

DESCRIPTION

Title of Invention: FLUID SYSTEM ABNORMALITY MONITORING AND DIAGNOSIS METHOD FOR FLUID ROTARY MACHINE

Technical Field

[0001] The present invention is related to a method for monitoring and diagnosing a fluidic system abnormality in a fluid rotary machine, in which a fluidic system abnormality in a fluid rotary machine is diagnosed by measuring and analyzing current signals (the current waveform) of an induction motor that drives the fluid rotary machine.

Background Art

[0002] For diagnosing a mechanical system abnormality, e.g., an abnormality of a bearing, a meshing abnormality of gears, deviation (misalignment) of the shaft center, and slackness or wear of a belt, in a motor or in various rotary machines each driven by a motor such as a pump and a speed reducer (a gear device), methods and apparatuses using vibration as the measurement parameter have been conventionally used for the reason that the diagnosing accuracy is high. However, depending on the position or environment the rotary machine is installed in, in some cases, it is too difficult to install a vibration sensor or the like, or too difficult to measure the vibration as people cannot easily approach the rotary machine. To cope with this, as a method and an apparatus, with no need of installing the sensor or the like on the site, for obtaining necessary data and conducting a diagnosis from somewhere away from the site such as an electric room, there have been suggested methods and apparatuses for diagnosing the current, as in, e.g., patent literatures 1 to 4, in which condition monitoring (i.e. an abnormality detection) for various rotary machines is carried out by analyzing the current signals of the motor.

Citation List

Patent Literature

[0003]

Patent Literature 1: Japanese Patent No. 4782218

Patent Literature 2: Japanese Patent No. 5733913

Patent Literature 3: Japanese Patent No. 6293388

Patent Literature 4: Japanese Patent No. 6410572

Summary of Invention

Technical Problem

[0004] In patent literatures 1 to 3, motors and rotary machines (loading equipment) each driven by a motor are subject to the diagnoses, and the rotary machines in here include the fluid rotary machines such as a pump, a blower (an air blower), and a compressor. However, what are diagnosed in patent literatures 1 to 3 are only the mechanical system abnormalities such as aforementioned, and diagnosing a fluidic system abnormality such as cavitation in a pump, and surge or rotating stall in a blower or a compressor is not expected.

While, patent literature 4 contains detecting a fluid abnormality in a loading device such as a pump (i.e. a fluid rotary machine) in addition to the mechanical system abnormality (i.e. a rotary system abnormality) similar to patent literatures 1 to 3. The fluid abnormality in here means an abnormality of the loading device, which can occur through the fluid, such as turbulence in the fluid caused by air entered the fluid in the pump. More concretely, entrainment of air from a valve or a flange is expected, but detecting a phenomenon such as the cavitation or the surge (i.e. a fluidic system abnormality) is not mentioned. Also, in patent literature 4, the abnormality is determined by dividing a spectrum of the result of a frequency analysis for a measured current waveform by a spectrum at a normal time to calculate the multiplying ratio, and

collating the multiplying ratio and a preset determining criterion. Thus, for diagnosing, the spectrum of the current waveform at the normal time has to be obtained and memorized in advance. Besides, since the influences of a fluidic system abnormality such as the cavitation and the surge on the current waveform is complicating, there is a possibility of overlooking the occurrence (or a sign) of such a fluidic system abnormality just by the aforementioned multiplying ratio of the spectrum.

From the above, a monitoring and diagnosing method that is effective for detecting a fluidic system abnormality such as the cavitation and the surge occurring in a fluid rotary machine has been desired to be established.

The present invention has been made in consideration of the above circumstances, and has as its object to provide a method for monitoring and diagnosing a fluidic system abnormality in a fluid rotary machine, with which a sign of a fluidic system abnormality occurring in the fluid rotary machine including the cavitation and the surge is reliably detected by monitoring and analyzing the current signals of an induction motor driving the fluid rotary machine, a deterioration trend of the fluid rotary machine is managed, and an appropriate maintenance can be provided.

Solution to Problem

[0005] In order to achieve the above object, according to the present invention, there is provided a method for monitoring and diagnosing a fluidic system abnormality in a fluid rotary machine used to detect a fluidic system abnormality occurring in a fluid rotary machine driven by an induction motor, in which the fluidic system abnormality is detected by analyzing and comparing: a criterial sine-wave signal waveform obtained from a rated current value of the induction motor to be diagnosed, and an at-diagnosis current waveform acquired by measuring a current of the induction motor during operation (i.e. when diagnosing).

In here, the induction motor may be a three-phase induction motor or be a

single-phase induction motor.

[0006] The method for monitoring and diagnosing a fluidic system abnormality in a fluid rotary machine according to the present invention includes:

measuring a current of the induction motor when diagnosing to acquire an at-diagnosis current waveform;

conducting a frequency analysis on the at-diagnosis current waveform to obtain a power-supply frequency of the induction motor;

calculating a value of a kurtosis β based on a spectral group within a predetermined range including the power-supply frequency of the induction motor by using an equation (1) and an equation (2) below; and

determining that there is a possibility that the fluidic system abnormality is occurring when the value of the kurtosis β is smaller than a preset criterial kurtosis or has a tendency to decrease with the lapse of time.

[0007] [Math. 1]

$$\beta = \frac{\left\{ \sum_{i=1}^N \frac{(x_i - x_{avg})^4}{N-1} \right\}}{x_{rms}^4} \quad \cdot \cdot \cdot (1)$$

[0008] [Math. 2]

$$x_{rms} = \sqrt{\frac{\sum_{i=1}^N (x_i - x_{avg})^2}{N-1}} \quad \cdot \cdot \cdot (2)$$

[0009] In here, x_i is an i-th data of N-number of data distributed within the predetermined range including the power-supply frequency, x_{avg} is an average value of the N-number of data, and x_{rms} is an unbiased standard deviation of the N-number of

data.

[0010] In the method for monitoring and diagnosing a fluidic system abnormality in a fluid rotary machine according to the present invention, it is preferred that the fluidic system abnormality be any of cavitation in a pump, and surge or rotating stall in a blower or a compressor.

[0011] In the method for monitoring and diagnosing a fluidic system abnormality in a fluid rotary machine according to the present invention, it is preferred that when a value of KI (Kullback-Leibler Information), which is calculated by using an equation (3) below from: a reference amplitude probability density function $f_r(x)$ obtained from the criterial sine-wave signal waveform; and an at-diagnosis amplitude probability density function $f_t(x)$ obtained from the at-diagnosis current waveform, becomes larger than a preset criterial KI value, the kurtosis β be calculated and whether or not there is an occurrence of the fluidic system abnormality be determined by using the calculated kurtosis β .

[0012] [Math. 3]

$$K I = \int_{-\infty}^{\infty} f_r(x) \log \frac{f_r(x)}{f_t(x)} dx \quad \cdot \cdot \cdot (3)$$

[0013] In the method for monitoring and diagnosing a fluidic system abnormality in a fluid rotary machine according to the present invention, when the induction motor is a three-phase induction motor, it is preferred to conduct the current measurement on all the three phases; however, the current measurement also may be conducted on any one of the three phases.

Conducting the current measurement on all the three phases in here allows the balance of the three phases to be checked as well, and the accuracy of the abnormality detection to improve.

While, by conducting the current measurement on only any one phase instead

of all the three phases for one three-phase induction motor, the current measurement can be conducted on three three-phase induction motors at once, and the fluidic system abnormalities in three fluid rotary machines each driven by one of the three three-phase induction motors can be monitored and detected at the same time.

Advantageous Effects of Invention

[0014] Since the method for monitoring and diagnosing a fluidic system abnormality in a fluid rotary machine according to the present invention is capable of detecting a fluidic system abnormality by comparing: the criterial sine-wave signal waveform obtained from the rated current value of the induction motor to be diagnosed; and the at-diagnosis current waveform acquired by measuring the current of the induction motor when diagnosing, the occurring status of a fluidic system abnormality in the fluid rotary machine can be monitored in a state where the fluid rotary machine is being driven by the induction motor. When there is a possibility that a fluidic system abnormality is occurring, by conducting a more detailed (more precise) inspection or the like, the fluid rotary machine can be maintained in a normal state. Therefore, it is excellent in reliability of detecting a fluidic system abnormality in a fluid rotary machine, and in maintenance efficiency of a fluid rotary machine.

Brief Description of Drawings

[0015]

Fig. 1 is an explanatory diagram illustrating the method for monitoring and diagnosing a fluidic system abnormality in a fluid rotary machine according to an embodiment of the present invention.

Fig. 2(A) illustrates a current spectrum of a three-phase induction motor when it is driving a pump that is in a normal state.

Fig. 2(B) illustrates a current spectrum of a three-phase induction motor when

it is driving a pump that is in a state where cavitation is occurring.

Description of Embodiment

[0016] The embodiment of the present invention will be explained next with reference to the accompanying drawings to provide an understanding of the present invention.

The method for monitoring and diagnosing a fluidic system abnormality in a fluid rotary machine according to the embodiment of the present invention is for detecting occurrence of cavitation (an example of the fluidic system abnormality) in a pump (an example of the fluid rotary machine) 11 driven by a three-phase induction motor (an example of the induction motor) 10 shown in Fig. 1.

[0017] As shown in Fig. 1, the three-phase induction motor 10 is supplied with power by a power supply 14 and drives the pump 11. When the pump 11 is in a normal state (i.e. in a state with no fluidic system abnormality occurring), the flow inside the pump 11 is steady, the load to the three-phase induction motor 10 is also steady and enters a steady state, and the peak value of the current flowing through each stator and the rotational frequency of the rotor each become constant (a constant). Thus, if the time series data of the current acquired by measuring the current of one of three phases of the three-phase induction motor 10 at this time is subject to the fast Fourier transformation to obtain the current spectrum, the obtained current spectrum becomes as shown in Fig. 2(A). As shown in the upper part of Fig. 2(A), at before and after the power-supply frequency (60 Hz in this case) of the three-phase induction motor 10 (i.e. in the range surrounded by the ellipse), the spectral peak of the power-supply frequency clearly protrudes from the spectral peaks around the spectral peak of the power-supply frequency. Also, in a higher harmonic region of the power-supply frequency shown in the lower part of Fig. 2(A), the higher harmonic spectral peaks clearly protrude. Incidentally, this tendency is also the case with the currents of the other two phases.

[0018] In contrast, in a state where cavitation is occurring in the pump 11, the fluid

flow inside the pump 11 becomes unstable, and the load to the three-phase induction motor 10 enters an unsteady state. Due to the unsteady state (i.e. fluctuation) of the load, the magnetic field inside the three-phase induction motor 10 becomes disturbed, and the disturbance in the magnetic field affects the coil of each stator and excites a weak back electromotive force. As a result, amplitude modulation of the current flowing through each stator and frequency modulation of the rotor occur, and the peak value of the current flowing through each stator and the rotation frequency of the rotor become unsteady (time variables). Thus, if the time series data of the current acquired by measuring the current of one of the three phases of the three-phase induction motor 10 at this time is subject to the fast Fourier transformation to obtain the current spectrum, the obtained current spectrum becomes as shown in Fig. 2(B). As shown in the upper part of Fig. 2(B), at before and after the power-supply frequency (60 Hz in this case) of the three-phase induction motor 10 (i.e. in the range surrounded by the ellipse), the spectral peak of the power-supply frequency reduces, there becomes no protruding peak in a spectral group around the spectral peak of the power-supply frequency, and the entire spectral group becomes to have a swollen shape. Also, in the higher harmonic region of the power-supply frequency shown in the lower part of Fig. 2(B), a similar tendency can be seen. Incidentally, this tendency is also the case with the currents of the other two phases.

[0019] From the aforementioned, a fluidic system abnormality in the pump 11 can be detected by analyzing and comparing: the criterial sine-wave signal waveform obtained from the rated current value of the three-phase induction motor 10 to be diagnosed, and the at-diagnosis current waveform acquired by measuring the current of the three-phase induction motor 10 when diagnosing. At this time, the current flowing through each stator can be easily measured by connecting, e.g., a clamp-type current detector 16 to each of the three power lines 15 that connect the power supply 14 and the three-phase induction motor 10 (i.e. each stator). Although a higher accuracy diagnosis can be

carried out when the currents of all the three phases are measured, a diagnosis can be carried out as well even by only measuring the current of any one of the three phases. An analog current waveform measured by the current detector 16 is converted to a digital current data by an A/D converter (not shown in the figures), and processed by a processing unit (not shown in the figures). The processing unit is composed of a conventionally-known computing unit (i.e. a computer) including a RAM, a CPU, a ROM, I/O devices, and buses connecting these elements. The process by the processing unit is carried out by conducting a predetermined program with the CPU. Incidentally, transmission of the current data from the A/D converter to the processing unit can be done by using a LAN, a USB cable, or the like, and the installing place of the processing unit may be selected as appropriate. Also, the installing place and number of monitors for displaying the diagnosis from the processing unit may be selected as appropriate, and the diagnosis can be checked also from a remote place by using the LAN. Moreover, by using a cloud environment, a plurality of workers and administrators can share the measured data and the diagnosis processed by the processing unit.

[0020] The method for monitoring and diagnosing a fluidic system abnormality in a fluid rotary machine according to the present invention is applied in order to carry out a diagnosis of a fluidic system abnormality simply and quantitatively. The details of the method for monitoring and diagnosing a fluidic system abnormality in a fluid rotary machine according to this embodiment (hereinafter also simply referred to as the method for monitoring and diagnosing a fluidic system abnormality) will be explained below. Note that, in here, the diagnosis is carried out while focusing only on the current of one of the three phases of the three-phase induction motor 10 (i.e. the current flowing through one of the stators).

First, the reference amplitude probability density function $fr(x)$ is obtained from the criterial sine-wave signal waveform obtained from the rated current value of

the three-phase induction motor 10 and is stored in a memorizing means (a RAM or a ROM) (a first step). The criterial sine-wave signal waveform is a non-distorted waveform of the rated current that vibrates at the power-supply frequency (in here, 60 Hz).

[0021] Next, the at-diagnosis current waveform acquired by measuring the current of one of the three phases of the three-phase induction motor 10 during operation (i.e. when diagnosing) is A/D-converted and transmitted to the processing unit, and from a plurality of point data acquired during a predetermined sampling time, the at-diagnosis amplitude probability density function $f_t(x)$ is obtained and is stored in the memorizing means (a second step).

Incidentally, the measuring time (the sampling time) of the current in the second step is, e.g., approximately 8 to 16 seconds.

An amplitude probability density function (such as the reference amplitude probability density function and the at-diagnosis amplitude probability density function) is for obtaining the probability that a fluctuating signal exists at a specific amplitude level, and also for analyzing how much fluctuation is occurring around which amplitude level.

[0022] Next, KI is calculated from the reference amplitude probability density function $f_r(x)$ and the at-diagnosis amplitude probability density function $f_t(x)$ by using the aforementioned equation (3) (a third step).

[0023] Then, when the value of KI calculated by using the equation (3) becomes larger than a preset criterial KI value, it is determined that there is a possibility that a fluidic system abnormality is occurring in the pump 11 (a fourth step). At this time, it may be so made as to set a first criterial KI value and a second criterial KI value in advance, to call attention when the calculated KI value approaches the first criterial KI value (e.g. 0.5), and to warn that there is a danger when the calculated KI value approaches the

second criterial KI value (e.g. 1). These notifications may be displayed on the monitor or may be emailed to the administrator or the like.

[0024] Also, since the value of KI that changes with the lapse of time is revealed by doing the second and third steps repeatedly at predetermined time intervals, when the KI value shows the tendency to increase as time lapses, it can be determined that there is a possibility that a fluidic system abnormality is occurring in the pump 11. In this case, the deterioration trend of the pump 11 can be figured out even before the value of KI reaches the criterial KI value (i.e. the first or second criterial KI value), and it allows the pump 11 to receive maintenance before it is severely damaged by the fluidic system abnormality.

In cases where the value of KI that changes with the lapse of time is made into a graph and is displayed on the monitor, it becomes easy for the administrator to visually check the deterioration trend (i.e. a sign of a fluidic system abnormality) of the pump, and it is excellent in simplicity and reliability of the deterioration trend management.

[0025] Next, the power-supply frequency of the three-phase induction motor 10 is obtained by conducting a frequency analysis on the at-diagnosis current waveform acquired by measuring the current of the three-phase induction motor 10 when diagnosing. The frequency analysis on the at-diagnosis current waveform is carried out with a conventionally-known method, in which after a filtering process is conducted with respect to the sampled at-diagnosis current waveform (a time series data of the current) on an as-needed basis, the at-diagnosis current waveform becomes subject to the fast Fourier transformation to acquire the current spectrum. The power-supply frequency (in here, 60 Hz) is obtained from the peaks of the current spectrum (refer to the graph in the upper part of Fig. 2(B)), the kurtosis β of a spectral group within a predetermined range including the power-supply frequency (e.g. a predetermined region having the power-supply frequency in the middle) is calculated by using the

aforementioned equations (1) and (2). In here, x_i is an i -th data of N -number of data distributed within the predetermined range including the power-supply frequency, x_{avg} is an average value of the N -number of data, and x_{rms} is an unbiased standard deviation of the N -number of data (a fifth step).

[0026] At a normal time, since the spectral peak at the power-supply frequency is sharp (refer to the graph in the upper part of Fig. 2(A)) in the predetermined region including the power-supply frequency (i.e. in the N -number of data), the value of the kurtosis β becomes large. While, when a fluidic system abnormality occurs in the pump 11 and the fluid flow inside the pump 11 becomes unstable (unsteady), the spectral peak at the power-supply frequency decreases, there becomes no protruding peak in the spectral group around the spectral peak at the power-supply frequency (the predetermined region of before and after the power-supply frequency), and the entire spectral group becomes to have a swollen shape (refer to the graph in the upper part of Fig. 2(B)), and thus, the value of the kurtosis β becomes small.

Therefore, when the value of the kurtosis β calculated by the equation (1) is smaller than the preset criterial kurtosis or has a tendency to decrease with the lapse of time, it can be determined that there is a possibility that a fluidic system abnormality is occurring in the pump 11 (a sixth step). At this time, it may be so made as to set a first criterial kurtosis and a second criterial kurtosis in advance, to call attention when the calculated value of the kurtosis β approaches the first criterial kurtosis (e.g. 80% of the kurtosis at the normal time), and to warn that there is a danger when the calculated value of the kurtosis β approaches the second criterial kurtosis (e.g. 70% of the kurtosis at the normal time). These notifications may be displayed on the monitor or may be emailed to the administrator or the like.

[0027] Also, since the value of the kurtosis β that changes with the lapse of time is revealed by doing the fifth step repeatedly at predetermined time intervals, when the value of the kurtosis β shows a tendency to decrease as time lapses, it can be determined

that there is a possibility that a fluidic system abnormality is occurring in the pump 11. In this case, the deterioration trend of the pump 11 can be figured out even before the value of the kurtosis β reaches the criterial kurtosis (i.e. the first or second criterial kurtosis), and it allows the pump 11 to receive maintenance before it is severely damaged by the fluidic system abnormality.

In cases where the value of the kurtosis β that changes with the lapse of time is made into a graph and is displayed on the monitor, it becomes easy for the administrator to visually check the deterioration trend (i.e. a sign of a fluidic system abnormality) of the pump, and it is excellent in simplicity and reliability of the deterioration trend management.

[0028] Especially by using KI and the kurtosis β together as the parameters for detecting a fluidic system abnormality and determining that there is a possibility that a fluidic system abnormality is occurring when the KI value is larger than a predetermined criterial KI value or has a tendency to increase with the lapse of time and the value of the kurtosis β is smaller than a predetermined criterial kurtosis or has a tendency to decrease with the lapse of time, a high accuracy diagnosis can be carried out.

Besides, the method for monitoring and diagnosing a fluidic system abnormality does not require approaching the pump 11 to be diagnosed, and the monitoring and diagnosing can be done from an electric room, near a control board (i.e. electric board), or an office or the like away (remote) from the site, thereby being excellent in work efficiency.

[0029] The present invention has been described above with reference to the embodiment. However, the present invention is not limited to the structures described in the above embodiment, and the present invention includes other embodiments and modifications conceivable within the scope of the matters described in the scope of the

claims.

For example, although the above embodiment deals with the pump as the fluid rotary machine and the cavitation as the fluidic system abnormality, the fluid rotary machine may be a blower (an air blower), a compressor, or the like, and the fluidic system abnormality may be surge, rotating stall, or the like.

Also, in the above embodiment, the case of diagnosing by measuring the current of only one of the three phases of the three-phase induction motor has been explained. However, for diagnosis, the currents of all the three phases may be measured and the same analysis may be conducted to each phase. In this case, a comprehensive judgment including the balance among the three phases can be made, thereby enhancing the diagnosing accuracy. Thus, depending on how important the device to be diagnosed is, on the number of years during which the device has been used, or on something else, the number of phases to be measured may be selected. Moreover, the method for monitoring and diagnosing a fluidic system abnormality is also applicable to a fluid rotary machine driven by a single-phase induction motor instead of a three-phase induction motor.

Note that determining a fluidic system abnormality can be also carried out based only on the value of the kurtosis β , i.e., without determining a fluidic system abnormality based on the KI value.

Industrial Applicability

[0030] The method for monitoring and diagnosing a fluidic system abnormality in a fluid rotary machine according to the present invention enables to reliably detect a sign of a fluidic system abnormality occurring in a fluid rotary machine, for example, cavitation in a pump, surge or rotating stall in a blower or a compressor, or the like, in a state where the fluid rotary machine is driven by an induction motor. This makes it possible to manage the deterioration trend of the fluid rotary machine and provide an

appropriate maintenance to the fluid rotary machine. Further, since there is no need to approach the fluid rotary machine to be diagnosed and the monitoring and diagnosing can be done from an electric room, near a control board, or an office or the like away (remote) from the site, it is excellent in work efficiency.

Reference Signs List

[0031] 10: three-phase induction motor (induction motor), 11: pump (fluid rotary machine), 14: power supply, 15: power line, 16: current detector

CLAIMS

1. A method for monitoring and diagnosing a fluidic system abnormality in a fluid rotary machine used to detect a fluidic system abnormality occurring in a fluid rotary machine driven by an induction motor, comprising:

measuring a current of the induction motor when diagnosing to acquire an at-diagnosis current waveform;

conducting a frequency analysis on the at-diagnosis current waveform to obtain a power-supply frequency of the induction motor;

calculating a value of a kurtosis β based on a spectral group within a predetermined range including the power-supply frequency of the induction motor by using an equation (1) and an equation (2) below; and

determining that there is a possibility that the fluidic system abnormality is occurring when the value of the kurtosis β is smaller than a preset criterial kurtosis or has a tendency to decrease with the lapse of time,

[Math. 1]

$$\beta = \frac{\left\{ \sum_{i=1}^N \frac{(x_i - x_{avg})^4}{N-1} \right\}}{x_{rms}^4} \quad \cdot \cdot \cdot (1)$$

[Math. 2]

$$x_{rms} = \sqrt{\frac{\sum_{i=1}^N (x_i - x_{avg})^2}{N-1}} \quad \cdot \cdot \cdot (2)$$

wherein x_i is an i -th data of N -number of data distributed within the predetermined range including the power-supply frequency, x_{avg} is an average value of

the N-number of data, and xrms is an unbiased standard deviation of the N-number of data.

2. The method for monitoring and diagnosing a fluidic system abnormality in a fluid rotary machine set forth in claim 1, wherein the fluidic system abnormality is any of cavitation in a pump, and surge or rotating stall in a blower or a compressor.

3. The method for monitoring and diagnosing a fluidic system abnormality in a fluid rotary machine set forth in either claim 1 or 2, wherein a value of KI is calculated, by using an equation (3) below, from:

a reference amplitude probability density function $f_r(x)$ obtained from a criterial sine-wave signal waveform obtained from a rated current value of the induction motor; and

an at-diagnosis amplitude probability density function $f_t(x)$ obtained from the at-diagnosis current waveform acquired by measuring the current of the induction motor during operation, and

when the value of KI becomes larger than a preset criterial KI value, the kurtosis β is calculated and whether or not there is an occurrence of the fluidic system abnormality is determined by using the calculated kurtosis β .

[Math. 3]

$$K I = \int_{-\infty}^{\infty} f_r(x) \log \frac{f_r(x)}{f_t(x)} dx \quad \cdot \cdot \cdot (3)$$