

TITLE OF THE INVENTION

An apparatus and method for detecting deterioration of a rotating part

FIELD OF THE INVENTION

5 An engineering in the field of an apparatus and method for detecting deterioration of a rotating part.

BACKGROUND OF THE INVENTION

10 In many industries, various machines usually use rotating parts, for example, bearings, rotary valves, and gears, as part of their components. In many cases, the rotating part such as bearing will be used for the low-speed machines, such as a rotary dryer, a paddle dryer, an extruder, etc. Accordingly, if the rotating part becomes defective, the machine needs to stop operating and receive repairs. Therefore, an efficient bearing status detection is important as it will allow for more efficient maintenance planning.

15 At present, the deterioration detection of a rotating part, especially a bearing, can be performed by detecting the sound emanating from the bearing when it rolls over the moving of the machine's wheel. However, the sound emanating from the bearing for the machine operating at low speed is usually masked by loud background noise. Therefore, it is difficult to detect the deterioration of the bearing in low-speed machines using such a sound detection method, particularly at an early stage of deterioration.

20 The following prior arts show examples of devices and methods which have been developed for detecting deterioration of the rotating parts.

25 US patent no. 4,843,885 discloses an apparatus for the detection of impact frequencies in moving railway train bearings. The apparatus transduces acoustic vibration of the bearings into an electrical signal and extracts an envelope modulated carrier frequency component from the electric signal. The envelope is extracted from the carrier frequency component and is analyzed by a bandpass filter. The bandpass filter includes a switch capacitor filter controlled by a master clock which, in turn, is controlled by train speed and/or direction sensors positioned along the track on which the train travels.

The above prior art uses a microphone to accommodate a sound recognition and convert it into electrical signal. Thus, the bearing detection can be easily disturbed by

various noises from the surrounding environment. Further, the said invention focuses only on bearing detection for railway trains.

US patent no. 6,923,063 B2 discloses a device and system for monitoring acoustic emissions from machinery to indicate levels of detected sound waves. Each incorporates an acoustic sensing device which incorporates a housing assembly constructed for removable attachment between a surface mounting region of the machinery and a measuring instrument to define a coupled state. An acoustic emissions sensor is disposed in the housing assembly's interior to detect sound waves propagating through the surface mounting region and to produce detection signals for processing by the measuring instrument.

However, the above US patent does not take into account the cooling of the acoustic emission sensor provided inside of the housing assembly which may result in decreased efficiency.

US patent publication no. 2016/0178478 A1 discloses a device for testing an acoustic emission sensor. The device is configured to monitor a bearing. The device comprises a signal generator and is a portable device that is arranged to be temporarily attached to a surface of the bearing so that at least a part of the signal generator is pressed against the surface of the bearing.

The above prior art merely involves the acoustic emission sensor to repair, calibrate, approve or re-test the sensor. The sensor does not measure the acoustic signal produced by real machines but measure that is emitted from the signal generator. This may result in an inaccuracy of the device.

None of the above-mentioned prior arts teach or suggest an apparatus and method for detecting deterioration of a rotating part, which allows detection of deterioration of the rotating part of machines operating at a low speed.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to overcome the above-mentioned disadvantages in the prior arts.

The present invention aims to improve an apparatus and method for detecting deterioration of a rotating part which allows detection of deterioration of the rotating part of machines operating at low speed.

In one aspect, the present invention relates to an apparatus for detecting deterioration of a rotating part comprising a metal case having a slot to which an acoustic emission (AE) sensor is mounted, and a waveguide rod having a proximal end connected to the AE sensor in an abutting relation and a distal end mounted to the rotating part wherein the waveguide rod has a length of at least 50 mm.

Another aspect of the present invention is to provide a method for detecting deterioration of the rotating part comprising steps of:

- a) obtaining the acoustic emission data using the apparatus according to the present invention; and
- b) processing the acoustic emission data obtained from step a) to determine deterioration of the rotating part

wherein the step b) comprises extracting at least one of predetermined frequencies from all frequencies and calculating a Kurtosis value (K) of the rotating part for said predetermined frequencies using the following equation:

$$K = \frac{\sum_{i=1}^N \frac{(X_i - \bar{X})^4}{N}}{S^4}$$

wherein

K represents a Kurtosis value of the rotating part

X represents an amplitude of the acoustic emission data

S represents a standard deviation value of the amplitude of the acoustic emission data, and

N represents number of the acoustic emission data used in calculating.

BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 is a perspective view of the apparatus for detecting deterioration of the rotating part according to an embodiment of the present invention.

Fig. 2 is a top view of the apparatus for detecting deterioration of the rotating part according to an embodiment of the present invention.

Fig. 3 is a graph showing a relationship between the lengths of the waveguide rod and % rate of abnormal changed of the apparatus according to an embodiment of the present invention.

Fig. 4 is a graph showing a relationship between the length of the waveguide rod and sensor temperatures of the apparatus with the length of the waveguide rod at 6 and 15 mm, respectively.

Fig. 5 is a graph showing a relationship between the lengths of the waveguide rod and % rate of abnormal changed of the apparatus with the length of the waveguide rod at 6 and 15 mm, respectively.

DETAILED DESCRIPTION OF THE INVENTION

The present invention relates to an apparatus and method for detecting deterioration of a rotating part which will be described by the following details with reference to the accompanying figures.

Any aspects represented herein shall mean to include the application with other aspects of this invention unless it has been specified otherwise.

All technical, engineering and scientific terms used herein have the meaning that will be understood by those ordinary skilled in the art unless it has been defined otherwise.

Use of singular nouns or pronouns when used with “comprising” in claims and/or specification means “one” and will also include “one or more”, “at least one”, and “one or more than one”.

The terms “comprise”, “has/have” and “include” are open-ended verbs, wherein one or more of these verb formats, for example “comprise”, “comprising”, “has/have”, “having”, “include”, “including” are also open-ended verbs. For example, any method that “comprises”, “has” or “includes” one step or more does not limit to one step or steps but also covers the steps that has not been indicated.

Any instrument, equipment or method mentioned herein, unless indicated otherwise, shall mean instrument, equipment or that are generally used or practiced by a person skilled in the art of this field.

5 The apparatus and method disclosed and claimed in this application are intended to cover aspects of the invention obtained from performing, operating, modifying, changing any factors without experimentations that are significantly different from this invention, and acquire the same which have properties, utilities, advantages and results similar to the aspects of the present invention according to those ordinary skilled in the art even without being indicated in claims specifically. Therefore, the substitution for or similarity to the
10 aspects of the present invention including minor modification or change that can be apparent to a person skilled in the art in this field shall be considered under the intention, concept and scope of this invention as appeared in the appended claims.

According to present invention, the term “rotating part” refers to any part of a machine, apparatus, device or equipment that supports another part, that turns around.
15 Examples of the rotating part of this invention include but not limited to a rotary valve, rotary dryer, roller bearing and gearbox.

The principal applied to this invention is that acoustic emission signals naturally generated by deterioration in rotating machinery. As the mechanical condition degrades, energy loss processes such as impact, friction and crushing generate sound wave activity.

20 The first aspect of the present invention relates to an apparatus for detecting deterioration of a rotating part. Referring to Fig. 1 and 2, the apparatus of this invention comprises a metal case (1) having a slot (1.1) to which an acoustic emission (AE) sensor (2) is mounted, and a waveguide rod (3) having a proximal end (3.1) connected with the AE sensor (2) in an abutting relation and a distal end (3.2) mounted to the rotating part.

25 The metal case (1) is configured to comprise a hollow body (1.2) having a plurality of fins (1.2.1) extending from an inner wall of the hollow body (1.2) to a wall of the slot (1.1), and a hole (1.2.2) through which the waveguide rod (3) is passed.

In one embodiment, the hollow body (1.2) has a rectangular or semi-circular shape and the plurality of fins (1.2.1) are spaced apart from each other along a radial line of the

hollow body (1.2). However, the shape of the hollow body (1.2) is not limited to the rectangular or semi-circular shape, other shapes are also possible.

According to the above embodiment, the metal case (1) allows the heat to be transferred out of the AE sensor (2). Further, such fins (1.2.1) allow the heat to be transferred out of the AE sensor (2) to the metal case (1) more rapidly, therefore, ensuring that the AE sensor (2) is not so hot that it stops functioning.

Preferably, the slot (1.1) is shaped to correspond with the shape of the AE sensor (2) and comprises a fastening means (1.1.1) for securely mounting the AE sensor (2) inside the slot (1.1). An exemplary of the fastening means (1.1.1) is two sets of screw ending with pad for mounting to two opposite sides of the AE sensor (2). The fastening means (1.1.1) allows the AE sensor (2) to be securely mounted to the metal case (1) without falling off due to the machine vibration.

The metal case (1) is preferably made of a material having a high coefficient of thermal conductivity ranging from 50 to 300 W/m.K, preferably from 100 to 200 W/m.K and more preferably from 100 to 150 W/m.K. For example, the metal case (1) may be made of brass, steel or aluminum. The material with a high coefficient of thermal conductivity has a good heat transfer property therefore the heat is transferred more rapidly out of the AE sensor (2). The material selection may be adjusted to be suitable with the shape of the fins (1.2.1) and the reasonable price. For example, if the fin has less exposed area, the inventor may use the material having a higher coefficient of thermal conductivity such as copper.

According to a preferred embodiment, the waveguide rod (3) has a length of at least 50 mm, preferably ranging from 100 to 320 mm, more preferably from 100 to 200 mm and most preferably from 140 to 160 mm.

The above-mentioned length ranges are developed so that it can respond precisely to the signal being transmitted from the rotating part. In more detail, the inventor experimented by varying the length of the waveguide rod (3) at 30, 40 and 51 mm for determining the beginning of the length range and finding the ending of the length range. From the experimental result, it is found that when the length increased to 50 mm, a Kurtosis value as shown in % rate of abnormal changed also increased, and then, when the length is still more,

the amplitude and frequency of resonant modes will be attenuated, that is, the Kurtosis value will be reduced.

As seen in Fig.3, the length range of the waveguide rod (3) at 50-320 mm can transmit signal of interested frequencies in low-speed machine due to % rate of abnormal changed is higher than 85 which is an appropriate value.

According to this invention, the waveguide rod (3) is a cylindrical rod with a diameter of at least 5 mm. Preferably, the waveguide rod (3) is a cylindrical rod with a diameter ranging from 5 to 15 mm, preferably from 6 to 12 mm, and more preferably from 6 to 10 mm.

An appropriate length will further facilitate the heat transfer of the AE sensor (2) as it is analyzed in the heat transfer by measuring the sensor temperatures as shown in the graph according to Fig. 4.

According to a study by the inventor and the experimental results as shown in Figs. 4 and 5, increasing the diameter of the waveguide rod (3) will lead to better signal transfer from an object to be detected to the waveguide rod (3), while reducing the diameter causes a limit of several modes by which signals can be transmitted. Conducting experiments by varying the diameter of the waveguide rod (3) at 6- and 15-mm shows that the amplitude tends to saturate at the diameter of 6 mm. Further, the experimental result shows that there is no obvious effect to the heat transfer when using the wider rod diameter.

The waveguide rod (3) should be made of a material having a high signal transmission coefficient and a transmission coefficient ranging from 0.4 to 0.7, preferably from 0.5 to 0.6, i.e. the waveguide rod (3) is made of brass, steel or aluminum. As the transmission coefficient depends on acoustic impedance and thermal conductivity, the most suitable material may be brass due to its capability to obtain high signal amplitude and proper heat transfer rate. However, this invention is not intended to limit only brass. Other materials such as steel or aluminum can also be used to produce the waveguide rod (3).

In an embodiment, the waveguide rod (3) is connected to the AE sensor (2) by means of a flange (4) provided at the proximal end (3.1) of the waveguide rod (3) and a spring (5) provided in a compressed manner between the flange (4) and the hole (1.2.2) of the hollow

body (1.2). The spring (5) facilitates firmly attachment of the waveguide rod (3) to the AE sensor (2).

The apparatus of this invention may further comprise a mounting means (6) provided at the distal end (3.2) of the waveguide rod (3) to facilitate mounting of the waveguide rod (3) to the rotating part. For example, the mounting means (6) may be a magnetic adaptor, thread or adhesive.

According to an embodiment, in case the machine casing is magnetic, the flat magnetic adaptor may be used to mount the waveguide rod (3) to the machine casing.

Alternatively, in case the machine casing is not magnetic, the thread or adhesive located at the distal end (3.2) of the waveguide rod (3) may be used to mount the waveguide rod (3) to the machine casing.

The apparatus of this invention may further comprise a processing unit (7) (not shown in the drawing) being in communication with the AE sensor (2) for receiving acoustic emission data from the AE sensor (2) and determining deterioration of the rotating part. The processing unit (7) is provided to receive the acoustic emission data from the AE sensor (2) to be processed in a processor to detect deterioration of the rotating part so that the operator can recognize a deterioration result of the rotating part.

The second aspect of the present invention relates to a method for detecting deterioration of the rotating part.

The method comprises steps of:

- a) obtaining the acoustic emission data using the apparatus according to the present invention; and
- b) processing the acoustic emission data obtained from the step a) to determine deterioration of the rotating part,

wherein step b) comprises extracting at least one of predetermined frequencies from all frequencies and calculating a Kurtosis value (K) of the rotating part for said predetermined frequencies using the following equation:

$$K = \frac{\sum_{i=1}^N \frac{(X_i - \bar{X})^4}{N}}{S^4}$$

wherein

- K represents a Kurtosis value of the rotating part
 X represents an amplitude of the acoustic emission data
 S represents a standard deviation value of the amplitude of the acoustic emission data, and
 N represents number of the acoustic emission data used in calculating.

The step of extracting at least one of the predetermined frequencies from all frequencies and calculating the Kurtosis value of said predetermined frequencies allows the operator to recognize deterioration of each sub-components as the Kurtosis value can indicate the severity of the deterioration and the sub-components that the deterioration occurs.

According to the present invention, the extraction of at least one of predetermined frequencies from all frequencies is conducted using a wavelet decomposition method.

In a preferred embodiment, the method according to this invention further comprises a step of c) defining an operation state of the rotating part based on the Kurtosis value (K) of the rotating part. For this invention, the operation state of the rotating part is classified into a normal state, a monitor state, an alarm state and a maintenance state based on the Kurtosis value (K), that is:

- the normal state when $K < 3$;
- the monitor state when $3 \leq K < 5$;
- the alarm state when $5 \leq K < 10$; and
- the maintenance state when $K \geq 10$.

According to the above embodiment, defining an operation state of the rotating part allows the user to recognize the rotating part status conveniently and quickly.

Yet another preferred embodiment, the method of this invention further comprises a step of d) sending information regarding the operation state of the rotating part to a user's electronic device, such as a mobile phone, personal computer, notebook, etc. Therefore, users can recognize the rotating part status at any time in a real-time manner.

Table 1 below shows details and quantity of machines used in applying the apparatus and method according to this invention for detecting bearings of low speed machines in a

plant. The machines to be detected include five types that are: agitator, rotary valve, dryer, extruder and screw conveyor. The number of detected machines is a total of 145.

Table 1

Machine type	Quantity	Speed (rpm)	Critical components
Agitator	46	18-120	bearings
Rotary valve	50	15-60	
Dryer	8	4-30	
Extruder	15	50-300	
Screw conveyor	26	30-80	

From detecting the machines according to Table 1 using the apparatus and method according to this invention, it is found that 31 machines are detected to have a problem about the rotating part. Examples of the rotating parts detected to have problems that affect the machine breakdown are support bearings, output shaft bearings and mechanical seal bearings.

The apparatus for detecting deterioration of the rotating part according to the present invention is invented by considering the relationship between the length, diameter and material of the waveguide rod (3) to effectively amplify rod resonance and maintain waveform integrity. Moreover, the metal case (1) to which the AE sensor is mounted is specifically designed to increase heat transfer rate such as protecting the AE sensor from an extreme temperature level.

The above-mentioned characteristics provide several advantages to the apparatus, for example, accuracy in the detection of deterioration of the rotating part of machines operating at a low speed, for example, provide accuracy in the detection of deterioration of the rotating part of machines operating at a low speed, particularly at a speed less than 600 rpm, in which case maintenance could be provided in time and provide easier manner for relocation- or installation-related operation.

Moreover, the method for detecting deterioration of the rotating part according to the present invention provides advantages that allow the operator to recognize the deterioration in a real-time manner and recognize deterioration of the bearing sub-components.

5 **BEST MODE OF THE INVENTION**

Best mode of the invention is as described in the detailed description of the invention.

CLAIMS

1. An apparatus for detecting deterioration of a rotating part, comprising
 - a metal case (1) having a slot (1.1) to which an acoustic emission (AE) sensor (2) is mounted; and
 - a waveguide rod (3) having a proximal end (3.1) connected with the AE sensor (2) in an abutting relation and a distal end (3.2) mountable to the rotating part,wherein the waveguide rod (3) has a length ranging from 50-320 mm.
2. The apparatus according to claim 1, wherein the waveguide rod (3) has a length ranging from 100-320 mm, preferably 100-200 mm, and more preferably 140-160 mm.
3. The apparatus according to claim 1, wherein the metal case (1) is configured to comprise a hollow body (1.2) having a plurality of fins (1.2.1) extending from an inner wall of the hollow body (1.2) to a wall of the slot (1.1), and a hole (1.2.2) through which the waveguide rod (3) is passed.
4. The apparatus according to claim 3, wherein the hollow body (1.2) has a rectangular or semi-circular shape, and the plurality of fins (1.2.1) are spaced apart from each other along a radial line of the hollow body (1.2).
5. The apparatus according to claim 1, wherein the slot (1.1) is shaped to correspond with the shape of the AE sensor (2) and comprises a fastening means (1.1.1) for securely mounting the AE sensor (2) inside the slot (1.1).
6. The apparatus according to claim 5, wherein the fastening means (1.1.1) are two sets of screw ending with pad for mounting with two opposite sides of the AE sensor (2).
7. The apparatus according to any one of claims 1-6, wherein the metal case (1) is made of a material having a thermal conductivity ranging from 50 to 300 W/m.K, preferably from 100 to 200 W/m.K, and more preferably from 100 to 150 W/m.K.
8. The apparatus according to claim 7 wherein the metal case (1) is made of brass, steel or aluminum.
9. The apparatus according to claim 1 or 2 wherein the waveguide rod (3) is a cylindrical rod with a diameter of at least 5 mm.

10. The apparatus according to claim 9 wherein the waveguide rod (3) has a diameter ranging from 5 to 15 mm, preferably from 6 to 12 mm, and more preferably from 6 to 10 mm.
11. The apparatus according to any one of claims 1-2 or 9-10, wherein the waveguide rod (3) is made of a material having a transmission coefficient ranging from 0.4 to 0.7, preferably 0.5 to 0.6.
12. The apparatus according to claim 11, wherein the waveguide rod (3) is made of brass, steel or aluminum.
13. The apparatus according to any one of claims 1-12, wherein the waveguide rod (3) is connected to the AE sensor (2) by means of a flange (4) provided at the proximal end (3.1) of the waveguide rod (3) and a spring (5) provided in a compressed manner between the flange (4) and the hole (1.2.2) of the hollow body (1.2).
14. The apparatus according to any one of claims 1-13 further comprises a mounting means (6) provided at the distal end (3.2) of the waveguide rod (3) to facilitate mounting of the waveguide rod (3) to the rotating part.
15. The apparatus according to claim 14, wherein the mounting means (6) is a magnetic adaptor, thread or adhesive.
16. The apparatus according to any one of claims 1-15 further comprises a processing unit (7) being in communication with the AE sensor (2) for receiving acoustic emission data from the AE sensor (2) and determining deterioration of the rotating part.
17. A method for detecting deterioration of the rotating part, comprising steps of:
 - a) obtaining the acoustic emission data using the apparatus according to any one of claims 1-16; and
 - b) processing the acoustic emission data obtained from step a) to determine deterioration of the rotating part

wherein the step b) comprises extracting at least one of predetermined frequencies from all frequencies and calculating a Kurtosis value (K) of the rotating part for said predetermined frequencies using the following equation:

$$K = \frac{\sum_{i=1}^N \frac{(X_i - \bar{X})^4}{N}}{S^4}$$

wherein

K represents a Kurtosis value of the rotating part

X represents an amplitude of the acoustic emission data

S represents a standard deviation value of the amplitude of the acoustic emission data, and

N represents number of the acoustic emission data used in calculating.

18. The method according to claim 17, wherein the step of extracting at least one of predetermined frequencies from all frequencies is conducted by a wavelet decomposition method.
19. The method according to claim 17 further comprises a step of c) defining an operation state of the rotating part based on the Kurtosis value (K) of the rotating part.
20. The method according to claim 19, wherein the operation state of the rotating part is classified into a normal state, a monitor state, an alarm state and a maintenance state based on the following Kurtosis value (K):
 - the normal state when $K < 3$;
 - the monitor state when $3 \leq K < 5$;
 - the alarm state when $5 \leq K < 10$; and
 - the maintenance state when $K \geq 10$.
21. The method according to claim 19 or 20 further comprises a step of d) sending information regarding the operation state of the rotating part to a user's electronic device.