

Title of Invention: ABNORMALITY DETECTION METHOD FOR ROTARY MECHANICAL SYSTEM, ABNORMALITY MONITORING METHOD FOR ROTARY MECHANICAL SYSTEM USING SAID ABNORMALITY DETECTION METHOD, AND ABNORMALITY MONITORING DEVICE FOR ROTARY MECHANICAL SYSTEM USING SAID ABNORMALITY DETECTION METHOD

#### Technical Field

[0001] The present invention relates to an abnormality detection method for a rotary mechanical system which detects an abnormality in the rotary mechanical system from the state of a current signal in operation from a three-phase induction motor as a drive source for the rotary mechanical system, an abnormality monitoring method for a rotary mechanical system which uses the abnormality detection method, and an abnormality monitoring device for a rotary mechanical system which uses the abnormality monitoring method.

#### Background Art

[0002] As an abnormality diagnosis method for a rotary mechanical system which uses a motor current signature analysis (MCSA), for example, patent literature 1 discloses a technique of detecting an abnormality in a rotary mechanical system by detecting a current signal in operation from an induction motor for the rotary mechanical system and using, as a parameter,

an information amount KI of an amplitude probability density function obtained from the waveform of the signal. It is, however, difficult to represent the state of the rotary mechanical system by using only one type of parameter. Therefore, there is a problem that this technique cannot be used for a condition analysis (i.e. precision diagnosis) aiming at identifying the type of abnormality that has occurred in a rotary mechanical system and specifying an abnormality location. Accordingly, a condition analysis for a rotary mechanical system based on motor current signature analysis is performed by obtaining the feature of a spectrum pattern (identifying the spectrum pattern) obtained by fast Fourier transformation (FFT) of a current signal in operation from the induction motor.

#### Citation List

##### Patent Literature

[0003] Patent Literature 1: Japanese Patent No. 5733913

##### Summary of Invention

##### Technical Problem

[0004] However, a diagnosis on the state of an induction motor based on the spectrum pattern of a current signal in operation from the induction motor requires a considerable amount of theoretical knowledge about an abnormality occurring

in a rotary mechanical system and in field experience concerning the rotary mechanical system. This also tends to cause variations in diagnosis result even with respect to one rotary mechanical system.

In addition, even if an abnormality type can be identified from the spectrum pattern of a current signal in operation from an induction motor, information on a corresponding response to the degree of abnormality occurring in the rotary mechanical system (for example, whether interchange (replacement) or repair is immediately required or a follow-up is sufficient for the time being for a device in which the abnormality has occurred, etc.,) cannot be obtained. This poses problems in terms of practicality.

[0005] The present invention has been made in consideration of the above circumstances, and has as its object to provide an abnormality detection method for a rotary mechanical system which detects an abnormality in the rotary mechanical system from the state of a current signal in operation from a three-phase induction motor as a drive source for the rotary mechanical system, an abnormality monitoring method for a rotary mechanical system which uses the abnormality detection method, and an abnormality monitoring device for a rotary mechanical system which uses the

abnormality monitoring method.

#### Solution to Problem

[0006] An abnormality detection method for a rotary mechanical system according to the first aspect configured for the object is an abnormality detection method for a rotary mechanical system which detects an abnormality occurring in the rotary mechanical system using a three-phase induction motor as a drive source based on an analysis result on a current signal in operation from the three-phase induction motor, the method performing a condition surveillance (i.e. simple diagnosis) including:

- a first process of measuring a current signal in operation from the three-phase induction motor and performing fast Fourier transformation of the current signal in operation;

- a second process of extracting sideband waves (see Fig. 5) of a current spectrum peak of a power supply frequency of the three-phase induction motor, from a current spectrum obtained from the fast Fourier transformation, which are located at frequency positions respectively separated from the current spectrum peak as the center to the low frequency side and the high frequency side by a feature frequency associated with an abnormality in the rotary mechanical system, and obtaining a current spectrum peak value or current spectrum

peak values of one or both of the sideband waves;

a third process of calculating a deterioration parameter of the rotary mechanical system by using the current spectrum peak value of the sideband wave obtained in the second process and a current spectrum peak value of the power supply frequency; and

a fourth process of recording a value of the deterioration parameter and detecting an abnormality when the value of the deterioration parameter reaches a preset deterioration determination criterion upon comparison between the value of the deterioration parameter and the preset deterioration determination criterion, and the feature frequency is a rotor bar slip frequency defined as the product of the number of rotor bars of the three-phase induction motor and the slip frequency of the three-phase induction motor.

An abnormality detection method for a rotary mechanical system according to the second aspect configured for the object is an abnormality detection method for a rotary mechanical system which detects an abnormality occurring in the rotary mechanical system using a three-phase induction motor as a drive source based on an analysis result on a current signal in operation from the three-phase induction motor, the method performing a condition surveillance including:

a first process of measuring a current signal in operation from the three-phase induction motor and performing fast Fourier transformation of the current signal in operation;

a second process of extracting sideband waves of a current spectrum peak of a power supply frequency of the three-phase induction motor, from a current spectrum obtained from the fast Fourier transformation, which are located at frequency positions respectively separated from the current spectrum peak as the center to the low frequency side and the high frequency side by a feature frequency associated with an abnormality in the rotary mechanical system, and obtaining a current spectrum peak value or current spectrum peak values of one or both of the sideband waves;

a third process of calculating a deterioration parameter of the rotary mechanical system by using the current spectrum peak value of the sideband wave obtained in the second process and a current spectrum peak value of the power supply frequency; and

a fourth process of recording a value of the deterioration parameter and detecting an abnormality when the value of the deterioration parameter reaches a preset deterioration determination criterion upon comparison between the value of the deterioration parameter and the preset deterioration

determination criterion, and the feature frequency is a blade passing frequency defined as the product of the number of blades of the impeller provided in a fluid rotary machine driven by the three-phase induction motor and the actual rotation frequency of the three-phase induction motor.

An abnormality detection method for a rotary mechanical system according to the third aspect configured for the object is an abnormality detection method for a rotary mechanical system which detects an abnormality occurring in the rotary mechanical system using a three-phase induction motor as a drive source based on an analysis result on a current signal in operation from the three-phase induction motor, the method performing a condition surveillance including:

- a first process of measuring a current signal in operation from the three-phase induction motor and performing fast Fourier transformation of the current signal in operation;

- a second process of extracting sideband waves of a current spectrum peak of a power supply frequency of the three-phase induction motor, from a current spectrum obtained from the fast Fourier transformation, which are located at frequency positions respectively separated from the current spectrum peak as the center to the low frequency side and the high frequency side by a feature frequency associated with an

abnormality in the rotary mechanical system, and obtaining a current spectrum peak value or current spectrum peak values of one or both of the sideband waves;

a third process of calculating a deterioration parameter of the rotary mechanical system by using the current spectrum peak value of the sideband wave obtained in the second process and a current spectrum peak value of the power supply frequency; and

a fourth process of recording a value of the deterioration parameter and detecting an abnormality when the value of the deterioration parameter reaches a preset deterioration determination criterion upon comparison between the value of the deterioration parameter and the preset deterioration determination criterion, and the feature frequency is a gear meshing frequency defined as the product of the number of teeth of a gear attached to the rotating shaft of the rotor of the three-phase induction motor and the actual rotation frequency of the three-phase induction motor.

An abnormality detection method for a rotary mechanical system according to the fourth aspect configured for the object is an abnormality detection method for a rotary mechanical system which detects an abnormality occurring in the rotary mechanical system using a three-phase induction motor as a

drive source based on an analysis result on a current signal in operation from the three-phase induction motor, the method performing a condition surveillance including:

a first process of measuring a current signal in operation from the three-phase induction motor and performing fast Fourier transformation of the current signal in operation;

a second process of extracting sideband waves of a current spectrum peak of a power supply frequency of the three-phase induction motor, from a current spectrum obtained from the fast Fourier transformation, which are located at frequency positions respectively separated from the current spectrum peak as the center to the low frequency side and the high frequency side by a feature frequency associated with an abnormality in the rotary mechanical system, and obtaining a current spectrum peak value or current spectrum peak values of one or both of the sideband waves;

a third process of calculating a deterioration parameter of the rotary mechanical system by using the current spectrum peak value of the sideband wave obtained in the second process and a current spectrum peak value of the power supply frequency; and

a fourth process of recording a value of the deterioration parameter and detecting an abnormality when the value of the

deterioration parameter reaches a preset deterioration determination criterion upon comparison between the value of the deterioration parameter and the preset deterioration determination criterion, and the feature frequency is a gear pole frequency defined as the product of the pole passing frequency of the three-phase induction motor and the number of teeth of a gear attached to the rotating shaft of the rotor of the three-phase induction motor.

An abnormality detection method for a rotary mechanical system according to the fifth aspect configured for the object is an abnormality detection method for a rotary mechanical system which detects an abnormality occurring in the rotary mechanical system using a three-phase induction motor as a drive source based on an analysis result on a current signal in operation from the three-phase induction motor, the method performing a condition surveillance including:

a first process of measuring a current signal in operation from the three-phase induction motor and performing fast Fourier transformation of the current signal in operation;

a second process of extracting sideband waves of a current spectrum peak of a power supply frequency of the three-phase induction motor, from a current spectrum obtained from the fast Fourier transformation, which are located at frequency

positions respectively separated from the current spectrum peak as the center to the low frequency side and the high frequency side by a feature frequency associated with an abnormality in the rotary mechanical system, and obtaining a current spectrum peak value or current spectrum peak values of one or both of the sideband waves;

a third process of calculating a deterioration parameter of the rotary mechanical system by using the current spectrum peak value of the sideband wave obtained in the second process and a current spectrum peak value of the power supply frequency; and

a fourth process of recording a value of the deterioration parameter and detecting an abnormality when the value of the deterioration parameter reaches a preset deterioration determination criterion upon comparison between the value of the deterioration parameter and the preset deterioration determination criterion, and the feature frequency is a belt rotation frequency defined as the product of the movement ratio of the movement amount of a belt accompanying one rotation of a pulley attached to the rotating shaft of the rotor of the three-phase induction motor to the total length of the belt and the actual rotation frequency of the three-phase induction motor.

[0007] An abnormality monitoring method for a rotary mechanical system according to the sixth aspect configured for the object is an abnormality monitoring method for a rotary mechanical system which is obtained by one or a combination of two or more of the abnormality detection methods for the rotary mechanical system according to the first to fifth aspects, the method including:

- a deterioration trend control process of repeating the plurality of condition surveillances; and

- a condition abnormality analysis (i.e. precision abnormality diagnosis) process of specifying the type of abnormality and an abnormality location in the rotary mechanical system based on the deterioration parameter which has reached the deterioration determination criterion upon detection of at least one abnormality by the plurality of condition surveillances.

[0008] An abnormality monitoring device for a rotary mechanical system according to the seventh aspect configured for the object is an abnormality monitoring device for a rotary mechanical system which uses an abnormality monitoring method for a rotary mechanical system according to the sixth aspect, the device including:

- a deterioration parameter calculation unit configured

to obtain the deterioration parameter from a current signal in operation from the three-phase induction motor;

a condition abnormality surveillance (i.e. simple abnormality diagnosis) unit configured to compare a value of the deterioration parameter with the deterioration determination criterion while recording a value of the deterioration parameter; and

a condition abnormality analysis unit configured to specify the type of abnormality and an abnormality location in the rotary mechanical system based on the deterioration parameter which has reached the deterioration determination criterion when the condition abnormality surveillance unit detects an abnormality in the rotary mechanical system.

#### Advantageous Effects of Invention

[0009] In the abnormality detection method for the rotary mechanical system according to the first to fifth aspects of the present invention, the abnormality monitoring method for the rotary mechanical system according to the sixth aspect, and the abnormality monitoring device for the rotary mechanical system according to the seventh aspect, the value of a deterioration parameter for the rotary mechanical system is calculated by extracting, from the current spectrum obtained by fast Fourier transformation of a current signal in operation

from a three-phase induction motor as a drive source for the rotary mechanical system, sideband waves of a feature frequency associated with an abnormality in the rotary mechanical system, and the value of the deterioration parameter is compared with a deterioration determination criterion to detect an abnormality. This makes it possible to accurately specify an abnormality location (a device in which an abnormality has occurred) in the rotary mechanical system regardless of the presence/absence of theoretical knowledge about an abnormality occurring in the rotary mechanical system and the presence/absence of experience in maintenance of the rotary mechanical system.

Since an abnormal state of the rotary mechanical system is presented as the value of a deterioration parameter, it is possible to take measures corresponding to the degree of an abnormality that has occurred in the rotary mechanical system (device) (for example, whether interchange (replacement) or repair is immediately required or a follow-up is sufficient for the time being with respect to a device in which the abnormality has occurred, etc.).

#### Brief Description of Drawings

[0010] Fig. 1 is a block diagram showing an abnormality monitoring device for a rotary mechanical system according to

an embodiment of the present invention;

Fig. 2 is a graph for explaining the deterioration trend control data and estimated expected service life of a three-phase current balance  $I_{ub}$ ;

Fig. 3 is a graph for explaining the deterioration trend control data and estimated expected service life of a shaft current ratio  $L_{shaft}$ ;

Fig. 4 is a flowchart showing an abnormality detection method and abnormality monitoring method for a rotary mechanical system according to an embodiment of the present invention; and

Fig. 5 is a graph for explaining sideband waves of the current spectrum peak of a power supply frequency.

#### Description of Embodiments

[0011] Embodiments of the present invention will be described next with reference to the accompanying drawings to provide an understanding of the invention.

As shown in Fig. 1, an abnormality monitoring device 10 for a rotary mechanical system according to an embodiment of the present invention includes a deterioration parameter calculation unit 13 that obtains deterioration parameters for quantitatively evaluating the comprehensive state of a rotary mechanical system 11 and each individual state caused by the

mechanical structure of the rotary mechanical system 11 based on an analysis result on a current signal in operation from a three-phase induction motor 12 as a drive source for the rotary mechanical system 11, a condition abnormality surveillance unit 14 that records the value of a deterioration parameter and compares the value of the obtained deterioration parameter with a deterioration determination criterion, and a condition abnormality analysis unit 15 that specifies the type of abnormality and an abnormality location in the rotary mechanical system 11 based on a deterioration parameter that has reached a deterioration determination criterion when the condition abnormality surveillance unit 14 detects an abnormality in the rotary mechanical system 11. Each unit will be described in detail below.

[0012] The deterioration parameter calculation unit 13 includes a current detector 16 (for example, a clamp current sensor) that detects a current signal in operation flowing through a power cable 12a for each of three phases, which supplies power from an electric room (control panel) for the rotary mechanical system 11 to the three-phase induction motor 12, an A/D converter 17 that converts the current signal in operation measured by the current detector 16 into a digital signal, and a processing unit 18 that processes the current

signal in operation output from the A/D converter 17.

[0013] The processing unit 18 includes a current information amount calculation means 19 for calculating a current information amount KI as a deterioration parameter for comprehensively evaluating the state of the rotary mechanical system 11, a current root mean square value calculation means 20 for calculating a current root mean square value  $I_{rms}$  as a deterioration parameter for evaluating the load fluctuation status of the rotary mechanical system 11, a three-phase current balance calculation means 21 for calculating a three-phase current balance  $I_{ub}$  of a current signal in operation as a deterioration parameter for evaluating power supply quality or the deterioration status of the stator and inverter of the three-phase induction motor 12, a current single harmonic wave ratio calculation means 22 for calculating a current single harmonic wave ratio  $i_{dis}$  of a current signal in operation as a deterioration parameter for evaluating power supply quality or the deterioration status of the stator and inverter of the three-phase induction motor 12, and a current total harmonic wave ratio calculation means 23 for calculating a current total harmonic wave ratio  $I_{dis}$  of a current signal in operation as a deterioration parameter for evaluating power supply quality or the deterioration status of the stator and

inverter of the three-phase induction motor 12. In this case, the processing unit 18 is provided with a fast Fourier transformer 24 that performs fast Fourier transformation (an example of frequency analysis) of the current signal in operation output from the A/D converter 17. The spectrum data (data representing the relationship between frequency and logarithmically transformed current spectrum) output from the fast Fourier transformer 24 is input to the current single harmonic wave ratio calculation means 22 and the current total harmonic wave ratio calculation means 23.

Note that the values of the respective deterioration parameters, i.e., the current information amount  $KI$ , the current root mean square value  $I_{rms}$ , the three-phase current balance  $I_{ub}$ , the current single harmonic wave ratio  $i_{dis}$ , and current total harmonic wave ratio  $I_{dis}$ , (these deterioration parameters are generically termed type 1 deterioration parameters), each have the property of increasing with the progress of deterioration of the rotary mechanical system 11.

[0014] In this case, when an amplitude probability density distribution obtained from the waveform of a current signal in operation in the normal state is defined as a reference distribution and an amplitude probability density distribution of a current signal in operation in the monitored

state is defined as a test distribution, the current information amount calculation means 19 obtains the current information amount KI by integrating an evaluation formula given as  $f_r(x) \log[f_r(x)/f_t(x)]$ , where  $f_r(x)$  and  $f_t(x)$  are respectively the reference distribution and test distribution of current signals with an amplitude  $x$ , with respect to  $x$  in the range from  $-\infty$  to  $\infty$ . Note that as a current signal in operation in the normal state, a sinusoidal signal wave with a rated current from the three-phase induction motor 12 can be used.

The current root mean square value calculation means 20 obtains the current root mean square value  $I_{rms}$  from  $\{(i_1^2 + i_2^2 + \dots + i_N^2)/N\}^{1/2}$ , where  $i$  is the sampling value of a current signal in operation and  $N$  is the number of sampling points.

[0015] Upon simultaneously measuring three phases of currents in operation, the three-phase current balance calculation means 21 obtains the three-phase current balance  $I_{ub}$  by dividing a difference  $\max(I_u, I_v, I_w) - \min(I_u, I_v, I_w)$  between the maximum and minimum values among three-phase current root mean square values  $I_u$ ,  $I_v$ , and  $I_w$  of a current signal in operation by a sum  $\max(I_u, I_v, I_w) + \min(I_u, I_v, I_w)$  of the maximum and minimum values.

The current single harmonic wave ratio calculation means

22 obtains the current single harmonic wave ratio  $i_{dis}$  by dividing a maximum value  $maxi_n$  within a preset degree  $n$  among the harmonic root mean square values of a current signal in operation by a power supply frequency root mean square value  $I_1$  of the current signal in operation.

The current total harmonic wave ratio calculation means 23 obtains the current total harmonic wave ratio  $I_{dis}$  by dividing the square-root of the sum of squares  $(I_2^2 + I_3^2 + \dots + I_n^2)^{1/2}$  of the respective harmonic root mean square values up to the preset degree  $n$  of the current signal in operation by power supply frequency root mean square value  $I_1$  of the current signal in operation.

[0016] The processing unit 18 also includes a shaft current ratio calculation means 25 for calculating a shaft current ratio  $L_{shaft}$  as a deterioration parameter for evaluating the load status of the rotary mechanical shaft system of the rotary mechanical system 11 by using spectrum data (data representing the relationship between frequency and logarithmically transformed current spectrum) formed by logarithmically transferring the current spectrum obtained from the fast Fourier transformer 24, a pole passing current ratio calculation means 26 for calculating a pole passing current ratio  $L_{pole}$  for evaluating the deterioration status of the rotor

of the three-phase induction motor 12, a rotor slip current ratio calculation means 27 for calculating a rotor slip current ratio  $L_{rs}$  as a deterioration parameter for estimating changes in the load torque of the three-phase induction motor 12 and the actual number of rotations of the rotor, and a blade passing current ratio calculation means 28 for calculating a blade passing current ratio  $L_{bp}$  as a deterioration parameter for estimating, if the rotary mechanical system 11 driven by the three-phase induction motor 12 is a fluid rotary machine, the occurrence status of wear and corrosion to of the blade and casing provided for the fluid rotary machine.

[0017] The processing unit 18 further includes a meshing current ratio calculation means 29 for calculating a meshing current ratio  $L_{gz}$  as a deterioration parameter for estimating, if the rotary mechanical system 11 driven by the three-phase induction motor 12 is a gear device (an example of gears attached to the rotating shaft of the rotor of the three-phase induction motor 12), abnormalities such as the wear of the gears, a lubrication failure, and breakage, a gear pole current ratio calculation means 29a for calculating a gear pole current ratio  $L_{gp}$  as a deterioration parameter for estimating abnormalities such as the wear of the gears, a lubrication failure, and breakage, and a belt rotation current ratio calculation means

30 for calculating a belt rotation current ratio  $L_{br}$  as a deterioration parameter for estimating, if the rotary mechanical system 11 driven by the three-phase induction motor 12 is a pulley belt driving system (an example of pulleys attached to the rotating shaft of the rotor of the three-phase induction motor 12), pulley misalignment and a belt tension abnormality.

Note that the values of the respective deterioration parameters, i.e., the shaft current ratio  $L_{shaft}$ , the pole passing current ratio  $L_{pole}$ , the rotor slip current ratio  $L_{rs}$ , the blade passing current ratio  $L_{bp}$ , the meshing current ratio  $L_{gz}$ , the gear pole current ratio  $L_{gp}$ , and the belt rotation current ratio  $L_{br}$ , (these deterioration parameters are generically termed type 2 deterioration parameters), each have the property of decreasing with the progress of deterioration of the rotary mechanical system 11.

[0018] In this case, the shaft current ratio calculation means 25 obtains, from spectrum data, one of the peak values of sideband waves of the current spectrum peak of a power supply frequency (the current spectrum peak of a power supply fundamental frequency or the current spectrum peak of a power supply harmonic frequency), which originate from the actual rotation frequency of the three-phase induction motor 12, i.e.,

one of the peak values of the sideband waves located at frequency positions respectively separated from the current spectrum peak of the power supply frequency as the center to the low frequency side and the high frequency side by the actual rotation frequency, for example, a maximum peak height  $20\log I_{\text{shaft}}$ , and a peak height  $20\log I_{\text{line}}$  of the current spectrum peak of the power supply frequency, and then evaluates the shaft current ratio  $L_{\text{shaft}}$  as  $20\log I_{\text{line}} - 20\log I_{\text{shaft}}$ , i.e.,  $20\log(I_{\text{line}}/I_{\text{shaft}})$ . In this case,  $I_{\text{shaft}}$  and  $I_{\text{line}}$  respectively represent the peak values of the current spectra of the sideband wave originating from the actual rotation frequency output from the fast Fourier transformer 24 and the power supply frequency.

[0019] The pole passing current ratio calculation means 26 obtains, from spectrum data, one of the peak values of sideband waves of the current spectrum peak of a power supply frequency, which originate from the pole passing frequency of the three-phase induction motor 12, i.e., one of the peak values of the sideband waves located at frequency positions respectively separated from the current spectrum peak of the power supply frequency as the center to the low frequency side and the high frequency side by the pole passing frequency, for example, a maximum peak value  $20\log I_{\text{pole}}$  ( $I_{\text{pole}}$  represents the current spectrum peak value of a sideband wave originating from

the pole passing frequency output from the fast Fourier transformer 24), and the peak height  $20\log I_{line}$  of the current spectrum peak of the power supply frequency, and then evaluates the pole passing current ratio  $L_{pole}$  as  $20\log I_{line} - 20\log I_{pole}$ , i.e.,  $20\log(I_{line}/I_{pole})$ .

[0020] The rotor slip current ratio calculation means 27 obtains, from spectrum data, one of the peak values of sideband waves of the current spectrum peak of a power supply frequency, which originate from the rotor bar slip frequency of the three-phase induction motor 12, i.e., one of the peak values of the sideband waves located at frequency positions respectively separated from the current spectrum peak of the power supply frequency as the center to the low frequency side and the high frequency side by the rotor bar slip frequency, for example, a maximum peak value  $20\log I_{rs}$  ( $I_{rs}$  represents the current spectrum peak value of a sideband wave originating from the rotor bar slip frequency output from the fast Fourier transformer 24), and the peak height  $20\log I_{line}$  of the current spectrum peak of the power supply frequency, and then evaluates the rotor slip current ratio  $L_{rs}$  as  $20\log I_{line} - 20\log I_{rs}$ , i.e.,  $20\log(I_{line}/I_{rs})$ .

[0021] The blade passing current ratio calculation means 28 obtains, from spectrum data, one of the peak values of

sideband waves of the current spectrum peak of a power supply frequency, which originate from the blade passing frequency of the three-phase induction motor 12, i.e., one of the peak values of the sideband waves located at frequency positions respectively separated from the current spectrum peak of the power supply frequency as the center to the low frequency side and the high frequency side by the blade passing frequency, for example, a maximum peak value  $20\log I_{bp}$  ( $I_{bp}$  represents the current spectrum peak value of a sideband wave originating from the blade passing frequency output from the fast Fourier transformer 24), and the peak height  $20\log I_{line}$  of the current spectrum peak of the power supply frequency, and then evaluates the blade passing current ratio  $L_{bp}$  as  $20\log I_{line} - 20\log I_{bp}$ , i.e.,  $20\log(I_{line}/I_{bp})$ .

[0022] The meshing current ratio calculation means 29 obtains, from spectrum data, one of the peak values of sideband waves of the current spectrum peak of a power supply frequency, which originate from the gear meshing frequency of the three-phase induction motor 12, i.e., one of the peak values of the sideband waves located at frequency positions respectively separated from the current spectrum peak of the power supply frequency as the center to the low frequency side and the high frequency side by the gear meshing frequency, for

example, a maximum peak value  $20\log I_{gz}$  ( $I_{gz}$  represents the current spectrum peak value of a sideband wave originating from the gear meshing frequency output from the fast Fourier transformer 24), and the peak height  $20\log I_{line}$  of the current spectrum peak of the power supply frequency, and then evaluates the meshing current ratio  $L_{gz}$  as  $20\log I_{line} - 20\log I_{gz}$ , i.e.,  $20\log(I_{line}/I_{gz})$ .

In addition, the gear pole current ratio calculation means 29a obtains, from spectrum data, one of the peak values of sideband waves of the current spectrum peak of a power supply frequency, which originate from the gear pole frequency of the three-phase induction motor 12, i.e., one of the peak values of the sideband waves located at frequency positions respectively separated from the current spectrum peak of the power supply frequency as the center to the low frequency side and the high frequency side by a gear pole frequency  $f_{gp}$  defined as the product of the pole passing frequency of the three-phase induction motor 12 and the number of teeth of the gear attached to the rotating shaft of the rotor of the three-phase induction motor 12, for example, a maximum peak value  $20\log I_{gp}$  ( $I_{gp}$  represents the current spectrum peak value of a sideband wave originating from the gear pole frequency output from the fast Fourier transformer 24), and the peak height  $20\log I_{line}$  of the

current spectrum peak of the power supply frequency, and then evaluates the gear pole current ratio  $L_{gp}$  as  $20\log I_{line} - 20\log I_{gp}$ , i.e.,  $20\log(I_{line}/I_{gp})$ .

[0023] The belt rotation current ratio calculation means 30 obtains, from spectrum data, one of the peak values of sideband waves of the current spectrum peak of a power supply frequency, which originate from the belt rotation frequency of the three-phase induction motor 12, i.e., one of the peak values of the sideband waves located at frequency positions respectively separated from the current spectrum peak of the power supply frequency as the center to the low frequency side and the high frequency side by the belt rotation frequency, for example, a maximum peak value  $20\log I_{br}$  ( $I_{br}$  represents the current spectrum peak value of a sideband wave originating from the belt rotation frequency output from the fast Fourier transformer 24), and the peak height  $20\log I_{line}$  of the current spectrum peak of the power supply frequency, and then evaluates the belt rotation current ratio  $L_{br}$  as  $20\log I_{line} - 20\log I_{br}$ , i.e.,  $20\log(I_{line}/I_{br})$ .

[0024] Note that the processing unit 18 is provided with a deterioration parameter selection means 31 for activating a calculation means required to calculate a deterioration parameter selected in accordance with the mechanical structure

of the rotary mechanical system 11 from the current information amount calculation means 19, the current root mean square value calculation means 20, the three-phase current balance calculation means 21, the current single harmonic wave ratio calculation means 22, the current total harmonic wave ratio calculation means 23, the fast Fourier transformer 24, the shaft current ratio calculation means 25, the pole passing current ratio calculation means 26, the rotor slip current ratio calculation means 27, the blade passing current ratio calculation means 28, the meshing current ratio calculation means 29, the gear pole current ratio calculation means 29a, and the belt rotation current ratio calculation means 30.

[0025] The condition abnormality surveillance unit 14 includes a database 32 that stores a deterioration determination criterion used to detect an abnormality in the rotary mechanical system 11 from the value of a deterioration parameter (determine whether an abnormality has occurred) and a condition surveillance means 33 for diagnosing the state of the rotary mechanical system 11 by acquiring the value of the deterioration parameter acquired from the deterioration parameter calculation unit 13 and a deterioration determination criterion corresponding to the deterioration parameter from the database 32 and comparing them.

In this case, the deterioration determination criterion is set on the basis of, for example, a destructive test using a model rotary mechanical system assumed from the rotary mechanical system 11 or past maintenance management records. With regard to a type 1 deterioration parameter, the condition surveillance means 33 determines that an abnormality has occurred when the value of the type 1 deterioration parameter is equal to or more than a set deterioration determination criterion. In contrast to this, with regard to a type 2 deterioration parameter, the condition surveillance means 33 determines that an abnormality has occurred when the value of the type 2 deterioration parameter is equal to or less than a deterioration determination criterion.

[0026] The condition abnormality surveillance unit 14 also includes a deterioration trend control means 34 for saving (recording) the values of deterioration parameters acquired from the deterioration parameter calculation unit 13 in chronological order and a residual service life prediction means 35 for obtaining an approximate function indicating the temporal change behavior of the values of deterioration parameters (deterioration trend control data) saved in the deterioration trend control means 34 and estimating and displaying the time (expected service life) taken for the value

of a deterioration parameter to coincide with a deterioration determination criterion. Note that a danger determination criterion and a warning determination criterion are set as deterioration determination criteria for each deterioration parameter in the residual service life prediction means 35. When the value of a deterioration parameter reaches the warning determination criterion, the residual service life prediction means 35 determines that an abnormality associated with the parameter has occurred. When the value of a deterioration parameter reaches the danger determination criterion, the residual service life prediction means 35 determines that an abnormality associated with the parameter may stop or damage the rotary mechanical system 11. When the value of a deterioration parameter reaches the warning range set in advance with respect to a warning determination criterion, the residual service life prediction means 35 obtains an approximate function based on temporal change in the value of the deterioration parameter within the warning range. Fig. 2 shows the deterioration trend control data and an estimated expected service life of the three-phase current balance  $I_{ub}$ . Fig. 3 shows the deterioration trend control data and an estimated expected service life of the shaft current ratio  $L_{shaft}$ .

[0027] In this case, the warning determination criterion is set on the basis of, for example, a destructive test using a model rotary mechanical system assumed from the rotary mechanical system 11 or past maintenance management records. A warning determination criterion for type 1 deterioration parameters is set to be smaller than a danger determination criterion, and a warning determination criterion for type 2 deterioration parameters is set to be larger than a danger determination criterion. This setting makes it possible to determine that the rotary mechanical system 11 is in a normal state when the value of a deterioration parameter has not reached the warning determination criterion, to determine that the rotary mechanical system 11 is in a warning state when the value of a deterioration parameter is between the warning determination criterion and the danger determination criterion, and to determine that the rotary mechanical system 11 is in a state of danger when the value of a deterioration parameter has reached the danger determination criterion (the value of a type 1 deterioration parameter is equal to or more than the danger determination criterion, and the value of a type 2 deterioration parameter is equal to or less than the danger determination criterion).

[0028] When the condition abnormality surveillance unit

14 determines that at least one of the current root mean square value  $I_{rms}$ , the three-phase current balance  $I_{ub}$ , the current single harmonic wave ratio  $i_{dis}$ , the current total harmonic wave ratio  $I_{dis}$ , the shaft current ratio  $L_{shaft}$ , the pole passing current ratio  $L_{pole}$ , the rotor slip current ratio  $L_{rs}$ , the blade passing current ratio  $L_{bp}$ , the meshing current ratio  $L_{gz}$ , the gear pole current ratio  $L_{gp}$ , and the belt rotation current ratio  $L_{br}$  has reached the deterioration determination criterion, the condition abnormality analysis unit 15 specifies the type of abnormality and an abnormality location in the rotary mechanical system 11 on the basis of the deterioration parameter that has reached the deterioration determination criterion. When, for example, the deterioration parameter that has reached the deterioration determination criterion is the current root mean square value  $I_{rms}$ , the condition abnormality analysis unit 15 determines that a load fluctuation has occurred in the rotary mechanical system 11, whereas when the deterioration parameter that has reached the deterioration determination criterion is the three-phase current balance  $I_{ub}$ , the current single harmonic wave ratio  $i_{dis}$ , or the current total harmonic wave ratio  $I_{dis}$ , the condition abnormality analysis unit 15 determines that the quality of power supplied to the rotary mechanical system 11 or the stator of the three-phase

induction motor 12 has deteriorated.

[0029] If the deterioration parameter that has reached the deterioration determination criterion is the shaft current ratio  $L_{\text{shaft}}$ , the condition abnormality analysis unit 15 estimates that the load on the rotary mechanical shaft system of the rotary mechanical system 11 has changed. That is, an abnormality such as shaft system misalignment or unbalance may be considered.

If the deterioration parameter that has reached the deterioration determination criterion is the pole passing current ratio  $L_{\text{pole}}$ , the condition abnormality analysis unit 15 estimates that the rotor of the three-phase induction motor 12 has deteriorated. That is, an abnormality such as damage to the rotor bar may be considered. If the deterioration parameter that has reached the deterioration determination criterion is the rotor slip current ratio  $L_{\text{rs}}$ , the condition abnormality analysis unit 15 estimates that the load torque of the three-phase induction motor 12 and the actual number of rotations of the rotor have changed.

[0030] If the deterioration parameter that has reached the deterioration determination criterion is the blade passing current ratio  $L_{\text{bp}}$ , the condition abnormality analysis unit 15 estimates that wear and corrosion have occurred to the blade

and casing provided for the fluid rotary machine driven by the three-phase induction motor 12.

If the deterioration parameter that has reached the deterioration determination criterion is the meshing current ratio  $L_{gz}$  or the gear pole current ratio  $L_{gp}$ , the condition abnormality analysis unit 15 estimates abnormalities such as wear, a lubrication failure, and breakage in gears of the gear device driven by the three-phase induction motor 12. If the deterioration parameter that has reached the deterioration determination criterion is the belt rotation current ratio  $L_{br}$ , the condition abnormality analysis unit 15 estimates pulley misalignment and a belt tension abnormality in pulleys of the pulley belt driving system driven by the three-phase induction motor 12.

[0031] The abnormality monitoring method for the rotary mechanical system using the abnormality monitoring apparatus 10 of the rotary mechanical system according to an embodiment of the present invention is the abnormality monitoring method for the rotary mechanical system 11 which is obtained by combining an abnormality detection method for the rotary mechanical system which performs a condition surveillance of obtaining the value of a deterioration parameter for evaluating the comprehensive state of the rotary mechanical system 11 and

detecting an abnormality in the rotary mechanical system 11 when the value of the deterioration parameter reaches the first deterioration determination criterion (warning determination criterion) set in advance and a plurality of abnormality detection methods for a rotary mechanical system which perform a condition surveillance of obtaining values of deterioration parameters each for quantitatively evaluating an individual state caused by the mechanical structure of the rotary mechanical system 11 and detecting an abnormality in the rotary mechanical system 11 when one of the values of a deterioration parameters has reached the first deterioration determination criterion (warning determination criterion) set in advance. As shown in Fig. 4, this method includes a deterioration trend control process of repeating a plurality of condition surveillances and a condition abnormality analysis process of specifying the type of abnormality and an abnormality location in the rotary mechanical system on the basis of a parameter when an abnormality in the rotary mechanical system 11 is detected by at least one of a plurality of condition surveillances and the value of the deterioration parameter has reached the second deterioration determination criterion (danger determination criterion) set in advance. The method will be described in detail below.

[0032] (Deterioration Trend Control Process)

According to the abnormality detection method for the rotary mechanical system which performs a condition surveillance using a deterioration parameter for evaluating the comprehensive state of the rotary mechanical system 11, first, the current detector 16 of the deterioration parameter calculation unit 13 detects a current signal in operation from the three-phase induction motor 12, and the A/D converter 17 obtains a digitized current signal in operation (step S-1). The digitized current signal in operation is then input to the current information amount calculation means 19 of the processing unit 18 of the deterioration parameter calculation unit 13 to calculate the current information amount KI (step S-2). The current information amount KI is input to the condition abnormality surveillance unit 14 to compare the current information amount KI with the first and second determination criteria (the warning determination criterion and the danger determination criterion). In addition, the current information amount KI is saved in the deterioration trend control means 34, and the residual service life prediction means 35 monitors the temporal change behavior of the current information amount KI by using the saved current information amount KI (step S-3). If the current information

amount KI has not reached the second deterioration determination criterion (danger determination criterion), the condition surveillance is repeated (step S-4).

[0033] In the abnormality detection method for the rotary mechanical system which performs a condition surveillance using a deterioration parameter for evaluating an individual state caused by the mechanical structure of the rotary mechanical system 11, first, a deterioration parameter is selected on the basis of the mechanical structure of the rotary mechanical system 11. For example, if the rotary mechanical system 11 is a fluid rotary machine driven by the three-phase induction motor 12, a deterioration parameter is selected from the following: the shaft current ratio  $L_{\text{shaft}}$  for evaluating the load status of the rotary mechanical shaft system of the rotary mechanical system 11; the pole passing current ratio  $L_{\text{pole}}$  for evaluating the deterioration status of the rotor of the three-phase induction motor 12; the rotor slip current ratio  $L_{\text{rs}}$  for estimating changes in the load torque and the actual number of rotations of the three-phase induction motor 12; and the blade passing current ratio  $L_{\text{bp}}$  for estimating the occurrence status of wear and corrosion to the blade and casing provided for the fluid rotary machine.

[0034] (Abnormality Detection Method for Rotary

## Mechanical System Which Performs Condition Surveillance Using Shaft Current Ratio $L_{shaft}$ )

In the first process, as shown in Fig. 4, the current detector 16 of the deterioration parameter calculation unit 13 measures a current signal in operation from the three-phase induction motor 12, and the A/D converter 17 obtains a digitized current signal in operation (step S-1). The digitized current signal in operation is then input to the fast Fourier transformer 24 of the processing unit 18 of the deterioration parameter calculation unit 13 to perform fast Fourier transformation of the signal to obtain a current spectrum (step S-5).

[0035] In the second process, the shaft current ratio calculation means 25 receives the obtained current spectrum, extracts, from the current spectrum, sideband waves, of the current spectrum peak of a power supply frequency of the three-phase induction motor 12, which are located at frequency positions respectively separated from the current spectrum peak of the power supply frequency as the center to the low frequency side and the high frequency side by the actual rotation frequency of the three-phase induction motor 12 (an example of the feature frequency associated with an abnormality in the rotary mechanical system 11, which will be simply

referred to as "feature frequency" hereinafter), and obtains the peak value  $20\log I_{\text{shaft}}$  of the sideband wave having a higher peak. In the third process, the shaft current ratio calculation means 25 calculates the shaft current ratio  $L_{\text{shaft}}$  as  $20\log(I_{\text{line}}/I_{\text{shaft}})$  by using the peak value  $20\log I_{\text{shaft}}$  and the peak value  $20\log I_{\text{line}}$  of the current spectrum peak of the power supply frequency (step S-6).

[0036] In the fourth process, the obtained shaft current ratio  $L_{\text{shaft}}$  is recorded as a deterioration parameter in the deterioration trend control means 34, and the value of the shaft current ratio  $L_{\text{shaft}}$  is compared with the first and second deterioration determination criteria (warning determination criterion and danger determination criterion) for the shaft current ratio  $L_{\text{shaft}}$ . In addition, the residual service life prediction means 35 monitors the temporal change behavior of the shaft current ratio  $L_{\text{shaft}}$  by using the saved shaft current ratio  $L_{\text{shaft}}$  (step S-3). If the shaft current ratio  $L_{\text{shaft}}$  has not reached the second deterioration determination criterion (danger determination criterion), the condition surveillance using the shaft current ratio  $L_{\text{shaft}}$  is repeated. If the shaft current ratio  $L_{\text{shaft}}$  has reached the second deterioration determination criterion (danger determination criterion), an abnormality which has been detected by the shaft current ratio

$L_{shaft}$  is input to the condition abnormality analysis unit 15 (step S-4).

[0037] (Abnormality Detection Method for Rotary Mechanical System Which Performs Condition Surveillance Using Pole Passing Current Ratio  $L_{pole}$ )

In the first process, as shown in Fig. 4, the current detector 16 of the deterioration parameter calculation unit 13 measures a current signal in operation from the three-phase induction motor 12, and the A/D converter 17 obtains a digitized current signal in operation (step S-1). The digitized current signal in operation is then input to the fast Fourier transformer 24 of the processing unit 18 of the deterioration parameter calculation unit 13 to obtain a current spectrum (step S-5).

[0038] In the second process, the pole passing current ratio calculation means 26 receives the obtained current spectrum, extracts, from the current spectrum, sideband waves which are located at frequency positions respectively separated from the current spectrum peak of the power supply frequency of the three-phase induction motor 12 as the center to the low frequency side and the high frequency side by the pole passing frequency of the three-phase induction motor 12 (an example of a feature frequency), and obtains the peak value

20log $I_{pole}$  of the sideband wave having a higher peak. In the third process, the pole passing current ratio calculation means 26 calculates the pole passing current ratio  $L_{pole}$  as 20log( $I_{line}/I_{pole}$ ) by using the peak value 20log $I_{pole}$  and the peak value 20log $I_{line}$  of the current spectrum peak of the power supply frequency (step S-6).

[0039] In the fourth process, the obtained pole passing current ratio  $L_{pole}$  is recorded in the deterioration trend control means 34, and the value of the pole passing current ratio  $L_{pole}$  is compared with the first and second deterioration determination criteria (warning determination criterion and danger determination criterion) for the pole passing current ratio  $L_{pole}$ . In addition, the residual service life prediction means 35 monitors the temporal change behavior of the pole passing current ratio  $L_{pole}$  by using the saved pole passing current ratio  $L_{pole}$  (step S-3). If the pole passing current ratio  $L_{pole}$  has not reached the second deterioration determination criterion (danger determination criterion), the condition surveillance using the pole passing current ratio  $L_{pole}$  is repeated. If the pole passing current ratio  $L_{pole}$  has reached the second deterioration determination criterion (danger determination criterion), an abnormality which has been detected by the pole passing current ratio  $L_{pole}$  is input

to the condition abnormality analysis unit 15 (step S-4).

[0040] (Abnormality Detection Method for Rotary Mechanical System Which Performs Condition Surveillance Using Rotor Slip Current Ratio  $L_{rs}$ )

In the first process, as shown in Fig. 4, the current detector 16 of the deterioration parameter calculation unit 13 measures a current signal in operation from the three-phase induction motor 12, and the A/D converter 17 obtains a digitized current signal in operation (step S-1). The digitized current signal in operation is then input to the fast Fourier transformer 24 of the processing unit 18 of the deterioration parameter calculation unit 13 to obtain a current spectrum (step S-5).

[0041] In the second process, the rotor slip current ratio calculation means 27 receives the obtained current spectrum, extracts, from the current spectrum, sideband waves which are located at frequency positions respectively separated from the current spectrum peak of the power supply frequency of the three-phase induction motor 12 as the center to the low frequency side and the high frequency side by the rotor bar slip frequency of the three-phase induction motor 12 (an example of a feature frequency), and obtains the peak value  $I_{rs}$  of the sideband wave having a higher peak. In the third

process, the rotor slip current ratio calculation means 27 calculates the rotor slip current ratio  $L_{rs}$  as  $20\log(I_{line}/I_{rs})$  by using the peak value  $20\log I_{rs}$  and the peak value  $20\log I_{line}$  of the current spectrum peak of the power supply frequency (step S-6).

In this case, in the second process, a rotor bar slip frequency is defined as a product  $hf_s$  of a number  $h$  of rotor bars of the three-phase induction motor 12 and a slip frequency  $f_s$  of the three-phase induction motor 12 (obtained as a difference  $f_x - f_r$  between a synchronous rotation frequency  $f_x$  and an actual rotation frequency  $f_r$  of the three-phase induction motor 12).

[0042] In the fourth process, the obtained rotor slip current ratio  $L_{rs}$  is recorded in the deterioration trend control means 34, and the value of the rotor slip current ratio  $L_{rs}$  is compared with the first and second deterioration determination criteria (warning determination criterion and danger determination criterion) for the rotor slip current ratio  $L_{rs}$ . In addition, the residual service life prediction means 35 monitors the temporal change behavior of the rotor slip current ratio  $L_{rs}$  by using the rotor slip current ratio  $L_{rs}$  (step S-3). If the rotor slip current ratio  $L_{rs}$  has not reached the second deterioration determination criterion (danger determination

criterion), the condition surveillance using the rotor slip current ratio  $L_{rs}$  is repeated. If the rotor slip current ratio  $L_{rs}$  has reached the second deterioration determination criterion (danger determination criterion), an abnormality which has been detected by the rotor slip current ratio  $L_{rs}$  is input to the condition abnormality analysis unit 15 (step S-4).

[0043] (Abnormality Detection Method for Rotary Mechanical System Which Performs Condition Surveillance Using Blade Passing Current Ratio  $L_{bp}$ )

In the first process, as shown in Fig. 4, the current detector 16 of the deterioration parameter calculation unit 13 measures a current signal in operation from the three-phase induction motor 12, and the A/D converter 17 obtains a digitized current signal in operation (step S-1). The digitized current signal in operation is then input to the fast Fourier transformer 24 of the processing unit 18 of the deterioration parameter calculation unit 13 to obtain a current spectrum (step S-5).

[0044] In the second process, the blade passing current ratio calculation means 28 receives the obtained current spectrum, extracts, from the current spectrum, sideband waves which are located at frequency positions respectively separated from the current spectrum peak of the power supply

frequency of the three-phase induction motor 12 as the center to the low frequency side and the high frequency side by the blade passing frequency of the three-phase induction motor 12 (an example of a feature frequency), and obtains the peak value  $I_{bp}$  of the sideband wave having a higher peak. In the third process, the blade passing current ratio calculation means 28 calculates the blade passing current ratio  $L_{bp}$  as  $20\log(I_{line}/I_{bp})$  by using the peak value  $20\log I_{bp}$  and the peak value  $20\log I_{line}$  of the current spectrum peak of the power supply frequency (step S-6).

In this case, in the second process, a blade passing frequency is defined as a product  $mf_r$  of a number  $m$  of blades of the impeller provided for the fluid rotary machine and the actual rotation frequency  $f_r$  of the three-phase induction motor 12.

[0045] In the fourth process, the obtained blade passing current ratio  $L_{bp}$  is recorded in the deterioration trend control means 34, and the value of the blade passing current ratio  $L_{bp}$  is compared with the first and second deterioration determination criteria (warning determination criterion and danger determination criterion) for the blade passing current ratio  $L_{bp}$ . In addition, the residual service life prediction means 35 monitors the temporal change behavior of the blade

passing current ratio  $L_{bp}$  by using the saved blade passing current ratio  $L_{bp}$  (step S-3). If the blade passing current ratio  $L_{bp}$  has not reached the second deterioration determination criterion (danger determination criterion), the condition surveillance using the blade passing current ratio  $L_{bp}$  is repeated. If the blade passing current ratio  $L_{bp}$  has reached the second deterioration determination criterion (danger determination criterion), an abnormality which has been detected by the blade passing current ratio  $L_{bp}$  is input to the condition abnormality analysis unit 15 (step S-4).

[0046]           (Condition Abnormality Analysis Process)

The condition abnormality analysis unit 15 receives information concerning the deterioration parameter associated with the abnormality detected by the condition abnormality surveillance unit 14, and specifies the type of abnormality that has occurred in the rotary mechanical system 11 and an abnormality location in the rotary mechanical system 11 on the basis of the type of input deterioration parameter (step S-7). The condition abnormality analysis unit 15 displays the results, for example, on a display device (step S-8).

[0047]           In this case, if the deterioration parameter input to the condition abnormality analysis unit 15 is the shaft current ratio  $L_{shaft}$ , the condition abnormality analysis unit

15 estimates that the load on the rotary mechanical shaft system of the rotary mechanical system 11 has changed. In this case, an abnormality such as shaft system misalignment or unbalance may be considered. If the deterioration parameter is the pole passing current ratio  $L_{pole}$ , the condition abnormality analysis unit 15 estimates that the rotor of the three-phase induction motor 12 has deteriorated. In this case, an abnormality such as damage to the rotor bar may be considered. If the deterioration parameter is the rotor slip current ratio  $L_{rs}$ , the condition abnormality analysis unit 15 estimates that the load torque of the three-phase induction motor 12 and the actual number of rotations of the rotor have changed. If the deterioration parameter is the blade passing current ratio  $L_{bp}$ , the condition abnormality analysis unit 15 estimates that wear and corrosion have occurred to the blade and casing provided for the fluid rotary machine driven by the three-phase induction motor 12.

[0048] (Deterioration Trend Control Process)

In the case of a reduction gear in which the rotary mechanical system 11 is connected to the three-phase induction motor 12, the meshing current ratio  $L_{gz}$  is selected instead of the blade passing current ratio  $L_{bp}$ , and a condition surveillance using the meshing current ratio  $L_{gz}$  is performed

as an abnormality detection method for a rotary mechanical system. That is, in the first process, as shown in Fig. 4, the current detector 16 of the deterioration parameter calculation unit 13 measures a current signal in operation from the three-phase induction motor 12, and the A/D converter 17 obtains a digitized current signal in operation (step S-1). The digitized current signal in operation is then input to the fast Fourier transformer 24 of the processing unit 18 of the deterioration parameter calculation unit 13 to obtain a current spectrum (step S-5).

[0049] In the second process, the meshing current ratio calculation means 29 receives the obtained current spectrum, extracts, from the current spectrum, sideband waves which are located at frequency positions respectively separated from the current spectrum peak of the power supply frequency of the three-phase induction motor 12 as the center to the low frequency side and the high frequency side by the gear meshing frequency of the three-phase induction motor 12 (an example of a feature frequency), and obtains the peak value  $I_{gz}$  of the sideband wave having a higher peak. In the third process, the meshing current ratio calculation means 29 calculates the meshing current ratio  $L_{gz}$  as  $20\log(I_{line}/I_{gz})$  by using the peak value  $20\log I_{gz}$  and the peak value  $20\log I_{line}$  of the current

spectrum peak of the power supply frequency (step S-6).

In this case, in the second process, a gear meshing frequency is defined as a product  $zf_r$  of a number  $z$  of teeth of a gear attached to the rotating shaft of the rotor of the three-phase induction motor 12 and an actual rotation frequency  $f_r$  of the three-phase induction motor 12.

[0050] In the fourth process, the obtained meshing current ratio  $L_{gz}$  is recorded in the deterioration trend control means 34, and the value of the meshing current ratio  $L_{gz}$  is compared with the first and second deterioration determination criteria (warning determination criterion and danger determination criterion) for the meshing current ratio  $L_{gz}$ . In addition, the residual service life prediction means 35 monitors the temporal change behavior of the meshing current ratio  $L_{gz}$  by using the saved meshing current ratio  $L_{gz}$  (end of step S-3). If the meshing current ratio  $L_{gz}$  has not reached the second deterioration determination criterion (danger determination criterion), the condition surveillance using the meshing current ratio  $L_{gz}$  is repeated. If the meshing current ratio  $L_{gz}$  has reached the second deterioration determination criterion (danger determination criterion), an abnormality which has been detected by the meshing current ratio  $L_{gz}$  is input to the condition abnormality analysis unit 15 (step S-4).

[0051] (Condition Abnormality Analysis Process)

The condition abnormality analysis unit 15 receives information concerning the deterioration parameter associated with the abnormality detected by the condition abnormality surveillance unit 14, and specifies the type of abnormality that has occurred in the rotary mechanical system 11 and an abnormality location in the rotary mechanical system 11 on the basis of the type of input deterioration parameter (step S-7). The condition abnormality analysis unit 15 displays the results, for example, on a display device (step S-8).

If the deterioration parameter input to the condition abnormality analysis unit 15 is the meshing current ratio  $L_{gz}$ , the condition abnormality analysis unit 15 can estimate abnormalities such as wear, a lubrication failure, and breakage in gears of the gear device driven by the three-phase induction motor 12.

[0052] (Deterioration Trend Control Process)

In the case of a belt driving rotary machine in which the rotary mechanical system 11 is driven by the three-phase induction motor 12, the belt rotation current ratio  $L_{br}$  is selected instead of the blade passing current ratio  $L_{bp}$ , and a condition surveillance using the belt rotation current ratio  $L_{br}$  is performed as an abnormality detection method for a rotary

mechanical system.

That is, in the first process, as shown in Fig. 4, the current detector 16 of the deterioration parameter calculation unit 13 measures a current signal in operation from the three-phase induction motor 12, and the A/D converter 17 obtains a digitized current signal in operation (step S-1). The digitized current signal in operation is then input to the fast Fourier transformer 24 of the processing unit 18 of the deterioration parameter calculation unit 13 to perform fast Fourier transformation of the signal to obtain a current spectrum (step S-5).

[0053] In the second process, the belt rotation current ratio calculation means 30 receives the obtained current spectrum, extracts, from the current spectrum, sideband waves which are located at frequency positions respectively separated from the current spectrum peak of the power supply frequency of the three-phase induction motor 12 as the center to the low frequency side and the high frequency side by the belt rotation frequency of the three-phase induction motor 12 (an example of a feature frequency), and obtains the peak value  $I_{br}$  of the sideband wave having a higher peak. In the third process, the belt rotation current ratio calculation means 30 calculates the belt rotation current ratio  $L_{br}$  as

$20\log(I_{line}/I_{br})$  by using the peak value  $20\log I_{br}$  and the peak value  $20\log I_{line}$  of the current spectrum peak of the power supply frequency (step S-6).

In this case, in the second process, a belt rotation frequency is defined as the product of the movement ratio of the belt movement amount accompanying one rotation of the pulley provided for the rotating shaft of the rotor of the three-phase induction motor 12 to the total belt length and the actual rotation frequency of the three-phase induction motor 12.

[0054] In the fourth process, the obtained belt rotation current ratio  $L_{br}$  is recorded in the deterioration trend control means 34, and the value of the belt rotation current ratio  $L_{br}$  is compared with the first and second deterioration determination criteria (warning determination criterion and danger determination criterion) for the belt rotation current ratio  $L_{br}$ . In addition, the residual service life prediction means 35 monitors the temporal change behavior of the belt rotation current ratio  $L_{br}$  by using the saved belt rotation current ratio  $L_{br}$  (step S-3). If the belt rotation current ratio  $L_{br}$  has not reached the second deterioration determination criterion (danger determination criterion), the condition surveillance using the belt rotation current ratio

$L_{br}$  is repeated. If the belt rotation current ratio  $L_{br}$  has reached the second deterioration determination criterion (danger determination criterion), an abnormality which has been detected by the belt rotation current ratio  $L_{br}$  is input to the condition abnormality analysis unit 15 (step S-4).

[0055] (Condition Abnormality Analysis Process)

The condition abnormality analysis unit 15 receives information concerning the deterioration parameter associated with the abnormality detected by the condition abnormality surveillance unit 14, and specifies the type of abnormality that has occurred in the rotary mechanical system 11 and an abnormality location in the rotary mechanical system 11 on the basis of the type of input deterioration parameter (step S-7). The condition abnormality analysis unit 15 displays the results, for example, on a display device (step S-8).

If the deterioration parameter input to the condition abnormality analysis unit 15 is the belt rotation current ratio  $L_{br}$ , the condition abnormality analysis unit 15 can estimate a pulley misalignment, a belt tension abnormality and an abnormality of wear of a belt in pulleys of the pulley belt driving system driven by the three-phase induction motor 12.

[0056] The present invention has been described above with reference to the embodiment. However, the present invention

is not limited to anything of the arrangement described in the above embodiment, and includes other embodiments and modifications conceivable within the range of particulars described in the scope of the claims.

For example, the above description has exemplified the abnormality monitoring method for the rotary mechanical system which uses the online abnormality detection method for the rotary mechanical system which detects a current signal in operation from the three-phase induction motor by using the current detector of the deterioration parameter calculation unit, digitizes the signal by using the A/D converter, and inputs the signal to the deterioration parameter calculation unit. However, there is also conceivable an abnormality monitoring method for a rotary mechanical system which uses an offline abnormality detection method for a rotary mechanical system which measures and saves a current signal in operation from a three-phase induction motor and then inputs the signal to a deterioration parameter calculation unit.

[0057] The abnormality detection method for the rotary mechanical system is configured to simultaneously execute a plurality of condition surveillances using deterioration parameters for evaluating individual states caused by the mechanical structure of the rotary mechanical system. However,

this method may be executed by selecting one deterioration parameter.

The above description has also exemplified the case in which a gear meshing frequency as a feature frequency is defined as the product of the number of teeth of the gear attached to the rotating shaft of the rotor of the three-phase induction motor and the actual rotation frequency of the three-phase induction motor. However, a feature frequency may be defined as the gear pole frequency, the product of the number of teeth of the gear attached to the rotating shaft of the rotor of the three-phase induction motor and the pole passing frequency of the three-phase induction motor, and the embodiment may adopt both a gear meshing frequency and a gear pole frequency as feature frequencies.

As a deterioration parameter for evaluating an individual state caused by the mechanical structure of the rotary mechanical system, one or a combination of two or more of the current root mean square value  $I_{rms}$ , the three-phase current balance  $I_{ub}$  of a current signal in operation, the current single harmonic wave ratio  $i_{dis}$  of the current signal in operation, and the current total harmonic wave ratio  $I_{dis}$  can be added.

If an abnormality is detected by the current root mean

square value  $I_{rms}$ , it is possible to estimate that an abnormality has occurred in the load of the rotary mechanical system. If an abnormality is detected by the three-phase current balance  $I_{ub}$ , the current single harmonic wave ratio  $i_{dis}$ , or the current total harmonic wave ratio  $I_{dis}$ , it is possible to estimate that an abnormality has occurred in power supply quality or the rotor of the three-phase induction motor.

When the current spectrum peak values of both the sideband waves of the current spectrum peak of a power supply frequency are obtained, the average value of the current spectrum peak values is the current spectrum peak value of a sideband wave.

Note that even if the power supply of the three-phase induction motor is an inverter power supply, the present invention can be applied.

[0058] A current signal in operation sent to the A/D converter 17 or a digitized current signal in operation from the A/D converter 17 can be recorded in a memory to allow the processing unit of the deterioration parameter calculation unit to analyze the recorded data so as to detect an abnormality in the rotary mechanical system.

#### Industrial Applicability

[0059] The abnormality detection method for the rotary mechanical system, the abnormality monitoring method for the

rotary mechanical system using the abnormality detection method, and the apparatus therefor according to the present invention allow, even for a rotary mechanical system installed in an inaccessible place such as a place in a dangerous environment or liquid, to measure a current signal in operation via a power cable for the three-phase induction motor of an electric panel in an electric room which supplies power to the three-phase induction motor that drives the rotary mechanical system, and an examiner can monitor and detect an abnormality in the rotary mechanical system without accessing the installation place of the three-phase induction motor.

In addition, when the present invention is applied to a plurality of rotary mechanical systems, the advantages of the invention are high. Furthermore, because it is possible to detect an abnormality in the rotary mechanical system from a current signal in operation from the three-phase induction motor, which is recorded and digitized, it is possible to detect or monitor an abnormality occurring in a rotary mechanical system even from a place located far from a plant where the rotary mechanical system is installed as long as a current signal in operation from the three-phase induction motor, which is recorded and digitized, is transmitted via the Internet or the like.

## Reference Signs List

[0060] 10: Abnormality monitoring apparatus for rotary mechanical system, 11: Rotary mechanical system, 12: Three-phase induction motor, 12a: Power cable, 13: Deterioration parameter calculation unit, 14: Condition abnormality surveillance unit, 15: Condition abnormality analysis unit, 16: Current detector, 17: A/D converter, 18: Processing unit, 19: Current information amount calculation means, 20: Current root mean square value calculation means, 21: Three-phase current balance calculation means, 22: Current single harmonic wave ratio calculation means, 23: Current total harmonic wave ratio calculation means, 24: Fast Fourier transformer, 25: Shaft current ratio calculation means, 26: Pole passing current ratio calculation means, 27: Rotor slip current ratio calculation means, 28: Blade passing current ratio calculation means, 29: Meshing current ratio calculation means, 29a: Gear pole current ratio calculation means, 30: Belt rotation current ratio calculation means, 31: Deterioration parameter selection means, 32: Database, 33: Condition surveillance means, 34: Deterioration trend control means, 35: Residual service life prediction means.

## CLAIMS

1. An abnormality detection method for a rotary mechanical system which detects an abnormality occurring in the rotary mechanical system using a three-phase induction motor as a drive source based on an analysis result on a current signal in operation from the three-phase induction motor, characterized by performing a condition surveillance including:

a first process of measuring a current signal in operation from the three-phase induction motor and performing fast Fourier transformation of the current signal in operation;

a second process of extracting sideband waves of a current spectrum peak of a power supply frequency of the three-phase induction motor, from a current spectrum obtained from the fast Fourier transformation, which are located at frequency positions respectively separated from the current spectrum peak as a center to the low frequency side and the high frequency side by a feature frequency associated with an abnormality in the rotary mechanical system, and obtaining a current spectrum peak value or current spectrum peak values of one or both of the sideband waves;

a third process of calculating a deterioration parameter of the rotary mechanical system by using the current spectrum peak value of the sideband wave obtained in the second process and a current spectrum peak value of the power supply frequency; and

a fourth process of recording a value of the deterioration parameter and detecting an abnormality when the value of the deterioration parameter reaches a preset deterioration determination criterion upon comparison between the value of the deterioration parameter and the deterioration determination criterion,

further characterized in that the feature frequency is a rotor bar slip frequency defined as a product of a number of rotor bars of the three-phase induction motor and a slip frequency of the three-phase induction motor.

2. An abnormality detection method for a rotary mechanical system which detects an abnormality occurring in the rotary mechanical system using a three-phase induction motor as a drive source based on an analysis result on a current signal in operation from the three-phase induction motor, characterized by performing a condition surveillance including:

a first process of measuring a current signal in

operation from the three-phase induction motor and performing fast Fourier transformation of the current signal in operation;

a second process of extracting sideband waves of a current spectrum peak of a power supply frequency of the three-phase induction motor, from a current spectrum obtained from the fast Fourier transformation, which are located at frequency positions respectively separated from the current spectrum peak as a center to the low frequency side and the high frequency side by a feature frequency associated with an abnormality in the rotary mechanical system, and obtaining a current spectrum peak value or current spectrum peak values of one or both of the sideband waves;

a third process of calculating a deterioration parameter of the rotary mechanical system by using the current spectrum peak value of the sideband wave obtained in the second process and a current spectrum peak value of the power supply frequency; and

a fourth process of recording a value of the deterioration parameter and detecting an abnormality when the value of the deterioration parameter reaches a preset deterioration determination criterion upon comparison

between the value of the deterioration parameter and the deterioration determination criterion,

further characterized in that the feature frequency is a blade passing frequency defined as a product of a number of blades provided for a fluid rotary machine driven by the three-phase induction motor and an actual rotation frequency of the three-phase induction motor.

3. An abnormality detection method for a rotary mechanical system which detects an abnormality occurring in the rotary mechanical system using a three-phase induction motor as a drive source based on an analysis result on a current signal in operation from the three-phase induction motor, characterized by performing a condition surveillance including:

a first process of measuring a current signal in operation from the three-phase induction motor and performing fast Fourier transformation of the current signal in operation;

a second process of extracting sideband waves of a current spectrum peak of a power supply frequency of the three-phase induction motor, from a current spectrum obtained from the fast Fourier transformation, which are located at frequency positions respectively separated from

the current spectrum peak as a center to the low frequency side and the high frequency side by a feature frequency associated with an abnormality in the rotary mechanical system, and obtaining a current spectrum peak value or current spectrum peak values of one or both of the sideband waves;

a third process of calculating a deterioration parameter of the rotary mechanical system by using the current spectrum peak value of the sideband wave obtained in the second process and a current spectrum peak value of the power supply frequency; and

a fourth process of recording a value of the deterioration parameter and detecting an abnormality when the value of the deterioration parameter reaches a preset deterioration determination criterion upon comparison between the value of the deterioration parameter and the deterioration determination criterion,

further characterized in that the feature frequency is a gear meshing frequency defined as a product of a number of teeth of a gear attached to a rotating shaft of a rotor of the three-phase induction motor and an actual rotation frequency of the three-phase induction motor.

4. An abnormality detection method for a rotary

mechanical system which detects an abnormality occurring in the rotary mechanical system using a three-phase induction motor as a drive source based on an analysis result on a current signal in operation from the three-phase induction motor, characterized by performing a condition surveillance including:

- a first process of measuring a current signal in operation from the three-phase induction motor and performing fast Fourier transformation of the current signal in operation;

- a second process of extracting sideband waves of a current spectrum peak of a power supply frequency of the three-phase induction motor, from a current spectrum obtained from the fast Fourier transformation, which are located at frequency positions respectively separated from the current spectrum peak as a center to the low frequency side and the high frequency side by a feature frequency associated with an abnormality in the rotary mechanical system, and obtaining a current spectrum peak value or current spectrum peak values of one or both of the sideband waves;

- a third process of calculating a deterioration parameter of the rotary mechanical system by using the

current spectrum peak value of the sideband wave obtained in the second process and a current spectrum peak value of the power supply frequency; and

a fourth process of recording a value of the deterioration parameter and detecting an abnormality when the value of the deterioration parameter reaches a preset deterioration determination criterion upon comparison between the value of the deterioration parameter and the deterioration determination criterion,

further characterized in that the feature frequency is a gear pole frequency defined as a product of a pole passing frequency of the three-phase induction motor and a number of teeth of a gear attached to a rotating shaft of a rotor of the three-phase induction motor.

5. An abnormality detection method for a rotary mechanical system which detects an abnormality occurring in the rotary mechanical system using a three-phase induction motor as a drive source based on an analysis result on a current signal in operation from the three-phase induction motor, characterized by performing a condition surveillance including:

a first process of measuring a current signal in operation from the three-phase induction motor and

performing fast Fourier transformation of the current signal in operation;

a second process of extracting sideband waves of a current spectrum peak of a power supply frequency of the three-phase induction motor, from a current spectrum obtained from the fast Fourier transformation, which are located at frequency positions respectively separated from the current spectrum peak as a center to the low frequency side and the high frequency side by a feature frequency associated with an abnormality in the rotary mechanical system, and obtaining a current spectrum peak value or current spectrum peak values of one or both of the sideband waves;

a third process of calculating a deterioration parameter of the rotary mechanical system by using the current spectrum peak value of the sideband wave obtained in the second process and a current spectrum peak value of the power supply frequency; and

a fourth process of recording a value of the deterioration parameter and detecting an abnormality when the value of the deterioration parameter reaches a preset deterioration determination criterion upon comparison between the value of the deterioration parameter and the

deterioration determination criterion,

further characterized in that the feature frequency is a belt rotation frequency defined as a product of a movement ratio of a movement amount of a belt accompanying one rotation of a pulley attached to a rotating shaft of a rotor of the three-phase induction motor to a total length of the belt and an actual rotation frequency of the three-phase induction motor.

6. An abnormality monitoring method for a rotary mechanical system which is obtained by one or a combination of not less than two of abnormality detection methods for a rotary mechanical system defined in claims 1 to 5, characterized by comprising:

a deterioration trend control process of repeating the plurality of condition surveillances; and

a condition abnormality analysis process of specifying a type of abnormality and an abnormality location in the rotary mechanical system based on the deterioration parameter which has reached the deterioration determination criterion upon detection of at least one abnormality by the plurality of condition surveillances.

7. An abnormality monitoring device for a rotary mechanical system which is used for an abnormality

monitoring method for a rotary mechanical system defined in claim 6, characterized by comprising:

- a deterioration parameter calculation unit configured to obtain the deterioration parameter from a current signal in operation from the three-phase induction motor;

- a condition abnormality surveillance unit configured to compare a value of the deterioration parameter with the deterioration determination criterion while recording a value of the deterioration parameter; and

- a condition abnormality analysis unit configured to specify a type of abnormality and an abnormality location in the rotary mechanical system based on the deterioration parameter which has reached the deterioration determination criterion when the condition abnormality surveillance unit detects an abnormality in the rotary mechanical system.