as an example, the case where the IPMSM 300 has rotational symmetry. Therefore, the design region does not have to be the entire region of the IPMSM 300, provided that it is a region including, for example, a region constituting one pole of the rotor 310 of the region of the IPMSM 300. The acquisition unit 411 sets the design region based on the configuration condition information.

[0044] The analysis condition information is information regarding conditions of the electromagnetic field analysis. The analysis condition information includes pieces of information on the positions, sizes, and shapes of minute regions (meshes), for example. The minute regions (the meshes) are set within a region including, for example, the region of the IPMSM set in the coordinate plane (or the coordinate space). The acquisition unit 411 sets meshes for the design

region based on the analysis condition information. Further, the acquisition unit 411 sets, based on the configuration condition information, physical property values and the like of a region corresponding to each of the meshes.

[0045] The region condition information is information indicating conditions regarding the region where a magnetic flux obstructing part (a flux barrier in this embodiment) is generated. The region condition information may be any information capable of specifying a region where generation of a magnetic flux obstructing part is permitted. The region condition information may include information indicating a region where generation of a magnetic flux obstructing part is permitted. For example, the region condition information may include coordinates, among the coordinates occupied by the original core, where generation of a magnetic flux obstructing part is permitted. Further, the region condition information may include information indicating a region where generation of a magnetic flux obstructing part is prohibited (hereinafter, the region where generation of a magnetic flux obstructing part is prohibited is also referred to as a prohibited region). In this case, the region other than the prohibited region within the region occupied by the original core is specified as the region where generation of a magnetic flux obstructing part is permitted (hereinafter, the region where generation

of a magnetic flux obstructing part is permitted is also referred to as the permitted region). For example, the region condition information may include coordinates of the prohibited region among the coordinates occupied by the original core. The prohibited region can be specified by the configuration condition information. The prohibited region is, for example, a region occupied by a permanent magnet. Therefore, such a region does not have to be specified by the region condition information.

[0046] This embodiment explains, as an example, the case where the distribution of the magnetic properties in the original core is calculated by the later-described distribution calculation unit 412, and information for specifying the distribution of the magnetic properties is output by the later-described output unit 415 (see also Steps S502, S503). Therefore, this embodiment explains, as an example, the case where the designer determines the region condition information by referring to the distribution of the magnetic properties in the original core. Accordingly, this embodiment explains, as an example, the case where the acquisition unit 411 acquires the region condition information and sets the permitted region based on the region condition information at Step S504. However, this embodiment does not necessarily need to be configured in this manner. For example, the designer may

determine the region condition information without referring to the distribution of the magnetic properties in the original core. For example, the region condition information may be information indicating that of the region of the original core, a region where a representative value of magnetic flux density in one cycle is equal to or less than a threshold is set as the permitted region. In this case, the acquisition unit 411 may acquire the region condition information at Step S501, for example. Incidentally, the cycle here is a time cycle. Further, the representative value may be, for example, a time average value of the absolute value of instantaneous values, a root mean square value, or a maximum value.

[0047] The region condition information enables, for example, inhibiting the generation of a magnetic flux obstructing part at a position having an obviously small degree of contribution to the characteristics of the core and the apparatus. For example, it is possible to inhibit the generation of a magnetic flux obstructing part in the vicinity of an inner peripheral surface 314 of the rotor core 311. Therefore, the calculation load can be further reduced.

[0048] As described above, this embodiment explains, as an example, the case where the acquisition unit 411 acquires the region condition information. However, the acquisition unit 411 does not have to

acquire the region condition information. For example, when the magnetic flux obstructing part may be located in any region of the original core that can be occupied by the magnetic flux obstructing part, the acquisition unit 411 does not have to acquire the region condition information.

[0049] Further, the timing at which the acquisition unit 411 acquires respective pieces of the prerequisite information PI (the operating condition information, the configuration condition information, the analysis condition information, and the region condition information) may be different timings or the same timing.

[0050] Incidentally, this embodiment explains, as an example, the case where the input processing device 420 includes a user interface. In this case, the designer inputs the prerequisite information PI into the input processing device 420 by operating the input processing device 420. However, as described above, the input processing device 420 is not limited to a device including a user interface.

[0051] <Distribution calculation unit 412, Output unit 415, Steps S502 to S503>

The distribution calculation unit 412 calculates the distribution of the magnetic properties in the original core based on the result of the electromagnetic field analysis of the design region (Step S502). As described above, the design region is a region in the cut surface of the original core

(specifically, the motor cross section). When the design region is a region constituting one pole of the rotor 310 in the region of the motor cross section of the IPMSM 300, the distribution of magnetic properties in the entire motor cross section of the IPMSM 300 is obtained by rotating the distribution of the magnetic properties in the one pole by $360/n^\circ$ at a time with the rotation axis 0 of the IPMSM 300 set as the rotation axis. Incidentally, as described above, n is the number of poles of the IPMSM 300 (rotor 310).

[0052] When the acquisition unit 411 acquires the region condition information before the processing at Step S502 starts, the distribution calculation unit 412 calculates the distribution of the magnetic properties in a region including the permitted region specified by the region condition information of the design region. The distribution calculation unit 412 may calculate the distribution of the magnetic properties only in the permitted region of the design region, or may calculate the distribution of the magnetic properties in the entire design region.

[0053] The magnetic properties are, for example, physical quantities obtained from a magnetization curve. Specifically, the magnetic properties may be one of magnetic flux density, magnetic field strength, and magnetic permeability. Further, the value of the magnetic properties may be a representative value in one cycle. Incidentally, the cycle here is a time

cycle. Further, the representative value may be, for example, a time average value of the absolute value of instantaneous values, a root mean square value, or a maximum value. Further, the magnetic properties may be, for example, iron loss.

[0054] This embodiment explains, as an example, the case where the magnetic properties are the time average value of the absolute value of the instantaneous values of the magnetic flux density. In the following explanation, the time average value of the absolute value of the instantaneous values of the magnetic flux density is abbreviated as the time average value of the magnetic flux density as necessary.

[0055] For example, when the original core is the rotor core 311 illustrated in Fig. 3, the distribution calculation unit 412 performs an electromagnetic field analysis based on the prerequisite information PI, to thereby calculate instantaneous values at each position in the design region of the IPMSM 300 as the instantaneous values of the magnetic flux density and the instantaneous values of the magnetic field strength when the IPMSM 300 illustrated in Fig. 3 is excited. In order to explain, as an example, the case where the distribution calculation unit 412 performs an electromagnetic field analysis (numerical calculation), this embodiment explains, as an example, the case where each position is represented as a

discretized position. Specifically, each position is represented, for example, by a position of a representative point of a mesh (for example, a position arbitrarily determined in advance such as a position of a vertex or a position of the center). However, each of the positions described above may be a representative position of a predetermined number of two or more meshes.

[0056] Incidentally, the electromagnetic field analysis is performed by solving the Maxwell equations using a well-known numerical calculation method such as the finite element method. When the electromagnetic field analysis by the finite element method is performed, for example, the instantaneous values of the magnetic flux density and the instantaneous values of the magnetic field strength are calculated as instantaneous values at the position of the representative point of each mesh. The distribution calculation unit 412 can calculate a time average value or the like of the magnetic properties in one cycle by calculating instantaneous values for one cycle as the instantaneous values of the magnetic flux density and the instantaneous values of the magnetic field strength. Incidentally, the method of electromagnetic field analysis itself is a common method, and thus a detailed explanation thereof is omitted here.

[0057] As described above, this embodiment explains, as an example, the case where the designer sets the

region condition information by referring to the distribution of the magnetic properties in the original core. Therefore, the output unit 415 outputs information that specifies the distribution of the magnetic properties in the original core (the distribution of the time average value of the magnetic flux density in this embodiment) (Step S503). Hereinafter, the information that specifies the distribution of the magnetic properties in the original core is also referred to as magnetic distribution information MP.

[0058] This embodiment explains, as an example, the case where the output unit 415 outputs the magnetic distribution information MP to the output processing device 430. Further, this embodiment explains, as an example, the case where the output processing device 430 includes a computer display. In this case, the magnetic distribution information MP output from the output unit 415 is displayed on the computer display. However, as described above, the output processing device 430 is not limited to a device including a computer display.

[0059] The designer determines the permitted region by referring to the magnetic distribution information MP output by the output unit 415. In this case, the acquisition unit 411 acquires the region condition information for specifying the permitted region determined by the designer (Step S504).

[0060] As described above, this embodiment explains,

as an example, the case where the distribution calculation unit 412 calculates the distribution of the magnetic properties in the original core. However, it is not always necessary for the processing device 410 (the distribution calculation unit 412) to calculate the distribution of the magnetic properties in the original core. For example, when there is a known distribution as the distribution of the magnetic properties in the original core, the processing device 410 (the acquisition unit 411) may acquire information indicating the known distribution. In this case, the processing at Step S502 (calculation of the distribution of the magnetic properties) does not have to be performed. Instead, for example, before the processing at Step S505 starts, the acquisition unit 411 performs processing to acquire known information as the magnetic distribution information MP.

[0061] Further, as described above, the acquisition unit 411 does not have to acquire the region condition information. That is, the processing at Step S504 does not have to be performed. When the processing at Step S504 is not performed, the processing at Step S503 (output of the magnetic distribution information MP) does not have to be performed.

[0062] <Index calculation unit 413, Step S505>
The index calculation unit 413 calculates a

distribution of a generation index indicating the ease with which a magnetic flux obstructing part is generated in the design region based on the distribution of the magnetic properties in the design region (Step S505). The distribution of the generation index may be any distribution capable of specifying how easily each position of the core to be designed is to become a magnetic flux obstructing part. As described above, this embodiment explains, as an example, the case where such a generation index is the distribution of the generation probability of the magnetic flux obstructing part in the design region. Hereinafter, the distribution of the generation probability of the magnetic flux obstructing part in the design region is also simply referred to as the distribution of the generation probability. The distribution of the generation probability may be any distribution capable of specifying the probability with which each position of the core to be designed is to become a magnetic flux obstructing part. The distribution of the generation probability may be a continuous probability distribution, a discrete probability distribution, or a probability density function. This embodiment explains, as an example, the case where the index calculation unit 413 calculates a probability density function as the distribution of the generation probability based on the magnetic distribution information MP. Incidentally, it is

preferable that the core to be designed and the original core differ only in the magnetic flux obstructing part (the flux barrier in this embodiment).

[0063] As described in the section of (Findings and Ideas), it is preferable to make the magnetic flux obstructing part (the flux barrier (void) in this embodiment) more likely to exist at a position having a high magnetic flux density in the original core. Further, it is preferable to make the magnetic flux obstructing part less likely to exist at a position having a low magnetic flux density in the original core. Therefore, the index calculation unit 413 may calculate the distribution of the generation probability such that the generation probability of the magnetic flux obstructing part and the magnetic flux density of the original core (the time average value of the magnetic flux density in this embodiment) have a positive correlation. That is, the generation probability of the magnetic flux obstructing part at a certain position may be higher as the magnetic flux density at that position in the original core is higher. For example, the generation probability of the magnetic flux obstructing part at each position within the core to be designed may be a probability proportional to the magnetic flux density at that position in the original core, or a probability proportional to the square of the magnetic flux density at that position.

[0064] Incidentally, at all the positions in the design region of the core to be designed (for example, positions of representative points of all meshes), the generation probability of the magnetic flux obstructing part and the magnetic flux density of the original core (the time average value of the magnetic flux density in this embodiment) do not have to have a positive correlation. For example, the index calculation unit 413 may uniformly set the generation probability at a position where the magnetic flux density of the original core (the time average value of the magnetic flux density in this embodiment) is equal to or less than a first threshold to a predetermined value (for example, 0% or the like) smaller than other generation probabilities set for positions where the magnetic flux density exceeds the first threshold. Further, for example, the index calculation unit 413 may uniformly set the generation probability at a position where the magnetic flux density exceeds a second threshold to a predetermined value (for example, 90% or the like) that is higher than other generation probabilities set for positions where the magnetic flux density is equal to or less than the second threshold and is smaller than 100%. A combination of these may be used, and in this case, the first threshold $\leq$ the second threshold is satisfied. As described above, the index calculation unit 413 may calculate the distribution of the generation probability of the magnetic flux

obstructing part such that the generation probability of the magnetic flux obstructing part and the magnetic flux density of the original core have a positive correlation in at least a portion of the distribution. Further, the index calculation unit 413 may calculate the distribution of the generation probability of the magnetic flux obstructing part such that the generation probability of the magnetic flux obstructing part and the magnetic flux density of the original core have a positive correlation in the entire distribution. Further, the positions where the generation probability is calculated and the positions where the electromagnetic field analysis is performed do not have to coincide. In this case, for example, among the meshes set for the design region for performing the electromagnetic field analysis, the generation probability may be calculated for each group of a predetermined number of adjacent meshes. Further, the aforementioned predetermined number may be individually set according to the location in the design region or the like.

In the following explanation, the information capable of specifying the distribution of the generation probability calculated by the index calculation unit 413 as described above is also referred to as probability distribution information GP.

[0065] <Determination unit 414, Output unit 415, Steps S505 to S506>

The determination unit 414 determines the region of the magnetic flux obstructing part in the design region based on the distribution of the generation probability (Step S505). Hereinafter, the region of the magnetic flux obstructing part in the design region is also simply referred to as the region of the magnetic flux obstructing part. The information on the region of the magnetic flux obstructing part determined by the determination unit 414 may be any information capable of specifying the region occupied by the magnetic flux obstructing part (the flux barrier in this embodiment) in the core. The number of regions of a magnetic flux obstructing part determined by the determination unit 414 may be one or more. When the permitted region is set, the determination unit 414 determines the region of the magnetic flux obstructing part within the permitted region. That is, the determination unit 414 determines the region of the magnetic flux obstructing part such that the entire region of the magnetic flux obstructing part is included within the permitted region. In other words, when at least a portion of the region of the magnetic flux obstructing part falls outside the permitted region, the determination unit 414 does not determine that region of the magnetic flux obstructing part as the region of the magnetic flux obstructing part. However, for example, the determination unit 414 may determine, as the region of the magnetic flux

obstructing part, a region obtained by excluding the region outside the permitted region from that region of the magnetic flux obstructing part.

[0066] The determination unit 414 samples points within the design region (for example, positions of representative points of meshes) based on, for example, the distribution of the generation probability. The method of sampling is preferably a method by which a position having a higher generation probability is more likely to be sampled. As described above, the distribution of the generation probability is calculated such that the generation probability of the magnetic flux obstructing part and the magnetic flux density of the original core (the time average value of the magnetic flux density in this embodiment) have a positive correlation.

Therefore, by making a position having a higher generation probability more likely to be sampled, a position having a higher magnetic flux density in the original core becomes more likely to be sampled.

Further, a position having a lower magnetic flux density in the original core becomes less likely to be sampled. Sampling may be performed, for example, by a Markov Chain Monte Carlo method or by rejection sampling. For example, a target distribution for sampling may be the distribution of the generation probability itself, or a distribution based on the distribution of the generation probability.

Incidentally, the Markov Chain Monte Carlo method and

the rejection sampling themselves are common methods, and thus, detailed explanations thereof are omitted here. Further, the method of sampling may be a method other than the Markov Chain Monte Carlo method and rejection sampling. This embodiment explains, as an example, the case where the determination unit 414 samples positions within the core to be designed from the distribution of the generation probability using the Markov Chain Monte Carlo method.

[0067] Fig. 6 is a view illustrating an example of a result of sampling in a region constituting one pole of the rotor core. The original core has the same configuration as the rotor core 311 illustrated in Fig. 3. In Fig. 6, a region having a higher concentration represents a higher number of samplings per unit area. As illustrated in Fig. 6, it can be seen that a large number of positions on the outer peripheral side of the rotor core (positions near the region where the permanent magnets 312a to 323b are installed) are sampled.

[0068] The determination unit 414 may select all or a portion of the plurality of sampled points (positions) as they are as the region of the magnetic flux obstructing part. Further, when a plurality of points adjacent mutually are sampled, the determination unit 414 may select the plurality of points as one region of a magnetic flux obstructing part. Alternatively, the determination unit 414 may select, as the region of the magnetic flux

obstructing part, a region having a preset shape and size so as to include the sampled points. In such a case, the determination unit 414 may select a region of a magnetic flux obstructing part having a preset shape and size as the region of the magnetic flux obstructing part with the sampled points as representative points. The position of the representative point is, for example, the center of gravity (or the centroid position) of a magnetic flux obstructing part. When the permitted region is set, the determination unit 414 may set only the positions within the permitted region as a target for sampling, or may set the entire design region as a target for sampling. When the entire design region is set as a target for sampling, the determination unit 414 may discard, for example, magnetic flux obstructing parts including any region that is not the permitted region. Further, for example, when a region that is not the permitted region is included in a portion of the magnetic flux obstructing part, the determination unit 414 may select, as the region of the magnetic flux obstructing part, a region obtained by excluding that portion of the region. In this embodiment, the region selected as the region of the magnetic flux obstructing part in this manner is an example of a selected region selected from the design region.

[0069] The determination unit 414 may determine the region selected as described above as the region of the magnetic flux obstructing part. However, this

embodiment explains, as an example, the case where the determination unit 414 determines the region of the magnetic flux obstructing part as below based on the probability distribution information GP so as to be able to further improve the characteristics of the core to be designed and the apparatus (the rotor core and the IPMSM in this embodiment). Fig. 7 is a view explaining an example of a method of determining the region of the magnetic flux obstructing part. Fig. 7 illustrates, as an example, the case where an original core 711 is the rotor core 311 illustrated in Fig. 3.

[0070] First, the determination unit 414 selects a region including the points sampled based on the probability distribution information GP from a design region of the original core 711. Then, the determination unit 414 generates an evaluation core 721 provided with magnetic flux obstructing parts (flux barriers in this embodiment) in the selected region.

[0071] Then, the determination unit 414 calculates a characteristic value of the apparatus provided with the evaluation core 721 and determines the region of the magnetic flux obstructing part in the design region based on the calculated characteristic value. This embodiment explains, as an example, the case where the determination unit 414 performs an electromagnetic field analysis of the evaluation core 721 to calculate the characteristic value of the

apparatus provided with the evaluation core 721. In this case, the determination unit 414 determines the region of the magnetic flux obstructing part based on the result of the electromagnetic field analysis. Incidentally, the characteristic value of the apparatus may be any value indicating the characteristics of the apparatus. The characteristics of the apparatus may be, for example, characteristics indicating the performance of the apparatus.

[0072] To explain a specific example of the processing by the determination unit 414 when performing the electromagnetic field analysis of the evaluation core 721, first, the determination unit 414 selects candidates for the region of the magnetic flux obstructing part such that the points sampled based on the probability distribution information GP coincide with representative points. As described above, the position of the representative point is, for example, the center of gravity (or the centroid position) of a magnetic flux obstructing part. When the permitted region is set as described above, the determination unit 414 may set only the positions within the permitted region as a target for sampling, or may set the entire design region as a target for sampling.

[0073] For example, the determination unit 414 may determine the region of the magnetic flux obstructing part using a method obtained by improving the method

described in Patent Literature 1. In the method described in Patent Literature 1, a region of a basic shape of a flux barrier is set within the design region. For example, the determination unit 414 may set a circular region as the region of the basic shape of the flux barrier in a region other than permanent magnets 713aa to 713e and flux barriers 712a to 612h in the design region of the original core 711 illustrated in Fig. 7. There may be one or more such regions. Further, the basic shape may be a shape other than a circular shape. Alternatively, the regions of the flux barriers 712a to 712h illustrated in Fig. 7 may be set as the region of the basic shape of the flux barrier. Then, the determination unit 414 calculates an optimal solution for a mapping applied to the region of the basic shape of the flux barrier using an optimization algorithm. At that time, the determination unit 414 uses the characteristic value of the apparatus, such as the average torque of the rotor, as the value of the objective function.

[0074] When calculating the optimal solution for the mapping applied to the region of the basic shape of the flux barrier using metaheuristics such as a genetic algorithm, the determination unit 414 calculates a candidate solution for the mapping. Hereinafter, the optimal solution and the candidate solution for the mapping applied to the region of the basic shape of the flux barrier are also simply

referred to as the optimal solution and the candidate solution, respectively. The determination unit 414 generates a flux barrier by applying the mapping represented by the candidate solution to the region of the basic shape of the flux barrier. The number of flux barriers may be one or more. When there are a plurality of flux barriers, there may be a plurality of candidate solutions. In this case, the determination unit 414 may select a candidate solution corresponding to each of the plurality of flux barriers. Further, in this case, the determination unit 414 may apply, to the region of the basic shape of the flux barrier, a mapping represented by the candidate solution corresponding to the flux barrier.

[0075] For example, in Fig. 7, the determination unit 414 sets the regions of the flux barriers 712a to 712h in the region of the original core 711 as the region of the basic shape of the flux barrier. The determination unit 414 generates the evaluation core 721 by applying the mapping represented by the candidate solution to the basic shape of the flux barrier. Fig. 7 illustrates, as an example, the case where flux barriers 712a to 722g and 732a to 732e are generated as a result of such mappings being applied. In this case, the regions of the flux barriers 722a to 722e and 732a to 732e are examples of the selected region.

[0076] The determination unit 414 generates an

evaluation core provided with one or more flux barriers to which the mapping has been applied as described above. In Fig. 7, the determination unit 414 generates evaluation cores 721 and 731. Then, the determination unit 414 calculates the value of the objective function by calculating the characteristic value of the IPMSM including the evaluation core 721. The determination unit 414 updates the candidate solution according to the optimization algorithm such as a genetic algorithm based on the value of the objective function calculated as above. Incidentally, the optimization algorithm may be metaheuristics or other algorithms. The optimal solution is calculated by repeatedly performing such updates of the candidate solution until the convergence condition is satisfied. The determination unit 414 determines the region of the flux barrier in the design region of the original core 711 by applying the mapping represented by the optimal solution to the region of the basic shape of the flux barrier.

[0077] Fig. 7 illustrates, as an example, the case where the flux barriers 732a to 732e are generated by applying the mapping represented by the optimal solution to the regions of the flux barriers 712a to 712h (the regions of the basic shape of the flux barrier) in the design region of the original core 711. Incidentally, in this case, the flux barriers 722a to 722e are flux barriers generated by applying

the mapping represented by the candidate solution other than the optimal solution to the regions of the flux barriers 712a to 712h.

[0078] As described above, as long as the optimal solution is calculated by solving the optimization problem, a core that exhibits better values as the characteristic values of the apparatus can be designed, which is preferable. However, the determination unit 414 does not necessarily have to solve the optimization problem. For example, the designer may vary the design variables on a trial-and-error basis. In this case, the determination unit 414 may explore design variables, among the design variables specified by the designer, with which the characteristic value of the apparatus satisfies a predetermined condition. The aforementioned predetermined condition may be, for example, that the characteristic value of the apparatus is better than a predetermined value.

[0079] For example, in the method described in Patent Literature 1, the determination unit 414 may calculate an initial candidate solution such that the position of the representative point of the flux barrier, when the mapping is applied to the region of the basic shape of the flux barrier, coincides with the position of the point sampled as described above.

[0080] Further, when updating the candidate solution, the determination unit 414 may calculate the updated candidate solution such that the position of the

representative point of the flux barrier, when the mapping represented by the updated candidate solution is applied, coincides with the position of the point sampled as described above.

The determination unit 414 may calculate both the initial candidate solution and the updated candidate solution as described above, or may calculate only one of them as described above.

[0081] In the manner described above, according to the distribution of the generation probability, a position having a greater influence on the characteristics of the core and the apparatus is more likely to be calculated as a representative point of the flux barrier. In addition, a position having a smaller influence on the characteristics of the core and the apparatus is less likely to be calculated as a representative point of the flux barrier.

Therefore, it is possible to increase the probability that the sampled points are included in the magnetic flux obstructing part while reducing the calculation load.

[0082] Incidentally, in the method described in Patent Literature 1, for example, the shape of the flux barrier is modified by applying a mapping to the region of the basic shape of the flux barrier.

Further, in the method described in Patent Literature 1, for example, as a result of applying the mapping to the region of the basic shape of the flux barrier, one flux barrier may be separated into a plurality of

flux barriers. In such a case, since the number of flux barriers increases, flux barriers are added. On the other hand, a plurality of flux barriers may be merged into one flux barrier. In such a case, the number of flux barriers decreases. Further, in the method described in Patent Literature 1, the flux barrier may exist, or may not exist in the original core. When no flux barrier exists in the original core, for example, the region of the basic shape of the flux barrier is added, and thereby a flux barrier is added to the original core. Further, when a flux barrier exists in the original core, the region of that flux barrier may be set as the region of the basic shape of the flux barrier. Further, for example, when the entire flux barrier is located outside the design region as a result of applying the mapping to the region of the basic shape of the flux barrier, the flux barrier is deleted. When using the method obtained by improving the method described in Patent Literature 1 as described above, the determination unit 414 performs at least one of addition, modification, and deletion of a flux barrier with respect to the original core.

[0083] Further, for example, the determination unit 414 may determine the region of the magnetic flux obstructing part using the method obtained by improving the method described in Non Patent Literature 1. In the method described in Non Patent Literature 1, when an output $y(x_e)$ of a NGnet in a

certain mesh is 0 or more, the state of that mesh is set to an on state. x_e is the position of the center of gravity of the mesh. On the other hand, when the output $y(x_e)$ of the NGnet in a certain mesh is less than 0, the state of that mesh is set to an off state. Incidentally, in Non Patent Literature 1, the mesh is referred to as a cell.

[0084] For example, in the method described in Non Patent Literature 1, the determination unit 414 may modify a threshold for the output $y(x_e)$ of the NGnet in each mesh depending on whether or not the mesh is a mesh sampled as described above. For example, the determination unit 414 may set a threshold for the output $y(x_e)$ of the NGnet in a sampled mesh to be smaller than a threshold for the output $y(x_e)$ of the NGnet in an unsampled mesh. Further, the determination unit 414 may add a positive real number to the output $y(x_e)$ of the NGnet in the sampled mesh. Further, the determination unit 414 may add a negative real number to the output $y(x_e)$ of the NGnet in the unsampled mesh. Further, the determination unit 414 may also perform both the addition of a positive real number and the addition of a negative real number. Further, the determination unit 414 may also multiply a weighting coefficient for the normalized Gaussian function by a positive real number or a negative real number. For example, when the value of the normalized Gaussian function for the unsampled mesh is a positive value, the determination

unit 414 may multiply the weighting coefficient by a negative real number. When the value of the normalized Gaussian function for the unsampled mesh is a negative value, the determination unit 414 may multiply the weighting coefficient by a positive real number. Further, when the value of the normalized Gaussian function for the sampled mesh is a positive value, the determination unit 414 may multiply the weighting coefficient by a positive real number. When the value of the normalized Gaussian function for the sampled mesh is a negative value, the determination unit 414 may multiply the weighting coefficient by a negative real number. Incidentally, as explained in the section of Background Art, in the method described in Non Patent Literature 1, the weighting coefficient for the normalized Gaussian function is a design variable. Therefore, when multiplying the weighting coefficient for the normalized Gaussian function by a positive or negative real number, the design variable is modified. The determination unit 414 may perform all of the modification of a threshold, the addition of a positive real number, and the multiplication of a positive or negative real number, or it may perform one or two of these.

[0085] Even in the manner described above, similarly to the case of improving the method described in Patent Literature 1, according to the distribution of the generation probability, a position having a

greater influence on the characteristics of the core and the apparatus is more likely to be calculated as a position of the flux barrier (namely, more likely to be in the on state). Further, a position having a smaller influence on the characteristics of the core and the apparatus is less likely to be calculated as a position of the flux barrier (namely, more likely to be in the off state). Therefore, it is possible to increase the probability that the sampled points are included in the magnetic flux obstructing part while reducing the calculation load.

[0086] Incidentally, as a method of improving the method described in Non Patent Literature 1, a method that does not perform sampling may be used. For example, the determination unit 414 may modify the threshold for the output $y(x_e)$ of the NGnet in each mesh according to the value of the generation probability in each mesh. In this case, for example, the determination unit 414 may set a smaller threshold as the generation probability of a mesh is higher. Further, for example, the determination unit 414 may add, according to the value of the generation probability in each mesh, a positive real number or a negative real number to the output $y(x_e)$ of the NGnet in the mesh. In this case, the determination unit 414 may set a larger value for the positive real number to be added to the output $y(x_e)$ of the NGnet as the generation probability is higher. Further, the determination unit 414 may increase the absolute

value of the negative real number to be added to the output $y(x_e)$ of the NGnet as the generation probability is lower. Further, the determination unit 414 may multiply the weighting coefficient for the normalized Gaussian function by a positive real number or a negative real number.

[0087] Incidentally, by performing the electromagnetic field analysis of the evaluation cores 721 and 731 as described above to calculate the characteristic value of the apparatus including the evaluation cores 721 and 731, the characteristic value of the apparatus can be calculated easily and accurately, which is preferable. However, the characteristic value of the apparatus including the evaluation cores 721 and 731 does not have to be calculated by performing the electromagnetic field analysis of the evaluation cores 721 and 731. For example, the determination unit 414 may calculate the characteristic value of the apparatus using a trained model (machine learning model) that has learned the relationship between an image including magnetic flux obstructing parts and the characteristic value of the apparatus. Further, the determination unit 414 may calculate the characteristic value of the apparatus by using an equivalent circuit method or the like. Incidentally, the equivalent circuit method is a method for calculating characteristic values of an apparatus using an equivalent circuit of the apparatus. The equivalent circuit is represented by,

for example, using resistance, inductance, and electromotive force. Further, the equivalent circuit may be represented by further using capacitance.

[0088] In the following explanation, the information capable of specifying the region of the magnetic flux obstructing part determined by the determination unit 414 as described above is also referred to as obstructing part information M0.

The output unit 415 outputs the obstructing part information M0 (Step S506). This embodiment explains, as an example, the case where the output unit 415 outputs the obstructing part information M0 to the output processing device 430. Further, as described above, this embodiment explains, as an example, the case where the output processing device 430 includes a computer display. In this case, the obstructing part information M0 output from the output unit 415 is displayed on the computer display.

[0089] The designer may design the core (the rotor core in this embodiment) based on the obstructing part information M0. At that time, based on the magnetic flux obstructing part (the flux barrier in this embodiment) specified by the obstructing part information M0, the designer determines information necessary for manufacturing the magnetic flux obstructing part, such as the number, position, shape, and size of the magnetic flux obstructing part. The information necessary for manufacturing the magnetic flux obstructing part may include information

regarding the manufacturing method of the magnetic flux obstructing part.

[0090] The designer may design a core provided with a magnetic flux obstructing part in the whole or a portion of at least one of the regions of the magnetic flux obstructing parts specified by the obstructing part information MO. That is, the designer may design a core provided with a magnetic flux obstructing part in the whole or a portion of all the regions of the magnetic flux obstructing parts specified by the obstructing part information MO, or may design a core provided with a magnetic flux obstructing part in the whole or a portion of some of all the regions of the magnetic flux obstructing parts specified by the obstructing part information MO. For example, the designer may adopt the magnetic flux obstructing part itself specified by the obstructing part information MO. Further, the designer may modify the magnetic flux obstructing part specified by the obstructing part information MO. For example, in the case where the shape of the magnetic flux obstructing part specified by the obstructing part information MO is not smooth, the designer may modify the magnetic flux obstructing part such that the shape thereof becomes smooth, in order to facilitate manufacturing of the magnetic flux obstructing part. In this case, the ratio of a volume (or an area) of the modified magnetic flux obstructing part to a volume (or an area) of the

magnetic flux obstructing part before modification is preferably 0.8 or more and 1.2 or less, and more preferably 0.9 or more and 1.1 or less. Further, the number of magnetic flux obstructing parts provided in the core is preferably 0.5 times or more and 1.5 times or less the number of magnetic flux obstructing parts specified by the obstructing part information MO, more preferably 0.75 times or more and 1.25 times or less, and even more preferably 1 time. Further, the shortest distance between the position of the representative point of the magnetic flux obstructing part before modification and the position of the representative point of the modified magnetic flux obstructing part is, for example, preferably 0.04 times or more and 0.06 times or less the length of the core, more preferably 0.02 times or more and 0.04 times or less the length, even more preferably greater than 0.00 times and 0.02 times or less the length, and most preferably 0 mm. Here, the length of the core is, for example, the maximum length of the core in a cross section perpendicular to the center axis of the core. In the example illustrated in Fig. 3, the length of the core is the outside diameter of the rotor core 311.

[0091] The apparatus (the IPMSM in this embodiment) designed as described above is manufactured using a manufacturing apparatus. The manufacturing apparatus itself may be a known manufacturing apparatus. In the step of manufacturing the core, a core provided

with the magnetic flux obstructing part according to the aforementioned design is manufactured. When the magnetic flux obstructing part is a flux barrier, the flux barrier is formed in the core using, for example, a cutting machine that cuts a soft magnetic sheet. The cutting may be performed by punching, laser processing, or any other method. Incidentally, the output unit 415 may output the obstructing part information MO to a control device that controls the cutting machine. In this case, the control device may control the cutting machine based on the obstructing part information MO. The output processing device 430 may include the control device.

[0092] <Hardware>

As described above, the processing device 410 can be implemented by using various hardware, and for example, it can be implemented by using the hardware illustrated in Fig. 8.

[0093] In Fig. 8, the processing device 410 includes a processor 801, a main memory 802, an auxiliary memory 803, a communication circuit 804, a signal processing circuit 805, an image processing circuit 806, an I/F circuit 807, and a bus 808.

[0094] The processor 801 comprehensively controls the entire processing device 410. The processor 801 uses the main memory 802 as a work area to execute a program stored in the auxiliary memory 803. In this embodiment, the program stored in the auxiliary memory 803 includes, for example, a program for

executing the flowchart illustrated in Fig. 5. The processor 801 may be, for example, a CPU or a GPU. The main memory 802 temporarily stores data. The auxiliary memory 803 stores various data in addition to programs to be executed by the processor 801.

[0095] The communication circuit 804 is a circuit intended for performing communication with the outside of the processing device 410. The communication circuit 804 may perform wireless communication or wired communication with the outside of the processing device 410.

[0096] The signal processing circuit 805 performs various pieces of signal processing on signals received by the communication circuit 804 and signals input according to the control by the processor 801. The image processing circuit 806 performs various pieces of image processing on signals input according to the control by the processor 801. The signal that has been subjected to the image processing by the image processing circuit 806 is output to the output processing device 430 provided with a computer display via the I/F circuit 807, for example.

[0097] The I/F circuit 807 exchanges data with a device communicably connected to the I/F circuit 807. Fig. 8 illustrates the input processing device 420 and the output processing device 430 as devices communicably connected to the I/F circuit 807. However, the device to be connected to the I/F circuit 807 is not limited to these. For example, a

portable storage medium may be connected to the I/F circuit 807. Further, when the output processing device 430 includes the aforementioned control device, for example, the communication circuit 804 and the output processing device 430 are communicably connected to each other. In this case, the output processing device 430 (for example, a user interface) communicably connected to the I/F circuit 807 and the output processing device 430 (for example, the aforementioned control device) communicably connected to the communication circuit 804 are separate devices.

[0098] Incidentally, the processor 801, the main memory 802, the auxiliary memory 803, the signal processing circuit 805, the image processing circuit 806, and the I/F circuit 807 are connected to the bus 808. Communication among these components is performed via the bus 808. Further, the hardware of the processing device 410 is not limited to the hardware illustrated in Fig. 8, as long as it can perform the aforementioned functions of the processing device 410. For example, the processing device 410 may include a plurality of processors 801.

[0099] (Calculation example)

Next, a calculation example is explained. In this calculation example, using the rotor core 311 of the IPMSM 300 illustrated in Fig. 3 as an original core, a flux barrier was generated in the original core by each of the method of this embodiment and the method of Patent Literature 1.

[0100] In this calculation example, the number of poles of the IPMSM 300 was set to 8. Further, the number of slots of the IPMSM 300 was set to 24. Further, the outside diameter of the stator core 321 was set to 55 mm. Further, the outside diameter of the rotor core 311 was set to 27.5 mm. Further, the residual magnetic flux density of the permanent magnets 312a to 312b was set to 1.2 T. Further, the rotation speed of the IPMSM 300 was set to 1500 rpm (the excitation frequency was set to 100 Hz). Further, the lead angle was set to 40° . Further, the root mean square value of the excitation current was set to 20 A. Further, a real-coded genetic algorithm was used as the algorithm for the optimization calculation. Further, the value of the average torque of the IPMSM was set as the value of the objective function.

[0101] Incidentally, as described in Patent Literature 1, the torque was calculated based on Maxwell stress. Further, the average torque was calculated based on the torque in each mesh. Further, in order to make the amount of calculation equivalent between the method of this embodiment and the method described in Patent Literature 1, the number of iterations in the optimization calculation (convergence calculation) was made the same for each method. That is, the solution obtained when the optimization calculation (convergence calculation) was performed for the specified number of iterations

was taken as the optimal solution.

[0102] The average torques of the IPMSMs when the optimal solutions were obtained in the method of this embodiment and the method described in Patent Literature 1 were taken as the average torques of the IPMSMs provided with the flux barriers calculated by the respective methods. Further, the average torque of the IPMSM 300 illustrated in Fig. 3 was calculated.

[0103] The average torque of the IPMSM provided with the flux barrier generated by the method of this embodiment increased by 82.4% compared to that of the IPMSM 300 illustrated in Fig. 3. On the other hand, the average torque of the IPMSM provided with the flux barrier generated by the method described in Patent Literature 1 increased by 55.7% compared to that of the IPMSM 300 illustrated in Fig. 3. From this, it was found that when the amount of calculation was equivalent, the method of this embodiment was able to calculate a superior optimal solution (flux barrier) compared to the method described in Patent Literature 1. That is, the method of this embodiment was able to shorten the time until convergence to the optimal solution compared to the method described in Patent Literature 1. It is considered that the calculation load was reduced because the exploration range for the solution in the method of this embodiment was narrower than the range in the method described in Patent Literature 1.

[0104] Fig. 9A is a view illustrating an example of a result of generating flux barriers in the method of this embodiment. Fig. 9B is a view illustrating an example of a result of generating flux barriers in the method described in Patent Literature 1.

[0105] As illustrated in Fig. 9A, in the method of this embodiment, representative points of the flux barriers are sampled based on the distribution of the generation probability. For this reason, it is considered that the flux barriers were generated in a concentrated manner at positions having a large contribution to the average torque of the IPMSM. On the other hand, as illustrated in Fig. 9B, the method described in Patent Literature 1 fails to consider the ease (or difficulty) with which each position in the design region is selected when generating the flux barriers. For this reason, it is considered that in the method described in Patent Literature 1, the flux barriers were also generated at positions having a small contribution to the average torque of the IPMSM. Further, it is considered that in the method described in Patent Literature 1, a large number of flux barriers were generated over a wide range. Incidentally, the results illustrated in Fig. 9A and Fig. 9B indicate that the method of this embodiment resulted in a smaller number of flux barriers and larger individual flux barriers than the method described in Patent Literature 1. Therefore, it is considered that the method of this embodiment

is capable of generating flux barriers that are easier to manufacture than the method described in Patent Literature 1.

[0106] (Summary)

In this embodiment, the processing device 410 calculates, based on the distribution of the magnetic properties in the design region of the original core 711, a distribution of a generation index for evaluating the ease with which a magnetic flux obstructing part is generated in the design region. Then, the processing device 410 determines the region of the magnetic flux obstructing part in the design region of the original core 711 based on the distribution of the generation index. Consequently, for example, depending on the position in the design region of the original core 711, it is possible to determine the ease (or difficulty) with which a magnetic flux obstructing part is generated based on the magnetic properties before the magnetic flux obstructing part is generated. As a result, for example, in the process of exploration of the solutions, it is possible to reduce the possibility of generating a magnetic flux obstructing part that does not contribute to the improvement of the characteristics of the core. Therefore, for example, it is possible to generate a magnetic flux obstructing part that improves the characteristics of the core without imposing a significant calculation load.

[0107] Further, in this embodiment, the processing device 410 selects a selected region from the design region of the original core 711 based on the distribution of the generation index, and generates the evaluation cores 721 and 731 provided with magnetic flux obstructing parts in the selected region. Then, the processing device 410 calculates a characteristic value of the apparatus including the evaluation cores 721 and 731, and determines the region of the magnetic flux obstructing part in the design region based on the characteristic value. Therefore, for example, a magnetic flux obstructing part that improves the characteristics of the apparatus can be generated based on the characteristic value of the apparatus, which is a quantitative indicator.

[0108] Further, in this embodiment, the processing device 410 samples points within the design region based on the distribution of the generation probability, and generates magnetic flux obstructing parts based on the sampled points. Therefore, for example, it is possible to quantitatively determine which position within the core is to be set as a magnetic flux obstructing part according to the generation probability. Accordingly, for example, it is possible to more reliably generate a magnetic flux obstructing part that improves the characteristics of the core.

[0109] Further, in this embodiment, the processing

device 410 samples points within the design region as representative points of the magnetic flux obstructing parts based on the distribution of the generation probability. Therefore, for example, attributes of the magnetic flux obstructing parts other than the representative points can be calculated without using the distribution of the generation probability. Consequently, for example, the degree of freedom in generating a magnetic flux obstructing part can be increased. Incidentally, the processing device 410 may calculate the attributes of the magnetic flux obstructing parts other than the representative points using the distribution of the generation probability.

[0110] Further, in this embodiment, the processing device 410 generates the magnetic flux obstructing parts based on the results of the electromagnetic field analysis of the evaluation cores 721 and 731. Therefore, for example, it is possible to quantitatively evaluate the degree to which the magnetic flux obstructing part including the sampled points contributes to the improvement of the characteristics of the core. Consequently, for example, a magnetic flux obstructing part that improves the characteristics of the core can be generated more reliably.

[0111] Further, in this embodiment, the processing device 410 generates the magnetic flux obstructing parts by performing at least one of addition,

modification, and deletion of a magnetic flux obstructing part with respect to the original core 711. Incidentally, the modification of the magnetic flux obstructing part refers to, for example, modifying at least one of the position, size, and shape of an already existing magnetic flux obstructing part. Therefore, for example, the magnetic flux obstructing part can be generated by modifying the original core 711. Consequently, for example, components other than the magnetic flux obstructing part can be set in advance by the original core 711. This makes it possible to reduce the calculation load compared to, for example, the case where components other than the magnetic flux obstructing part and the magnetic flux obstructing parts are generated simultaneously.

[0112] Further, in this embodiment, the processing device 410 calculates the distribution of the magnetic properties based on the result of the electromagnetic field analysis of the original core 711. Therefore, for example, even when there is no distribution of the magnetic properties in the original core 711, the distribution of the magnetic properties in the original core 711 can be obtained. Consequently, for example, original cores having various configurations can be used as the original core.

[0113] Further, in this embodiment, the processing device 410 acquires the region condition information

capable of specifying the permitted region. Then, the processing device 410 generates magnetic flux obstructing parts within the permitted region. Therefore, for example, by limiting the region for generating the magnetic flux obstructing part to within the permitted region, the calculation load can be further reduced. Further, for example, it is possible to inhibit a magnetic flux obstructing part from being generated at a position where no magnetic flux obstructing part can exist in the design region. [0114] Further, in this embodiment, the processing device 410 uses, for example, the generation probability of the magnetic flux obstructing part as the generation index for evaluating the ease with which a magnetic flux obstructing part is generated. Therefore, for example, the ease (or difficulty) with which a magnetic flux obstructing part is generated can be quantitatively evaluated.

[0115] Further, in this embodiment, the processing device 410 uses a distribution of representative values of magnetic properties in one cycle as the distribution of the magnetic properties. Therefore, for example, as the distribution of the magnetic properties, a distribution in which the magnetic properties of the core are more accurately reflected can be used. Accordingly, for example, a magnetic flux obstructing part that improves the characteristics of the core can be generated more reliably.

[0116] (Other embodiments)

Incidentally, the embodiment of the present disclosure explained above can be implemented by causing a computer to execute a program. Further, a computer-readable recording medium in which the aforementioned program is recorded and a computer program product such as the aforementioned program can also be applied as the embodiment of the present disclosure. As the recording medium, it is possible to use a flexible disk, a hard disk, an optical disk, a magneto-optic disk, a CD-ROM, a magnetic tape, a nonvolatile memory card, a ROM, or the like, for example.

Further, the embodiment of the present disclosure explained above merely illustrates concrete examples of implementing the present invention, and the technical scope of the present invention is not to be construed in a restrictive manner by the embodiment. That is, the present invention may be implemented in various forms without departing from the technical spirit or main features thereof.

INDUSTRIAL APPLICABILITY

[0117] The present disclosure can be utilized, for example, for designing and manufacturing a core.

CLAIMS

[Claim 1] A processing device for performing processing for designing a core provided with a magnetic flux obstructing part, the processing device comprising:

an index calculation unit configured to calculate, based on a distribution of magnetic properties in a design region of an original core that serves as a prototype of a designed core, a distribution of a generation index for evaluating the ease with which the magnetic flux obstructing part is generated in the design region; and

a determination unit configured to determine a region of the magnetic flux obstructing part in the design region based on the distribution of the generation index,

wherein the design region is a region in a cut surface of the original core, and

wherein the cut surface of the original core is a cut surface in a direction perpendicular to a direction in which the magnetic flux obstructing part is viewed in a plan view.

[Claim 2] The processing device according to claim 1,

wherein the determination unit

selects a selected region from the design region based on the distribution of the generation index,

generates an evaluation core provided with the magnetic flux obstructing part in the selected region,

calculates a characteristic value of an apparatus

including the evaluation core, and

determines the region of the magnetic flux obstructing part in the design region based on the calculated characteristic value.

[Claim 3] The processing device according to claim 2,

wherein the determination unit samples points within the design region based on the distribution of the generation index, and selects the selected region based on the sampled points.

[Claim 4] The processing device according to claim 3,

wherein the determination unit samples points within the design region as representative points of the magnetic flux obstructing part.

[Claim 5] The processing device according to any one of claims 2 to 4,

wherein the determination unit calculates the characteristic value of the apparatus by an electromagnetic field analysis of the evaluation core.

[Claim 6] The processing device according to any one of claims 2 to 5,

wherein the determination unit generates the evaluation core by performing at least one of addition, modification, and deletion of the magnetic flux obstructing part with respect to the design region.

[Claim 7] The processing device according to any one of claims 1 to 6, further comprising:

a distribution calculation unit configured to calculate a distribution of magnetic properties in

the design region based on results of the electromagnetic field analysis of the original core.

[Claim 8] The processing device according to any one of claims 1 to 7, further comprising:

an acquisition unit configured to acquire prerequisite information indicating prerequisite conditions for generating the magnetic flux obstructing part,

wherein the prerequisite information includes region condition information capable of specifying a permitted region permitted to be determined as a region of a magnetic flux obstructing part in the core, and

wherein the determination unit determines the region of the magnetic flux obstructing part in the core within the permitted region.

[Claim 9] The processing device according to any one of claims 1 to 8,

wherein the generation index is a generation probability of the magnetic flux obstructing part.

[Claim 10] The processing device according to any one of claims 1 to 9,

wherein the distribution of the magnetic properties is a distribution of representative values of the magnetic properties in one cycle.

[Claim 11] The processing device according to any one of claims 1 to 10,

wherein the magnetic flux obstructing part includes a void.

[Claim 12] The processing device according to any one of claims 1 to 11,

wherein the magnetic properties are magnetic flux density, magnetic field strength, or magnetic permeability.

[Claim 13] A processing method for performing processing for designing a core provided with a magnetic flux obstructing part, the processing method comprising:

an index calculation step of calculating, based on a distribution of magnetic properties in a design region of an original core that serves as a prototype of a designed core, a distribution of a generation index for evaluating the ease with which the magnetic flux obstructing part is generated in the design region; and

a determination step of determining a region of the magnetic flux obstructing part in the design region based on the distribution of the generation index,

wherein the design region is a region in a cut surface of the original core, and

wherein the cut surface of the original core is a cut surface in a direction perpendicular to a direction in which the magnetic flux obstructing part is viewed in a plan view.

[Claim 14] A program for causing a computer to function as each unit of the processing device according to any one of claims 1 to 12.

[Claim 15] A core provided with the magnetic flux obstructing part in the whole or a portion of at least one of the regions determined by the determination unit included in the processing device according to any one of claims 1 to 12.