(19) **DANMARK**

(10) **DK/EP 2952860 T3**

Patent- og
Varemærkestyrelsen

(12)

Oversættelse af europæisk patentskrift

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(51) Int.Cl.: ***G 01 H 1/00 (2006.01)***

(45) Oversættelsen bekendtgjort den: **2019-11-04**

(80) Dato for Den Europæiske Patentmyndigheds
bekendtgørelse om meddelelse af patentet: **2019-07-31**

(86) Europæisk ansøgning nr.: **15170132.3**

(86) Europæisk indleveringsdag: **2015-06-01**

(87) Den europæiske ansøgnings publiceringsdag: **2015-12-09**

(30) Prioritet: **2014-06-06 US 201414298361**

(84) Designerede stater: **AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR**

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(54) Benævnelse: **SYSTEM OG FREMGANGSMÅDE TIL AT BESKYTTE ROTERENDE MASKINER**

(56) Fremdragne publikationer:
EP-A1- 2 458 204
FR-A1- 2 692 668
US-A1- 2012 257 967

DESCRIPTION

[0001] The present invention relates generally to rotary machines, and more particularly to a system and method for protecting rotary machines using a simple, frequency discriminator.

[0002] Rotary machines include, such as large turbine-generator units having gas, steam, or wind turbines which turn generators to produce electric power. Wind power is considered one of the cleanest, most environmentally friendly energy sources presently available, and wind turbines have gained increased attention in this regard. A modern wind turbine typically includes a tower, a generator, a gearbox, a nacelle, and a rotor. The rotor typically includes a rotatable hub having one or more rotor blades attached thereto. The rotor blades capture kinetic energy of wind using known airfoil principles. The rotor blades transmit the kinetic energy in the form of rotational energy so as to turn a shaft coupling the rotor blades to a gearbox, or if a gearbox is not used, directly to the generator. The generator then converts the mechanical energy to electrical energy that may be deployed to a utility grid.

[0003] During installation and/or operation of a rotary machine, it is common for the machine to become imbalanced. For example, during installation of a wind turbine, faulty blade-zero marking or high pitch offsets may result in excessive vibration in the generator frame. In addition, manufacturing tolerances of the generator typically cause the generator to have a mass imbalance about its longitudinal axis, which causes vibrations within the wind turbine.

[0004] Rotary machines are designed to withstand a certain amount of vibrations; however, excessive vibrations can lead to the eventual wearing out, or even sudden failure, of machine parts. Further, replacement of vibration-worn parts of the rotary machine can require the unit to be taken off-line, increasing both time and expenses associated with the rotary machine. Thus, it would be advantageous to detect such vibrations before such damage occurs.

[0005] To facilitate preventing damage to the machine, the machine components are commonly monitored to detect performance issues, e.g. excessive vibrations that may cause component failure or damage. See FR 2 692 668 for one such monitoring system. For example, certain conventional control technologies primarily focus on utilizing the phase lock loop (PLL), which is a control system that generates an output signal having a phase that is related to the phase of an input signal. For example, for a wind turbine, such a system detects a vibration signal of a rotor having a phase and relates it to a desired phase for the rotor. The system then adjusts the vibration signal to keep the phases matched. Such a control technology involves complex calculations and is sensitive to noise within the vibration signal that can lead to skewed results or incorrect detection of a particular frequency in the output signal.

[0006] Accordingly, an improved system and method that detects excessive vibrations and implements a corrective action so as to protect the rotary machine before damage occurs would be advantageous. More specifically, an improved system and method for protecting a rotary machine that addresses the aforementioned issued would be welcomed in the art.

[0007] Various aspects and advantages of the invention will be set forth in part in the following description, or may be clear from the description, or may be learned through practice of the invention.

[0008] The present invention is defined by the appended claims.

[0009] Various features, aspects and advantages of the present invention will become better understood with reference to the following description and appended claims. The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention. In the drawings:

FIG. 1 illustrates a perspective view of a wind turbine in accordance with the present disclosure;

FIG. 2 illustrates a simplified, internal view of one embodiment of a nacelle of a wind turbine;

FIG. 3 illustrates a schematic diagram of one embodiment of a controller according to the present disclosure;

FIG. 4 illustrates a graph of one embodiment of a measured vibration signal premodulation according to the present disclosure;

FIG. 5 illustrates a schematic diagram of one embodiment of a system for protecting a rotary machine according to the present disclosure;

FIG. 6 illustrates graphs of a Sine modulating signal (top) and Cosine modulating signal (bottom) according to the present disclosure;

FIG. 7 illustrates graphs of a measured vibration signal that has been modulated at a Sine waveform of a known frequency (top) and a Cosine waveform of a known frequency (bottom) according to the present disclosure;

FIG. 8 illustrates graphs of a measured vibration signal that has been modulated at a Sine waveform of a known frequency and filtered (top) and a Cosine waveform of a known frequency and filtered (bottom) according to the present disclosure; and

FIG. 9 illustrates a flow diagram of one embodiment of a method for protecting a rotary machine according to the present disclosure.

[0010] Generally, the present disclosure is directed to a system and method for identifying an imbalance within a rotary machine in a high noise environment and protecting the rotary machine from damage caused by the imbalance. More specifically, in one embodiment, the system is configured to measure the low amplitude (peak-to-peak) of the first excitation frequency (IP) or rotational speed of a rotor of a wind turbine. For example, at least one sensor measures a vibration signal within the rotor during operation of the wind turbine, which typically operates in a high noise and direct current (DC) component environment. Next, the system modulates the noisy data signal at a desired frequency to generate a modulated signal so as to convert the vibration signal to a direct current (DC) value. As such, the modulated signal can then be easily filtered via a low pass filter. After filtering, the amplitude of the filtered signal can be easily extracted and compared to a threshold amplitude for the rotor of the wind turbine. The threshold amplitude is chosen so as to ensure safe operation of the machine, therefore, if the amplitude of the modulated signal exceeds the amplitude of the threshold amplitude, the wind turbine is shut down to prevent damage caused by the IP frequency.

[0011] The present disclosure has many advantages not present in the cited art. For example, the present disclosure it not limited to detecting IP frequencies, but can reliably detect any low frequency amplitude in a high noise environment (e.g. 2P, 3P, and so on). Further, the present disclosure can be implemented using one or more simple, low-pass filters and does not require complex filtering. In addition, it should be understood that the following description explains the present disclosure as it relates to a wind turbine, however, the present disclosure can be implemented with any type of rotary machine, including but not limited to a wind turbine, a gas turbine, a hydroelectric generator, a steam turbine, or similar. As such, the figures and description are meant to be illustrative of one embodiment and are not intended to be limiting.

[0012] Referring now to the drawings, FIG. 1 illustrates a perspective view of one embodiment of a variable speed wind turbine 10 according to the present disclosure. As shown, the wind turbine 10 generally includes a tower 12 extending from a support surface 14, a nacelle 16 mounted on the tower 12, and a rotor 18 coupled to the nacelle 16. The rotor 18 includes a rotatable hub 20 and at least one rotor blade 22 coupled to and extending outwardly from the hub 20. For example, in the illustrated embodiment, the rotor 18 includes three rotor blades 22. However, in an alternative embodiment, the rotor 18 may include more or less than three rotor blades 22. Each rotor blade 22 may be spaced about the hub 20 to facilitate rotating the rotor 18 to enable kinetic energy to be transferred from the wind into usable mechanical energy, and subsequently, electrical energy. For instance, the hub 20 may be rotatably coupled to an electric generator 24 (FIG. 2) positioned within the nacelle 16 to permit electrical energy to be produced.

[0013] The wind turbine 10 may also include a wind turbine controller 26 centralized within the nacelle 16. However, in other embodiments, the controller 26 may be located within any other component of the wind turbine 10 or at a location outside the wind turbine. Further, the controller 26 may be communicatively coupled to any number of the components of the wind turbine 10 in order to control the operation of such components and/or implement a corrective action. As such, the controller 26 may include a computer or other suitable processing unit. Thus, in several embodiments, the controller 26 may include suitable computer-readable instructions that, when implemented, configure the controller 26 to perform various different functions, such as receiving, transmitting and/or executing wind turbine control signals.

Accordingly, the controller 26 may generally be configured to control the various operating modes (e.g., start-up or shut-down sequences) and/or de-rating or up-rating the wind turbine, which will be discussed in more detail below.

[0014] Referring now to FIG. 2, a simplified, internal view of one embodiment of the nacelle 16 of the wind turbine 10 shown in FIG. 3 is illustrated. As shown, a generator 24 may be disposed within the nacelle 16. In general, the generator 24 may be coupled to the rotor 18 for producing electrical power from the rotational energy generated by the rotor 18. For example, as shown in the illustrated embodiment, the rotor 18 may include a rotor shaft 34 coupled to the hub 20 for rotation therewith. The rotor shaft 34 may, in turn, be rotatably coupled to a generator shaft 36 of the generator 24 through a gearbox 38. As is generally understood, the rotor shaft 34 may provide a low speed, high torque input to the gearbox 38 in response to rotation of the rotor blades 22 and the hub 20. The gearbox 38 may then be configured to convert the low speed, high torque input to a high speed, low torque output to drive the generator shaft 36 and, thus, the generator 24.

[0015] Each rotor blade 22 may also include a pitch adjustment mechanism 32 configured to rotate each rotor blade 22 about its pitch axis 28. Further, each pitch adjustment mechanism 32 may include a pitch drive motor 40 (e.g., any suitable electric motor), a pitch drive gearbox 42, and a pitch drive pinion 44. In such embodiments, the pitch drive motor 40 may be coupled to the pitch drive gearbox 42 so that the pitch drive motor 40 imparts mechanical force to the pitch drive gearbox 42. Similarly, the pitch drive gearbox 42 may be coupled to the pitch drive pinion 44 for rotation therewith. The pitch drive pinion 44 may, in turn, be in rotational engagement with a pitch bearing 46 coupled between the hub 20 and a corresponding rotor blade 22 such that rotation of the pitch drive pinion 44 causes rotation of the pitch bearing 46. Thus, in such embodiments, rotation of the pitch drive motor 40 drives the pitch drive gearbox 42 and the pitch drive pinion 44, thereby rotating the pitch bearing 46 and the rotor blade 22 about the pitch axis 28. Similarly, the wind turbine 10 may include one or more yaw drive mechanisms 66 communicatively coupled to the controller 26, with each yaw drive mechanism(s) 66 being configured to change the angle of the nacelle 16 relative to the wind (e.g., by engaging a yaw bearing 68 of the wind turbine 10).

[0016] In addition, the wind turbine 10 may also include one or more sensors 48, 50, 52, 54, 56, 57 for monitoring various loading conditions and/or operational parameters of the wind turbine 10. As used herein, the term "loading parameter" may refer to any suitable loading condition and/or parameter that relates to a load acting on the wind turbine 10. For instance, loading conditions may include, but are not limited to, any load or moment acting on one of or a combination of the rotor blades 22, the rotor 18, the hub 20, the nacelle 16, the main shaft 34, the generator 24, the tower 12 or other similar component of the wind turbine 10. Further, the term "operational parameter" as used herein may refer to any suitable operating condition and/or parameter that relates to operation of the wind turbine 10 so as to provide information regarding the current or real-time operational state of the wind turbine. For instance, operating conditions may include, but are not limited to, a rotor speed, a generator speed, a position of one or more components of the wind turbine 10, or harmonics of one or more components of the wind turbine 10, or similar.

[0017] Still referring to FIG. 2, the one or more sensors may include blade sensors 48 for monitoring the rotor blades 22 (deflections, tip speed ratio, etc.); generator sensors 50 for monitoring the torque, the rotational speed, the acceleration and/or the power output of the generator 24; wind sensors 52 for monitoring the wind speed; and/or shaft sensors 54 for measuring the loads acting on the rotor shaft 34 and/or the rotational speed of the rotor shaft 34. Additionally, the wind turbine 10 may include one or more tower sensors 56 for measuring the loads transmitted through the tower 12 and/or the acceleration of the tower 12. Of course, the wind turbine 10 may further include various other suitable sensors for measuring any other suitable loading and/or operational parameter of the wind turbine 10. For example, the wind turbine 10 may also include one or more sensors 57 (e.g., accelerometers) for monitoring the acceleration of the gearbox 38 and/or the acceleration of one or more structural components of the machine head (e.g., the generator frame, the main frame or bedplate, etc.).

[0018] It should be understood that the sensors as described herein may be any suitable sensors known in the art. For example, the sensors may include a proximity sensor, a pressure sensor, an accelerometer, a strain gauge, a speed encoder, a Miniature Inertial Measurement Unit (MIMU), a vibration sensor, a Miniature Inertial Measurement Unit (MIMU), and/or any other suitable sensors. As is generally understood, MIMUs may include any combination of three-dimensional (3-D) accelerometers, 3-D gyroscopes and 3-D magnetometers and thus, when mounted on and/or within a rotor blade 22, may be capable of providing various types of blade-related measurements, such as 3-D blade orientation (pitch, roll, yaw) measurements, 3D blade acceleration measurements, 3-D rate of turn measurements, 3D magnetic field measurements and/or the like. As will be described below, such measurements may then be transmitted to the controller 26 and subsequently analyzed to determine real-time values for one or more of the loading and/or operational parameters.

[0019] It should be appreciated that, as used herein, the term "monitor" and variations thereof indicates that the various sensors of the wind turbine 10 may be configured to provide a direct measurement of the parameters being monitored or an indirect measurement of such parameters. Thus, the sensors may, for example, be used to generate signals relating to the condition being monitored, which can then be utilized by the controller 26 to determine the actual condition. For instance, as indicated above, MIMU sensors may be used to monitor one or more loading and/or operational parameters by providing various 3-D measurements, which may then be correlated to the loading and/or operational condition(s).

[0020] Referring now to FIG. 3, there is illustrated a block diagram of one embodiment of suitable components that may be included within the controller 26 in accordance with aspects of the present subject matter. As shown, the controller 26 may include one or more processor(s) 58 and associated memory device(s) 60 configured to perform a variety of computer-implemented functions (e.g., performing the methods, steps, calculations and the like and storing relevant data as disclosed herein). Additionally, the controller 26 may also include a communications module 62 to facilitate communications between the controller 26 and the various components of the wind turbine 10. Communication module 62 may include, without limitation, a network interface controller (NIC), a network adapter, a transceiver, and/or any suitable communication device that enables controller 26 to operate as described herein. Communication module 62 may connect to a network (not shown) and/or to one or more data communication systems using any suitable communication protocol, such as a wired Ethernet protocol or a wireless Ethernet protocol. Further, the communications module 62 may include a sensor interface 64 (e.g., one or more analog-to-digital converters) to permit signals transmitted from the sensors 48, 50, 52, 54, 56, 57 (such as loading and/or operational parameters) to be converted into signals that can be understood and processed by the processors 58 as will be discussed in more detail below. It should be appreciated that the sensors 48, 50, 52, 54, 56, 57 may be communicatively coupled to the communications module 62 using any suitable means. For example, as shown in FIG. 3, the sensors 48, 50, 52, 54, 56, 57 are coupled to the sensor interface 64 via a wired connection. However, in other embodiments, the sensors 48, 50, 52, 54, 56, 57 may be coupled to the sensor interface 64 via a wireless connection, such as by using any suitable wireless communications protocol known in the art.

[0021] During start-up and/or operation of the wind turbine 10, rotation of the rotor 18 induces vibrations into various wind turbine components. In addition, typical wind turbines and rotary machines as described herein operate in a high-noise environment. Such an environment typically generates data signals that have a low signal-to-noise ratio, for example, less than 1:1. The signal-to-noise ratio as described herein is generally defined as a ratio of the level of a desired signal to the level of background noise. Thus, a low signal-to-noise ratio (lower than 1:1) indicates less signal than noise and a ratio higher than 1:1 indicates more signal than noise. Though the system and method of the present disclosure is described herein as being suitable for high noise environments, it should be understood by those of ordinary skill in the art that the present disclosure is also suitable for any other environments as well.

[0022] The sensors 48, 50, 52, 54, 56, 57 are configured to detect and measure vibrations and transmit a signal representative of the vibration measurements for at least one revolution of the wind turbine 10 to the controller 26 for processing and/or analysis. For example, FIG. 4 illustrates one embodiment of a measured vibration signal 75 according to the present disclosure. As shown, the vibration signal 75 typically includes a plurality of frequency components, such as, without limitation, one or more rotor vibration frequencies, and/or one or more noise frequencies. In certain embodiments, the vibration signal 75 may be initially filtered so as to remove unwanted frequency content before modulation to decrease aliasing in the modulating signals. More specifically, in one embodiment, the vibration signal 75 may be initially filtered via at least one of a band-pass filter or a high-pass filter. In addition, any DC offset 72 may be removed from the vibration signal 75 before it is further processed and/or analyzed.

[0023] Referring now to FIG. 5, the processor 58 is configured to receive sensor data 70 (e.g. vibration signal 75) from at least one of the sensors 48, 50, 52, 54, 56, 57 during operation of the wind turbine 10 such that the signal 75 can be further processed and/or analyzed. The vibration signal may then be modulated at a desired frequency to generate one or more modulated signals so as to convert the vibration signal to a DC value. For example, as shown, the processor 58 includes a frequency modulator 80 that is configured to receive the vibration signal 75 and systematically vary the frequency of the signal 75 using a suitable algorithm. More specifically, as shown in FIGS. 5 and 6, the frequency modulator 80 modulates the vibration signal 75 at a desired frequency of certain Sine and Cosine waveforms 82, 84. In a particular embodiment, the frequency modulator 80 is configured to multiply the frequency of the vibration signal 75 with the desired frequency of the Sine and Cosine waveforms 82, 84 to determine a modulated signal(s). In certain embodiments, the desired frequency of the Sine and Cosine waveforms 82, 84 varies as a function of an operational parameter of the wind turbine 10. For example, in one embodiment, the desired frequency of the Sine and Cosine waveforms 82, 84 may correspond to a varying operational parameter of the wind turbine 10, such as a rotor and/or generator speed 78, a position of one or more components of the wind turbine 10, harmonics of one of more components of the wind turbine 10, or any other suitable operational parameter or combination thereof. More specifically, as shown in illustrated embodiment of FIG. 5, the rotor position 74 of the wind turbine 10 may be calculated via integrator 76 which integrates the high-resolution generator speed 78 scaled as to rotor speed.

[0024] Thus, when the measured signal 75 is modulated at the desired frequency, the measured signal is converted to DC values (i.e. the modulated signal(s) 83, 85) that can be easily filtered, as shown in FIG. 7. More specifically, modulating the vibration signal 75 moves the desired signal to a DC value, which makes the signal easier to filter using a simple low-pass filter (as will be discussed in more detail below). The unwanted frequencies are also shifted to other frequencies, but the low-pass filter will remove them. Further, as shown, the original vibration signal 75 is modulated at certain desired frequencies to generate a Sine modulated signal 83 and a Cosine modulated signal 85. Thus, as shown in FIG. 4, the modulated signal(s) 83, 85 can be further attenuated and filtered to extract the amplitude 96 of the frequency from the original vibration signal. More specifically, the frequency modulator 80 is configured to determine an attenuation factor 86 that automatically generates a time constant for the filtering assembly 88 based on the rotor speed.

[0025] Referring still to FIG. 5, the filtering assembly 88 includes one or more low-pass filters (LPF) that are configured to filter the modulated signal(s) 83, 85. For example, as shown, low-pass filter 90 is used to filter the Cosine modulated signal 85 and low-pass filter 92 is used to filter the Sine modulated signal 83, for a total of two low-pass filters. In still additional embodiments, the filtering assembly 88 may include more than two or less than two low-pass filters. In further embodiments, it should be understood that any number of low-pass filters can be utilized. In addition, it should be understood by those of ordinary skill in the art that the number of filters can be chosen so as to maximize DC rejection, while also balancing the increase in phase shift and required sample size. A low-pass filter, as described herein, is a filter that passes low-frequency signals and attenuates (i.e. reduces the amplitude of) signals with frequencies higher than the cutoff frequency. Thus, in one embodiment, the modulated signal(s) 83, 85, which include the low-frequency DC component of the original vibration signal 75, can be easily filtered to eliminate any high frequency signals, as shown by the filtered signals 93, 95 of FIG. 8.

[0026] After filtering, the processor 58 can easily extract the amplitude of the filtered signal via a filter output processor 94. For example, as shown in the embodiment of FIG. 5, the output signals from the filtering assembly 88, which includes the filtered Cosine modulated signal 85 and the filtered Sine modulated signal 83, can be squared and added together to determine an output signal. In a particular embodiment, the processor 58 then calculates the square root of the output signal and multiplies by two to determine the amplitude 96 of the signal. Next, the processor 58 compares the amplitude 96 of the output signal to a threshold amplitude for one or more components of the wind turbine 10. The threshold amplitude is indicative of an imbalance within one or more components of the wind turbine 10, and therefore is chosen so as to ensure safe operation of the wind turbine 10. In one embodiment, for example, the processor 58 determines the threshold amplitude based on one or more field measurements that are indicators of safe operation of the wind turbine 10. More specifically, in a particular embodiment, the threshold amplitude is determined by first perfectly or near perfectly balancing the wind turbine 10. After the wind turbine 10 is balanced, the sensors are configured to measure one or more initial oscillations that occur during start up and/or operation of the wind turbine 10. The processor 58 can then optionally store the information in the memory device 60. Next, the processor 58 alters one or more operational parameters of the wind turbine 10 and measures at least one subsequent oscillations of the wind turbine 10 in response to altering one or more parameters. Thus, the processor 58 is configured to determine a difference between the initial oscillations and the subsequent oscillations. Based on the difference, the processor 58 determines the threshold amplitude for one or more components of the wind turbine 10. In additional embodiments, the threshold amplitude may be determined using any other suitable means, e.g. using a computer model, using data from similar wind turbine in similar wind farms, etc.

[0027] After the amplitude 96 of the filtered signal is determined, the controller 26 is configured to operate the wind turbine 10 based on the comparison of the amplitude 96 and the threshold amplitude so as to protect the wind turbine 10 from damage caused by an imbalance within one or more wind turbine components. For example, if the amplitude 96 of the filtered output signal exceeds the threshold amplitude, the controller 26 is configured to implement a corrective action 98 to the wind turbine 10. In several embodiments, the corrective action 98 may include shutting down the wind turbine 10 or temporarily de-rating the wind turbine 10 to permit the loads acting on or more of the wind turbine components to be reduced or otherwise controlled. For example, de-rating the wind turbine 10 may include speed de-rating, torque de-rating or a combination of both, or pitching one or more of the rotor blades 22 about its pitch axis 28. More specifically, the controller 26 may generally control each pitch adjustment mechanism 32 in order to alter the pitch angle of each rotor blade 22 between 0 degrees (i.e., a power position of the rotor blade 22) and 90 degrees (i.e., a feathered position of the rotor blade 22). In still another embodiment, the wind turbine 10 may be temporarily de-rated by modifying the torque demand on the generator 24. In general, the torque demand may be modified using any suitable method, process, structure and/or means known in the art. For instance, in one embodiment, the torque demand on the generator 24 may be controlled using the controller 26 by transmitting a suitable control signal/command to the generator 24 in order to modulate the magnetic flux produced within the generator 24. The wind turbine 10 may also be temporarily de-rated by yawing the nacelle 16 to change the angle of the nacelle 16 relative to the direction of the wind. In other embodiments, the controller 26 may be configured to actuate one or more mechanical brake(s) in order to reduce the rotational speed of the rotor blades 22, thereby reducing component loading. In still further embodiments, de-rating the wind turbine 10 may include the controller 26 activating one or more airflow modifying elements on one or more of the rotor blades 22. For example, the controller 26 may activate one or more spoilers or flaps on the surface of one or more of the rotor blades 22. Additionally, the controller 26 may be configured to implement any appropriate corrective action known in the art. In even further embodiments, the loads on the wind turbine components may be reduced by performing a combination of two or more corrective actions, such as by altering the pitch angle of one or more of the rotor blades 22 together with modifying the torque demand on the generator 24.

[0028] Referring now to FIG. 9, a flow diagram of an exemplary method 100 for protecting for identifying an imbalance condition within a rotary machine in a high noise environment is illustrated. In an exemplary embodiment, instructions and/or data for method 100 are stored in a computer readable medium, such as memory device 60 (FIG. 3), and the instructions are executed by processor 58 (FIG. 3) to perform the steps of method 100. As shown, the method 100 includes a step 102 of measuring, by at least one sensor, a vibration signal during operation of the rotary machine. A next step 104 includes modulating the vibration signal at a desired frequency to generate a modulated signal so as to convert the vibration signal to a DC value, wherein the desired frequency varies as a function of an operational parameter of the rotary machine. Another step 106 includes filtering the modulated signal via one or more sensors. The method 100 also includes a step 108 of comparing an amplitude of the filtered signal to a threshold amplitude for one or more components of the rotary machine, the threshold amplitude being indicative of an imbalance within one or more components of the rotary machine. The method 100 may also include a step 110 of operating the rotary machine based on the comparison so as to protect the rotary machine from damage caused by the imbalance within the one or more components of the rotary machine.

[0029] Exemplary embodiments of methods and systems for protecting a rotary machine in a high noise environment are described above in detail. The methods and systems are not limited to the specific embodiments described herein, but rather, components of the systems and/or steps of the methods may be utilized independently and separately from other components and/or steps described herein. For example, the methods may also be used in combination with other measuring systems and methods, and are not limited to practice with only the rotary machines as described herein. Rather, the exemplary embodiment can be implemented and utilized in connection with many other power system applications.

[0030] Although specific features of various embodiments of the invention may be shown in some drawings and not in others, this is for convenience only. In accordance with the principles of the invention, any feature of a drawing may be referenced and/or claimed in combination with any feature of any other drawing.

[0031] This written description uses examples to disclose the invention, including the preferred mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they include structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- FR2692668 [0005]

Patentkrav

1. Fremgangsmåde (100) til at identificere en uligevægtstilstand i en roterende maskine omfattende en rotor i et støjende miljø, idet fremgangsmåden (100) omfatter:

at måle, via mindst en sensor, et vibrationssignal (75) under drift af den roterende maskine;

at modulere vibrationssignalet (75) ved en ønsket frekvens for at generere et moduleret signal, der har en jævnstrømsværdi, hvor den ønskede frekvens varierer som en funktion af et driftsparameter af den roterende maskine; **kendetegnet ved**:

at bestemme en dæmpningsfaktor (86) baseret på en hastighed af rotoren;

at filtrere det modulerede signal via et eller flere filtre, der har en tidskonstant, der er automatisk genereret fra dæmpningsfaktoren (86); og

at sammenligne en amplitude (96) af det filtrerede signal med en amplitude tærskelværdi for en eller flere komponenter af den roterende maskine, idet amplitude tærskelværdien er indikativ for en uligevægt i en eller flere komponenter af den roterende maskine.

2. Fremgangsmåden (100) ifølge krav 1, yderligere omfattende at implementere en korrigerende handling til den roterende maskine, når amplituden (96) af det filtrerede signal overstiger amplitude tærskelværdien for at beskytte den roterende maskine fra skade forårsaget af uligevægten i de en eller flere komponenter af den roterende maskine.

3. Fremgangsmåden (100) ifølge krav 2, hvor den korrigerende handling omfatter mindst en af standsning af den roterende maskine eller belastningsreduktion (de-rating) af den roterende maskine.

4. Fremgangsmåden (100) ifølge et hvilket som helst foregående krav, hvor at modulere vibrationssignalet (75) omfatter at multiplicere frekvensen af vibrationssignalet (75) med sinusoidaler af den ønskede frekvens.

5. Fremgangsmåden (100) ifølge et hvilket som helst foregående krav, hvor de et eller flere filtre omfatter mindst et lavpasfilter (90, 92).

6. Fremgangsmåden (100) ifølge et hvilket som helst foregående krav, hvor driftsparameteret af den roterende maskine omfatter mindst en af en hastighed af den roterende maskine, en position af en eller flere komponenter af den roterende maskine, eller harmoniske svingninger af en af flere komponenter af den roterende maskine.

7. Fremgangsmåden (100) ifølge et hvilket som helst foregående krav, yderligere omfattende at filtrere vibrationssignalet (75) inden vibrationssignalet (75) moduleres via mindst et af et båndpasfilter eller et højpasfilter.

8. Fremgangsmåden (100) ifølge et hvilket som helst foregående krav, hvor den mindst ene sensor omfatter mindst en af en nærhedssensor, et accelerometer, en stræksensor, en hastighedsindkoder, en MIMU (Miniature Inertial Measurement Unit) eller en vibrationssensor.

9. Fremgangsmåden (100) ifølge et hvilket som helst foregående krav, yderligere omfattende at bestemme amplitude tærskelværdien baseret på en eller flere feltmålinger, der er indikatorer af sikker drift af den roterende maskine, hvor det at bestemme amplitude tærskelværdien baseret på en eller flere feltmålinger yderligere omfatter:

at balancere den roterende maskine;
at måle et eller flere initiale oscillationer under drift af den roterende maskine;
at ændre et eller flere driftsparametre af den roterende maskine;
at måle et eller flere efterfølgende oscillationer af den roterende maskine som reaktion på ændringen af de et eller flere driftsparametre af den roterende maskine;
at bestemme en forskel mellem de initiale oscillationer og de efterfølgende oscillationer; og
baseret på forskellen, at bestemme amplitude tærskelværdien for en eller flere komponenter af den roterende maskine.

10. Fremgangsmåden (100) ifølge et hvilket som helst foregående krav, hvor den roterende maskine omfatter mindst en af en vindturbine (10), en gasturbine, en hydroelektrisk generator eller en dampturbine.

11. System til at beskytte en roterende maskine i et støjende miljø, idet systemet omfatter:

en eller flere sensorer konfigureret til at måle et vibrationssignal (75) under drift af den roterende maskine;

en processor (58) kommunikativt koblet til de en eller flere sensorer, idet processoren (58) er konfigureret til at udføre en eller flere operationer, idet operationerne omfatter:

at modulere vibrationssignalet (75) ved en ønsket frekvens for at generere et modulerede signal, der har en jævnstrømsværdi, hvor den ønskede frekvens varierer som en funktion af et driftsparameter af den roterende maskine, **kendetegnet ved**:

at bestemme en dæmpningsfaktor (86) baseret på en hastighed af rotoren;

at filtrere det modulerede signal via et eller flere filtre, der har en tidskonstant, der er automatisk genereret fra dæmpningsfaktoren (86), og

at sammenligne en amplitude (96) af det filtrerede signal med en amplitude tærskelvædi for en eller flere komponenter af den roterende maskine, idet amplitude tærskelvædien er indikativ for en uligevægt i et eller flere komponenter af den roterende maskine; og

en styringsenhed (26) kommunikativt koblet til processoren (58), idet styringsenheden (26) er konfigureret til at udføre en eller flere operationer, idet operationerne omfatter:

at drive den roterende maskine baseret på sammenligningen for at beskytte den roterende maskine fra skade forårsaget af uligevægten i de en eller flere komponenter af den roterende maskine.

DRAWINGS

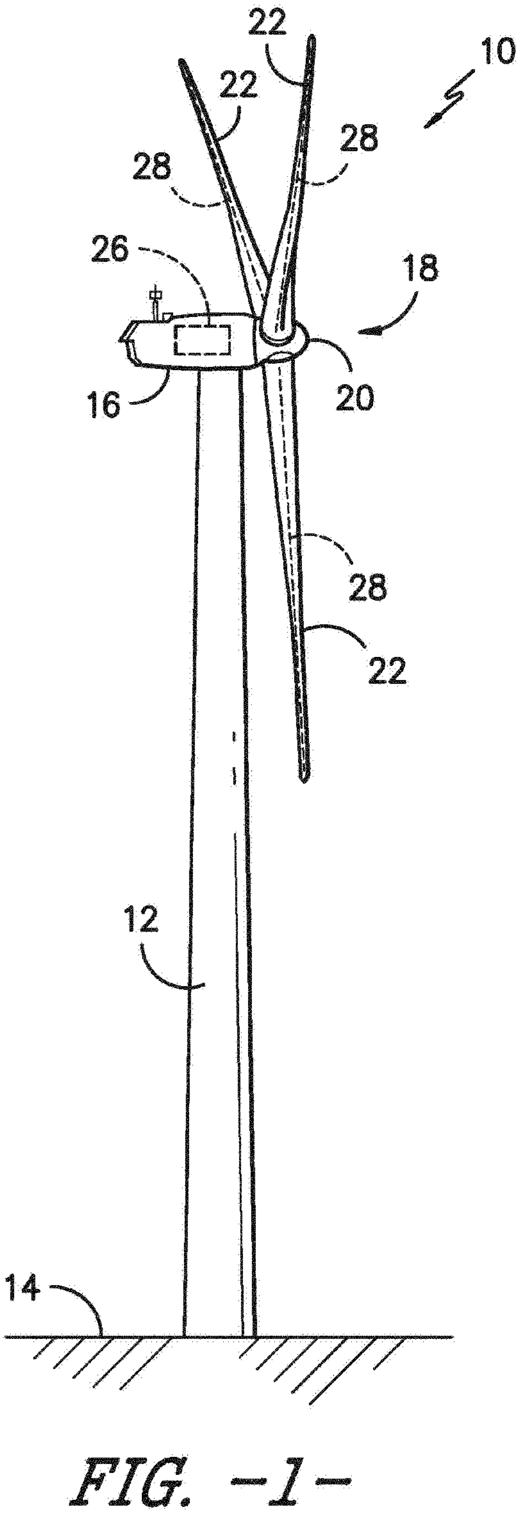
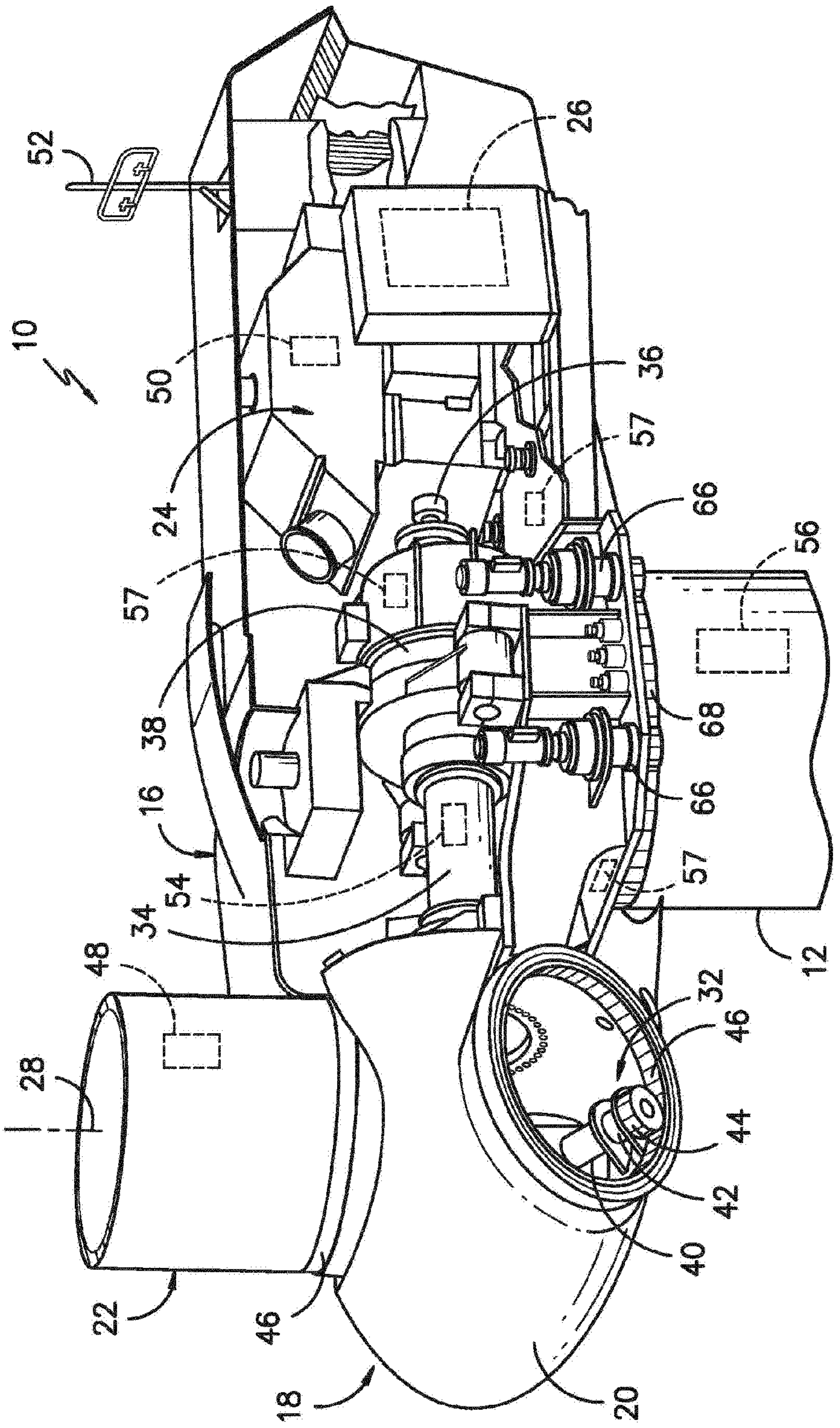


FIG. -1-


10
52
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12
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FIG. –2–

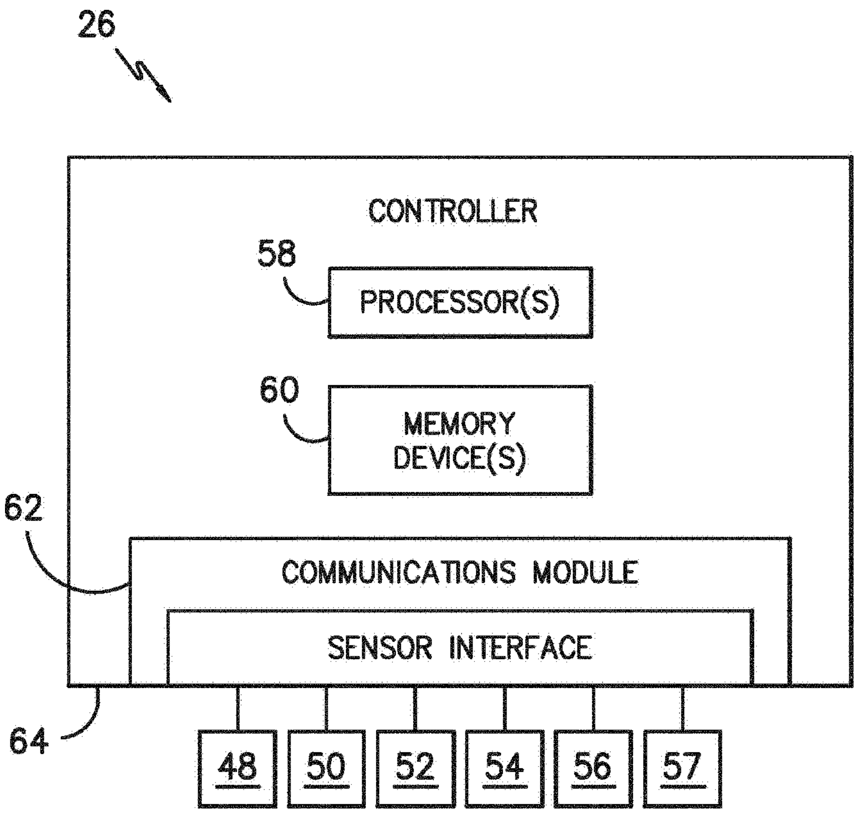
26
CONTROLLER
58
PROCESSOR(S)
60
MEMORY DEVICE(S)
62
COMMUNICATIONS MODULE
SENSOR INTERFACE
64
48
50
52
54
56
57

FIG. -3-

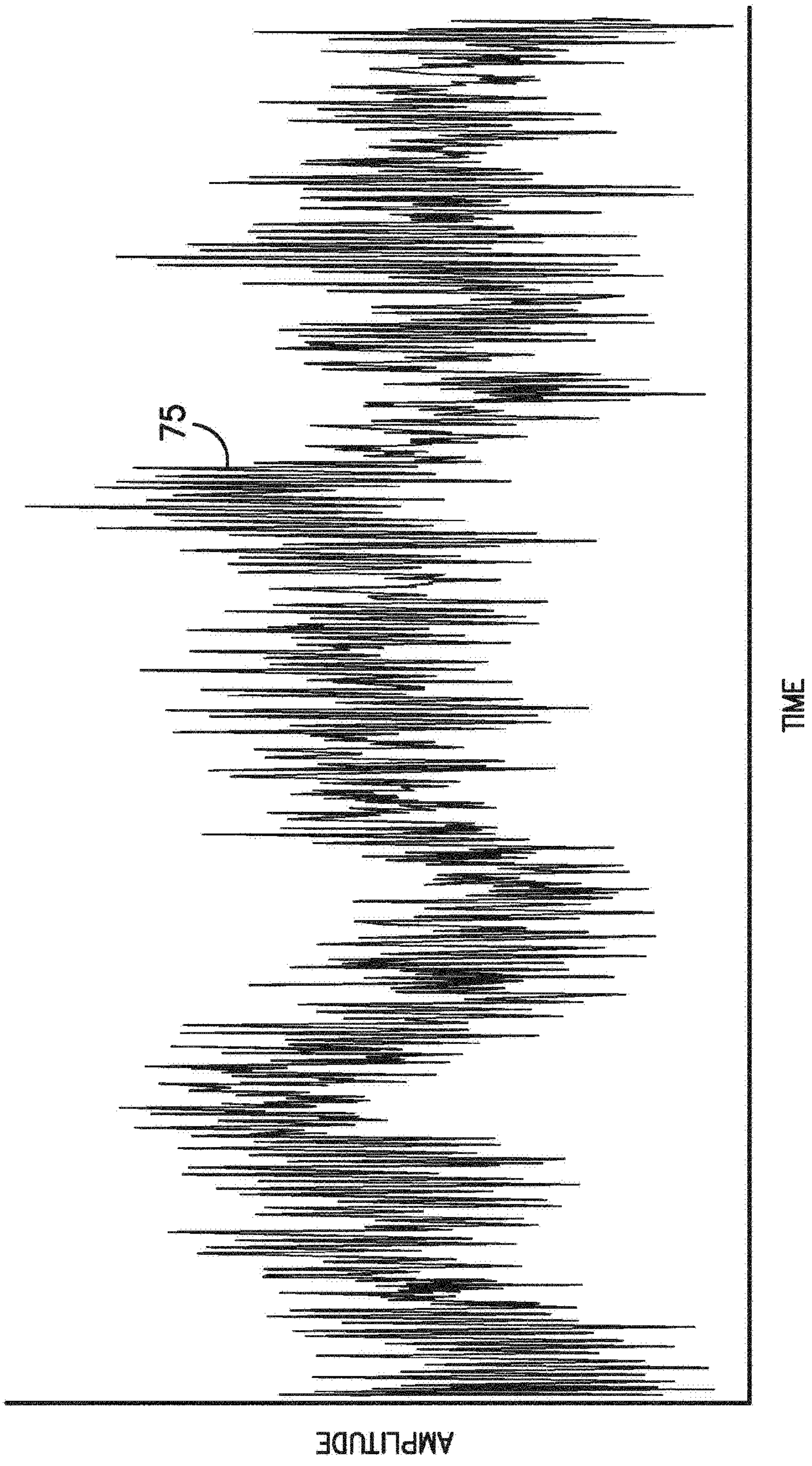

FIG. -4-

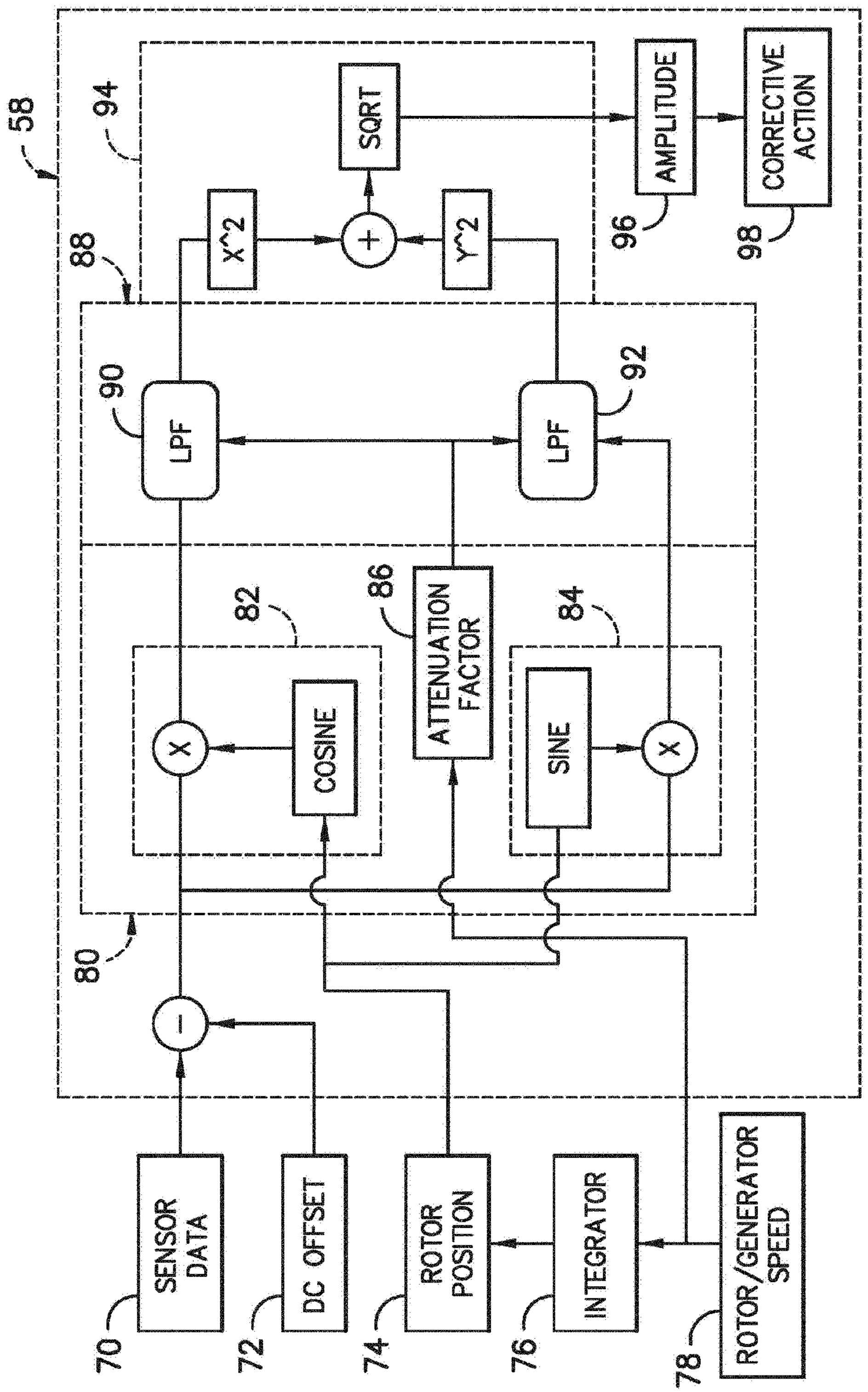
58
70
SENSOR DATA
72
DC OFFSET
74
ROTOR POSITION
76
INTEGRATOR
78
ROTOR/GENERATOR SPEED
80
-
82
X
COSINE
86
ATTENUATION FACTOR
84
SINE
X
88
90
LPF
92
LPF
94
X^2
Y^2
+
SQRT
96
AMPLITUDE
98
CORRECTIVE ACTION

FIG. –5–

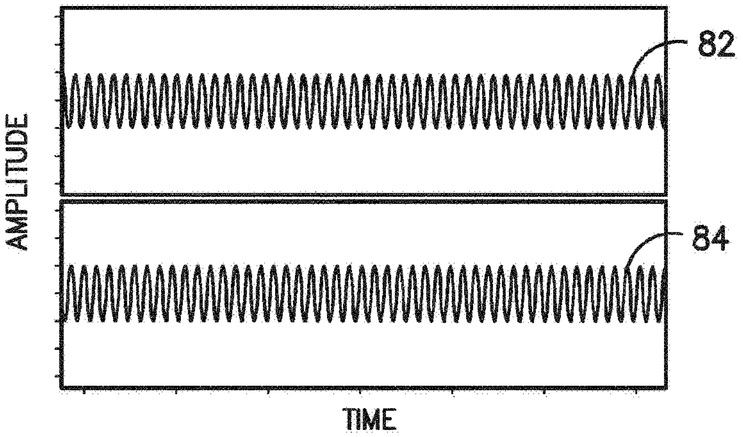

FIG. -6-

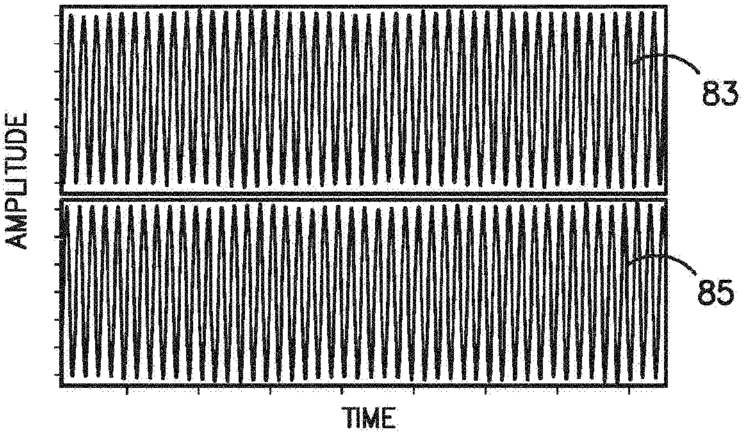

FIG. -7-

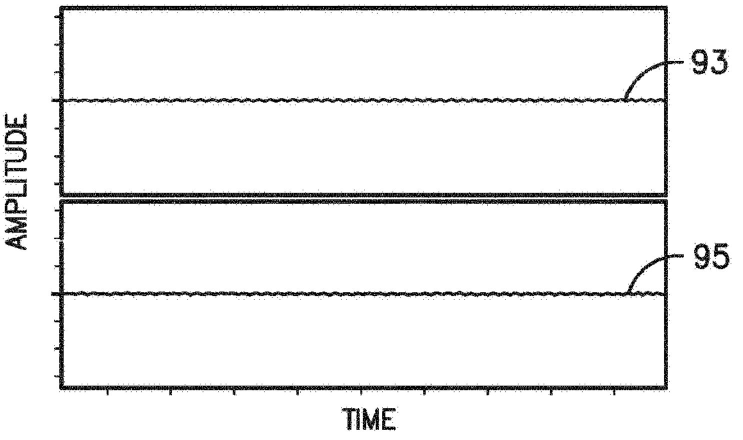

FIG. -8-

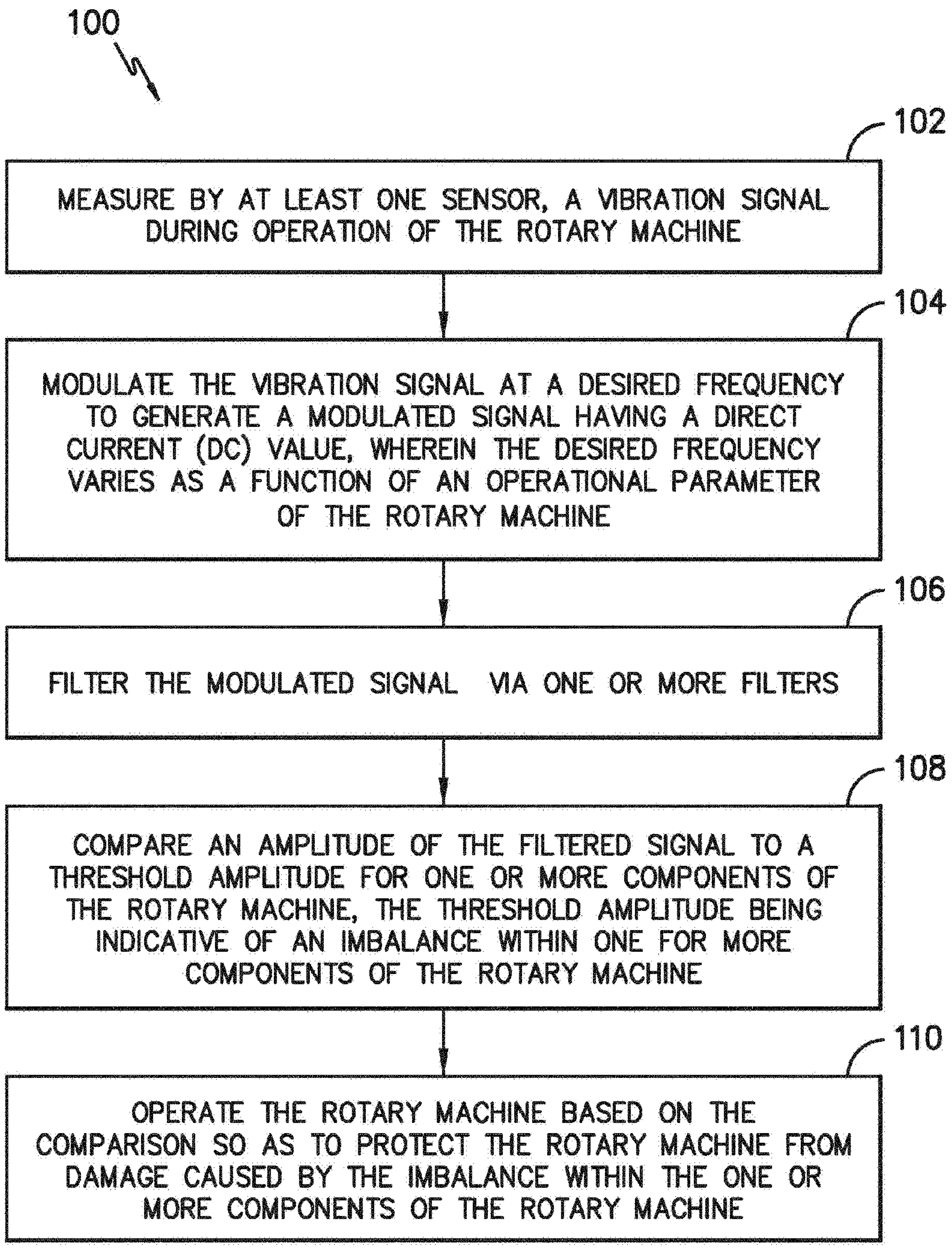
100
102
MEASURE BY AT LEAST ONE SENSOR, A VIBRATION SIGNAL DURING OPERATION OF THE ROTARY MACHINE
104
MODULATE THE VIBRATION SIGNAL AT A DESIRED FREQUENCY TO GENERATE A MODULATED SIGNAL HAVING A DIRECT CURRENT (DC) VALUE, WHEREIN THE DESIRED FREQUENCY VARIES AS A FUNCTION OF AN OPERATIONAL PARAMETER OF THE ROTARY MACHINE
106
FILTER THE MODULATED SIGNAL VIA ONE OR MORE FILTERS
108
COMPARE AN AMPLITUDE OF THE FILTERED SIGNAL TO A THRESHOLD AMPLITUDE FOR ONE OR MORE COMPONENTS OF THE ROTARY MACHINE, THE THRESHOLD AMPLITUDE BEING INDICATIVE OF AN IMBALANCE WITHIN ONE FOR MORE COMPONENTS OF THE ROTARY MACHINE
110
OPERATE THE ROTARY MACHINE BASED ON THE COMPARISON SO AS TO PROTECT THE ROTARY MACHINE FROM DAMAGE CAUSED BY THE IMBALANCE WITHIN THE ONE OR MORE COMPONENTS OF THE ROTARY MACHINE

FIG. -9-