(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
22 August 2024 (22.08.2024)

(10) International Publication Number
WO 2024/170905 A1

(51) International Patent Classification:
F03D 17/00 (2016.01)

(21) International Application Number:
PCT/GB2024/050408

(22) International Filing Date:
15 February 2024 (15.02.2024)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2302177.7 15 February 2023 (15.02.2023) GB

(71) Applicant: **INSIGHT ANALYTICS SOLUTIONS HOLDINGS LIMITED** [GB/GB]; Sunbury Secretaries Limited, Chertsey Road, Sunbury On Thames Middlesex TW16 7BP (GB).

(72) Inventors: **GRAETER, Jesse**; c/o Insight Analytics Solutions Holdings Ltd, University of Nottingham, Innovation Park, Triumph Road, Nottingham Nottinghamshire NG7 2TU (GB). **CAMERON, Adam**; c/o Insight Analytics Solutions Holdings Ltd, University of Nottingham, Innovation Park, Triumph Road, Nottingham Nottinghamshire NG7 2TU (GB).

(74) Agent: **BARKER BRETTELL LLP**; 100 Hagley Road, Edgbaston, Birmingham West Midlands B16 8QQ (GB).

(81) **Designated States** *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) **Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST,

(54) Title: WIND TURBINE ROTOR SHAFT MONITORING

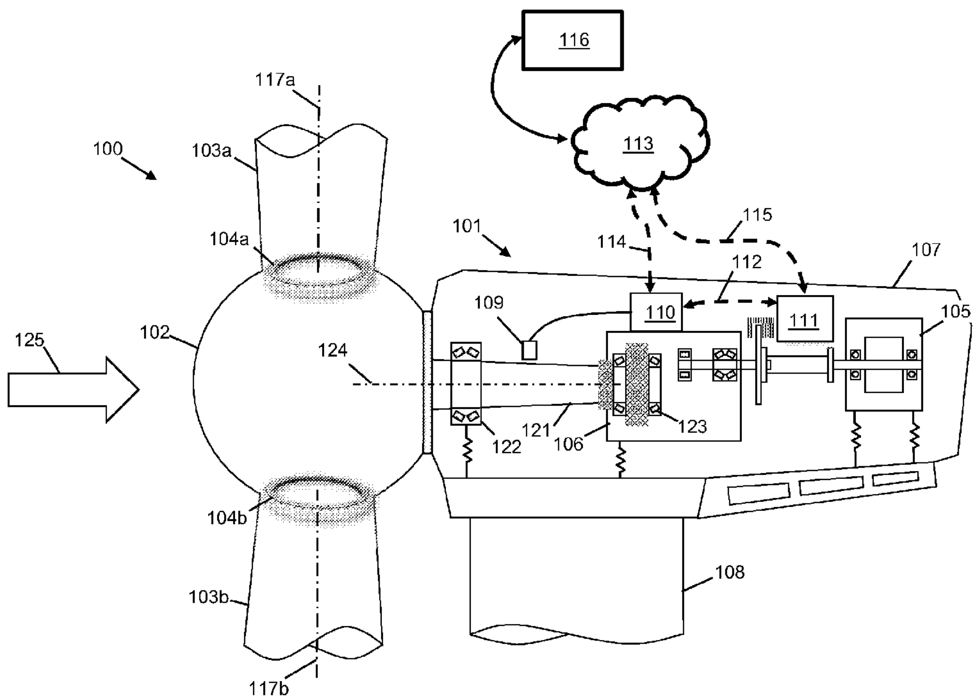

Fig. 1

(57) Abstract: The disclosure relates to monitoring a wind turbine rotor shaft by measuring runout. Examples disclosed include a method of monitoring a rotor shaft (121) of a wind turbine (100), the method comprising: measuring a runout of the rotor shaft (121) during operation of the wind turbine (100) using a first displacement sensor (109) mounted to measure a radial distance to an outer surface of the rotor shaft (121); recording the measured runout over time; and determining if the measured runout exceeds a predetermined threshold.

WO 2024/170905 A1

[Continued on next page]

SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

WIND TURBINE ROTOR SHAFT MONITORING

Field of the Invention

The invention relates to monitoring a rotor shaft of a wind turbine.

Background

Wind turbines are subjected to intermittent and varying loading during use, which can lead to unpredictable wear and damage of various components that are subject to such varying loads. The rotor shaft of a wind turbine is subjected to high torsional and bending loads, which can in some cases lead to cracking. A crack originating in a rotor shaft may over time propagate and weaken the shaft. Regular monitoring of the condition of the rotor shaft may in some cases be able to determine the presence of a crack or other defect in time to prevent failure, but early signs of impending failure may be difficult to detect through regular site inspections.

Summary of the Invention

According to a first aspect of the invention there is provided a method of monitoring a rotor shaft of a wind turbine, the method comprising:

measuring a runout of the rotor shaft during operation of the wind turbine using a first displacement sensor mounted to measure a radial distance to an outer surface of the rotor shaft;

recording the measured runout over time; and

determining if the measured runout exceeds a predetermined threshold.

The step of determining if the measured runout exceeds a predetermined threshold may comprise:

determining an amplitude of the measured runout; and

determining if the amplitude exceeds a predetermined amplitude threshold.

The method may comprise triggering an alert if the measured runout exceeds the predetermined threshold.

The amplitude may be a peak amplitude, an RMS amplitude or a peak to peak amplitude of the measured runout.

The method may further comprise:

measuring a runout of the rotor shaft during operation of the wind turbine using a second displacement sensor mounted to measure a radial distance to an outer surface of the rotor shaft at an angle to the first displacement sensor;

recording the measured runout from the second displacement sensor over time; and

determining if the measured runout from the second displacement sensor exceeds the predetermined threshold.

The second displacement sensor may be mounted orthogonally to the first displacement sensor.

The method may further comprise measuring an axial distance to a rotor flange connected to a first end of the rotor shaft using a third displacement sensor mounted to measure a distance to the rotor flange in a direction parallel to a rotational axis of the rotor shaft and recording the measured axial distance to the rotor flange over time.

The method may further comprise:

determining an amplitude of the measured axial distance to the rotor flange; and

triggering an alert if the amplitude of the measured runout exceeds a first predetermined amplitude threshold and an amplitude of the measured axial distance to the rotor flange is below a second predetermined threshold.

The method may comprise:

measuring a runout of the rotor shaft during operation of the wind turbine using a plurality of displacement sensors including the first displacement sensor, the plurality of displacement sensors mounted to measure a radial distance to an outer surface of the rotor shaft at different positions along the rotor shaft;

recording the measured runout from the plurality of displacement sensors over time; and

determining if the measured and recorded runout exceeds the predetermined threshold for one or more of the plurality of displacement sensors.

The plurality of displacement sensors may be positioned around the rotor shaft between first and second bearings within which the rotor shaft is rotatably mounted.

An end of the rotor shaft may be connected to a gearbox comprising a gearbox mount, the method further comprising measuring an axial distance to the gearbox mount using a fourth displacement sensor mounted to measure an axial distance to the gearbox mount in a direction parallel to a rotational axis of the rotor shaft and recording the measured axial distance to the gearbox mount over time.

The method may further comprise:

determining an amplitude of the measured axial distance to the gearbox mount; and

triggering an alert if the amplitude of the measured runout exceeds a first predetermined amplitude threshold and/or an amplitude of the measured axial distance to the gearbox mount is above a third predetermined threshold.

Triggering the alert may cause a controller of the wind turbine to cease or derate operation of the wind turbine.

The displacement sensor may be a non-contact displacement sensor, such as an inductive displacement sensor or an optical displacement sensor.

According to a second aspect there is provided a system for monitoring a rotor shaft of a wind turbine, the system comprising:

a first displacement sensor configured to measure a runout of the rotor shaft during operation of the wind turbine, the first displacement sensor mounted to measure a radial distance to an outer surface of the rotor shaft; and

a computer connected to the first displacement sensor, the computer configured to record the measured runout over time and determine if the runout exceeds a predetermined threshold.

The computer may be configured to determine if the measured runout exceeds a predetermined threshold by:

determining an amplitude of the measured runout; and

determining if the amplitude exceeds a predetermined amplitude threshold.

The computer may be configured to trigger an alert if the measured runout exceeds the predetermined threshold.

The computer may comprise a local computer located on the wind turbine and a remote computer, the local computer configured to periodically transmit recorded runout measurements to the remote computer.

The amplitude may be a peak amplitude, an RMS amplitude or a peak to peak amplitude of the measured runout.

The system may further comprise:

a second displacement sensor mounted to measure a radial distance to an outer surface of the rotor shaft at an angle to the first displacement sensor,

wherein the computer is configured to:

measure a runout of the rotor shaft from the second displacement sensor during operation of the wind turbine;

record the measured runout from the second displacement sensor over time; and

determine if the measured runout from the second displacement sensor exceeds the predetermined threshold.

The second displacement sensor may be mounted orthogonally to the first displacement sensor.

The system may further comprise a third displacement sensor mounted to measure an axial distance to a rotor flange in a direction parallel to a rotational axis of the rotor shaft, the rotor flange connected to a first end of the rotor shaft, the computer configured to record the measured axial distance to the rotor flange over time.

The computer may be configured to:

determine an amplitude of the measured axial distance to the rotor flange; and

trigger an alert if the amplitude of the measured runout exceeds a first predetermined amplitude threshold and an amplitude of the measured axial distance to the rotor flange is below a second predetermined threshold.

The computer may be configured to:

measure a runout of the rotor shaft during operation of the wind turbine using a plurality of displacement sensors including the first displacement sensor, the plurality of displacement sensors mounted to measure a radial distance to an outer surface of the rotor shaft at different positions along the rotor shaft;

record the measured runout from the plurality of displacement sensors over time; and

determine if the measured and recorded runout exceeds the predetermined threshold for one or more of the plurality of displacement sensors.

The plurality of displacement sensors may be positioned around the rotor shaft between first and second bearings within which the rotor shaft is rotatably mounted.

An end of the rotor shaft may be connected to a gearbox comprising a gearbox mount, the system further comprising a fourth displacement sensor mounted to measure an axial distance to the gearbox mount in a direction parallel to a rotational axis of the rotor shaft, the computer configured to measure an axial distance to the gearbox mount using the fourth displacement sensor and record the measured axial distance to the gearbox mount over time.

The computer may be configured to:

determine an amplitude of the measured axial distance to the gearbox mount; and

trigger an alert if the amplitude of the measured runout exceeds a first predetermined amplitude threshold and an amplitude of the measured axial distance to the gearbox mount is above a third predetermined threshold.

The computer may be configured to cause a controller of the wind turbine to cease or derate operation of the wind turbine if the alert is triggered.

The displacement sensor may be a non-contact displacement sensor, such as an inductive displacement sensor or an optical displacement sensor.

According to a third aspect there is provided a computer program comprising instructions to cause a computer to perform the method according to the first aspect.

Detailed Description

The invention is described in further detail below by way of example and with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram of a wind turbine incorporating a system for monitoring a rotor shaft of the wind turbine.

Figure 2 is a schematic diagram of an example rotor shaft with various displacement and other sensors.

Figure 3 is a photograph of displacement sensors mounted adjacent a rotor shaft of a wind turbine;

Figure 4 is a plot of displacement over time for two displacement sensors;

Figure 5 is a plot of peak-peak displacement for multiple recordings from displacement sensors;

Figure 6 is a plot of peak-peak displacement over time for different positions along a rotor shaft of a first turbine;

Figure 7 is a plot of peak-peak displacement over time for different positions along a rotor shaft of a second turbine;

Figure 8 is a plot of peak-peak displacement over time for orthogonally mounted displacement sensors adjacent a rotor shaft of the first turbine;

Figure 9 is a plot of peak-peak displacement over time for orthogonally mounted displacement sensors adjacent a rotor shaft of the second turbine;

Figure 10 is a plot of displacement over time for a rotor flange and a rotor shaft;

Figure 11 is a plot of peak-to-peak displacement over time for the rotor flange and rotor shaft;

Figure 12 is a plot of axial displacement over time for first and second gearbox mounts;

Figure 13 is a plot of peak-to-peak displacement over time for the first and second gearbox mounts;

Figure 14 is a flow diagram of an example method of monitoring a rotor shaft of a wind turbine;

Figure 15 is a schematic diagram of an example system for monitoring a rotor shaft of a wind turbine; and

Figure 16 is a schematic diagram of an example local computer for the system of Figure 15.

Figure 1 illustrates schematically a partial view of a wind turbine 100 comprising a monitoring system 101 for monitoring a rotor shaft 121 of the turbine 100. Wind turbine blades 103a, 103b are attached to the hub 102 via pitch bearings 104a, 104b, which permit the blades 103a, 103b to be rotated about their longitudinal axes 117a, 117b, driving rotation of the rotor shaft 121. The wind turbine 100 will typically have three blades, two of which are shown in Figure 1. The hub 102 is rotatably mounted to a generator 105 via a gearbox 106, both of which are located in a nacelle 107 mounted on top of a tower 108. The rotor shaft 121 connects the hub 102 to the gearbox 106 and is mounted on first and second bearings 122, 123 for rotation about a rotational axis 124. The first bearing 122 may be termed an upwind bearing and the second bearing 123 may be termed a downwind bearing, based on the direction 125 of the prevailing wind.

A displacement sensor 109 is mounted close to the rotor shaft 121 for measuring runout of the rotor shaft 121. The runout measurement may provide an indication of the condition of the rotor shaft 121. Runout is a measure of deviation of a shaft from its central axis of rotation. A perfectly aligned rotor shaft with a perfectly circular outer surface will have zero runout. A misaligned shaft will exhibit a periodically varying runout. Applied stresses, particularly bending stresses, will result in a varying runout measurement. A structural defect such as a crack will tend to weaken the rotor shaft, resulting in a reduction in bending stiffness. This reduction in stiffness may be exhibited as an elevated runout measurement under loading.

Typical runout measurements for a well aligned rotor shaft of a wind turbine in good condition may be around 0.1-0.2mm. A runout measurement of 0.4mm may raise concerns and a fractured rotor shaft may exhibit a runout measurement of around 2.0mm prior to failure. These amplitudes will vary depending on the size of the wind turbine and the type of rotor shaft, and are provided only as illustrative examples.

Runout measurements are typically performed periodically on the rotor shaft of a wind turbine using a manual dial indicator. If the manual dial indicator runout measurement is less than 1 mm, the rotor shaft is generally considered healthy. Performing manual dial indicator runout measurements periodically results in limited data on measured runout over time and how any changes with loading may affect this. Continuous monitoring of the dynamic loading of the rotor shaft during operation is therefore preferable to detect abnormal runout earlier than regular site inspections.

The monitoring system 101 may also comprise various other sensors, which may be mounted around or on the pitch bearings 104a, 104d, blades 103a, 103b or blade roots to enable the condition of the pitch bearings 104a, 104b and blade attachments to be monitored, as for example described in GB2209752.1 and GB2218937.7, the disclosures of which are incorporated herein by reference. The sensors may include one or more acoustic sensors, vibration sensors and displacement sensors. Further sensors may be located along the blades 104a, 104b for detecting damage events, or potential damage events, by measurement of vibration or displacement of the pitch bearings and/or the blades 104a, 104b. Sensor data is received by a computer 110 and recorded.

The computer 110 may communicate with a controller 111 of the wind turbine via a wired or wireless connection 112. The computer 110 may communicate to a network 113 via the controller 111 and/or via one or more wireless or wired connections 114, 115. The connections 114, 115 may for example be 4G or 5G radio communications links. Data recorded by the computer 110 may be periodically transmitted to a remote computer 116 via the network 113 for analysis. Analysis of the recorded data may also or alternatively be carried out locally by the computer 110.

The displacement sensor 109 is mounted to measure a radial distance to an outer surface of the rotor shaft 121. The computer 110 is configured to record the measured runout over time. The computer 110, or a remote computer 116, determines if the runout exceeds a predetermined threshold. The predetermined threshold represents a runout amplitude above which would suggest a significant weakening of the rotor shaft 101, which could for example be due to a crack. If the runout exceeds the predetermined threshold, the wind turbine may for example require visual inspection or its operation may need to be temporality ceased or derated. The predetermined threshold may be user configurable and may be based on, for example, estimates from simulations or measurements of rotor shafts recorded from other wind turbines.

The computer 110 or remote computer 116 may be further configured to analyse the measured runout and determine an amplitude of the measured runout. The runout amplitude may for example be defined as a peak amplitude, a peak-peak amplitude or an RMS amplitude, any of which may be taken from measurements over a plurality of rotations of the rotor shaft 121. The computer 110 or 116 may be further configured to trigger an alert if the runout magnitude exceeds a predetermined runout amplitude threshold.

The computer 110 may be configured to transmit the alert as a signal transmitted from the wind turbine 100 to the remote computer 116 via the network 113. The network 113 may operate via a wireless connection, such as 4G or Wi-Fi, or may operate via a physical wired connection such as ethernet. The data recorded by the computer 110 may be periodically transmitted to the remote computer 116 via the network 113 for analysis. The time interval between recording data and the length of time spent recording each data set may be user configurable. For example, the computer 110 may record the measured runout continuously for a period of 20 seconds every 6 hours.

The computer 110 may be configured to transmit the recorded runout data to a site server. The site server may store the runout data from a plurality of wind turbines present on a site. For example, each wind turbine on a site may comprise a system 101 for monitoring the rotor shaft 121 of each respective wind turbine. A plurality of computers 110 may then transmit their respective recorded runout data to the site server independently. The site server may then periodically transmit the data recorded by the plurality of computers 110 to the remote computer 116. In some embodiments, the data may be pushed to a cloud data storage service such as AWS, such that the data is accessible by the remote computer 116.

The computer 110, or the remote computer 116, may be configured to transmit the alert signal to a controller 111 of the wind turbine 100. The controller 111 may be configured to cause the wind turbine 100 to cease or derate operation on receiving the alert signal.

The displacement sensor 109 may provide an analogue signal representing the radial distance to an outer surface of the rotor shaft 121 to the computer 110. The computer 110 may sample the analogue signal to provide data representing the measured runout over time. The sampling rate of the measured runout data recorded by computer during the measurement period may be user configurable. The sampling rate may for example be around 100 Hz. The displacement sensor 109 may be a non-contact displacement sensor, for example an inductive displacement sensor or an optical displacement sensor. An example inductive displacement sensor may have a 1 μm resolution and a 20 mm circular sensing diameter.

Figure 2 is a simplified schematic diagram of an example rotor shaft 121 for the wind turbine 100 of Figure 1, together with other connected components. The rotor shaft 121 is shown in side view, while the gearbox 106 is shown in top view. A rotor flange 201 is connected to a first, or upwind, end of the rotor shaft 121 and the gearbox 106 is connected to an opposing second, or downwind, end of the rotor shaft 121. The rotor flange connects the first end of the rotor shaft 121 to the hub 102 of the wind turbine 100 (see Figure 1). The rotor shaft 121 is mounted to first and second bearings 122, 123 between the rotor flange 201 and the gearbox 106. An output shaft 202 of the gearbox

106 drives a generator 105 (Figure 1). The gearbox 106 is mounted on first and second (or port side and starboard side) gearbox mounts, or torque arms, 203a, 203b.

Various displacement sensors 109a-g are shown in Figure 2 positioned at various places around the rotor shaft 121, rotor flange 201 and gearbox mounts 203a, 203b. As a minimum requirement, at least one displacement sensor is mounted to measure a radial distance to an outer surface of the rotor shaft 121, i.e. one of the displacement sensors 109a, 109c-e. The displacement sensors 109a-g may each be non-contact sensors such as inductive displacement sensors or optical based sensors. Inductive displacement sensors tend to be advantageous over optical-based sensors due to their ability to provide reliable displacement measurements that are less affected by the condition of the surface being measured.

A displacement sensor 109b is shown positioned to measure an axial distance to the rotor flange 201, i.e. to measure a distance to the rotor flange in a direction parallel to the rotational axis 124. The displacement sensor 109b can thereby measure flexure of the rotor flange 201, which provides a measure of bending stresses being applied to the rotor shaft 121 during operation of the wind turbine. More than one such displacement sensor 109b may be mounted adjacent the rotor flange 201 to measure an axial distance at different locations around the rotor flange 201. Axial measurements taken for example at 90 degrees apart can provide an indication of the direction of bending the rotor shaft 121 is being subjected to. Combining the displacement measurements from two or more such displacement sensors 109b can thereby provide an indication of bending regardless of the direction.

Each of the displacement sensors 109a, 109c-e, measure a radial distance to the outer surface of the rotor shaft 121 and are mounted at different positions along the rotor shaft 121 between the first and second bearings 122, 123. In some situations, one or more of the radial displacement sensors may be positioned between the second bearing 123 and the gearbox 106, for example where access to the rotor shaft 121 between the first and second bearings 122, 123 may be limited.

Each of the displacement sensors 109a-e may be mounted to measure a displacement relative to one or both of the bearings 122, 123, which provide a fixed position from which to determine displacements. For displacement sensors 109a, 109c-e, each of the sensors may be mounted on a bar 301 (see Figure 3) extending between the first and second bearings 122, 123, as shown in Figure 3. Displacement sensor 109b may be mounted to either the first bearing 122 or a base on which the first bearing 122 is mounted.

The gearbox mounts 203a, 203b act to resist torque applied to the rotor shaft 121 against the gearbox but permit a small degree of movement to allow for a degree of flexibility and vibration isolation during operation of the wind turbine. The amount of axial movement of the gearbox mounts 203a, 203b can provide an indication of how much the rotor shaft 121 is bending. Increased bending of the rotor shaft 121 will tend to result in axial movement of the gearbox mounts 203a, 203b increasing. Further displacement sensors 109f, 109g may be mounted to measure this axial movement. One of the displacement sensors 109f, 109g may be sufficient to measure this movement, since the movement will tend to be roughly equal and out of phase for each of the two gearbox mounts 203a, 203b.

Vibration sensors 204a-c may be mounted on or around the gearbox 106, shown in Figure 2 on the gearbox mounts 203a, 203b and on the gearbox itself 106. The vibration sensors 204a-c provide an indication of the operation of the gearbox. Signals from the vibration sensors 204a-c can for example be used to determine the extent to which gears in the gearbox are worn.

Rotation sensors 205a, 205b may be provided on the rotor shaft 121 and the output shaft 202 to determine a rotational speed of the rotor shaft 121 and the output shaft 202. Each rotation sensor 205a, 205b may also be a non-contact displacement sensor located adjacent a feature on the respective shaft 121, 202 so that a rotation can be detected when the feature passes the sensor. The feature on the rotor flange 201 may for example be a bolt or series of bolts on the rotor flange 201 that connect the rotor flange 201 to the hub 102 or another index feature.

Figure 3 is a photograph of an example rotor shaft 121 with displacement sensors 109c-e mounted to a bar 301 extending between the first and second bearings 122, 123 to measure a radial distance to the outer surface of the rotor shaft 121 at three different positions along the rotor shaft 121. A first displacement sensor 109c is positioned towards a first, or upwind, end of the rotor shaft closer to the first bearing 122 (Figure 2). A second displacement sensor 109d is positioned midway between the first and second bearings 122, 123. A third displacement sensor 109e is positioned towards a second, or downwind, end of the rotor shaft closer to the second bearing 123. The displacement sensors 109c-e are each non-contact inductive sensors, each with a resolution of around 1 μm and a sensing diameter of around 20 mm.

In addition to the sensors 109c-e positioned along the side of the rotor shaft 121, each measuring a radial distance to the rotor shaft 121 in a horizontal direction, one or more further displacement sensors may be mounted for measuring a radial distance to the rotor shaft 121 is a vertical direction, as indicated in Figure 2 by displacement sensor 109a, i.e. positioned at around 90 degrees from the sensors 109c-e. Measuring radial displacement at two or more different angles around the rotor shaft may enable the displacement measurements to detect displacements due to bending of the rotor shaft in any direction.

Figure 4 illustrates examples of recorded runout measurements 401, 402 from respective first and second displacement sensors mounted orthogonally about a rotor shaft. The runout measurements 401, 402 were recorded over a 20s period, covering around 4 rotations of the rotor shaft. In an example implementation, analogue displacement data was recorded in bursts of 20 seconds every 6 hours. The length of each recording burst and the interval between each recorded burst was user configurable. These time domain waveforms were recorded by the local computer on the wind turbine and transmitted to a remote computer for analysis. In a general aspect, the measured runout may be periodically recorded over a preset time period covering a plurality of rotations of the rotor shaft. The preset time period may for example be greater than 10 seconds, optionally between 10 and 30 seconds. The preset time period may cover at least two rotations of the rotor shaft, for example between 2 and 10 rotations. The measured runout may be recorded at intervals of at least 1 hour, for example at intervals between around 1 hour and 24 hours.

A simple form of analysis is to determine a peak to peak displacement for each trace, the results of which are illustrated in Figure 5, which shows peak to peak displacements measured over a period of around seven days of monitoring, each point in the traces 501, 502 being a peak to peak displacement measurement from one recorded burst of displacement data. Each reading is between around 0.2 and 0.4 mm, which was determined to be in the normal range for the rotor shaft being monitored. A peak to peak threshold 503 of 1.1 mm was then determined on the basis of the recorded measurements. The threshold 503 could then be left set to allow ongoing unsupervised monitoring of the rotor shaft during subsequent measurements, enabling an alert to be automatically triggered if any of the runout measurements reached the threshold 503. In a general aspect therefore, the threshold may be determined based on previously recorded runout measurements, which will typically be taken on the same rotor shaft although in some cases a threshold may be set for a type of rotor shaft and wind turbine.

Although peak-peak displacements are shown in Figure 5, other ways of determining amplitude of the displacement may be used, for example by determining an RMS amplitude or a peak amplitude. An average RMS amplitude over each recorded period may be advantageous because this will tend to reduce the effect of any noise that may be part of the displacement signal and is uncorrelated to actual movement of the rotor shaft. To further reduce the effect of noise, the recorded amplitude may be low-pass filtered to remove higher frequency components.

Table 1 below provides a summary of peak-peak displacement readings for rotor shafts of two different turbines (termed Turbine 1 and Turbine 2), the readings being taken at upwind and downwind ends of the rotor shaft and, for the downwind end, at two different orthogonal positions around the rotor shaft. The manual dial indicator measurements, which were measured over a single revolution, show a consistent 0.13 mm runout for Turbine 1 and a variation from 0.13 to 0.20 mm for Turbine 2. The non-contact measurements, which were taken over a 20s sampling period covering around 5 rotations, indicated a higher reading at the downwind side for Turbine 1, indicating a possible issue with either the rotor shaft or the adjacent bearing. This was subsequently confirmed by the rotor shaft being determined to have a fracture. The measurements therefore indicate that continuous monitoring with non-contact displacement sensors is advantageous to detect possible fractures in rotor shafts. The measurements also tend to indicate that more than one displacement sensor at different positions along the shaft is advantageous because high runout measurements may be located in one location and not another.

Table 1 – Recorded peak-peak displacements for dial indicator and non-contact measurements on two wind turbine rotor shafts.

Location	Dial Indicator Turbine 1	Dial Indicator Turbine 2	Non-Contact Turbine 1	Non-Contact Turbine 2
Upwind	0.13mm	0.20mm	0.12mm	0.13mm
Downwind Top	0.13mm	0.15mm	1.02mm	0.35mm
Downwind Side	0.13mm	0.13mm	0.95mm	0.24mm
Average	0.13mm	0.16mm	0.70mm	0.24mm

The radial peak-peak measurements taken over a period of several days on the above-mentioned rotor shafts are illustrated in Figures 6 and 7. Figure 6 illustrates the radial peak-peak displacements for Turbine 1 while Figure 7 illustrates the radial peak-peak measurements for Turbine 2. In Figure 6, the upwind 601, midpoint 602 and downwind 603 measurements for Turbine 1 are shown. In Figure 7, the upwind 701, midpoint 702 and downwind 703 measurements for Turbine 2 are shown. For Turbine 1, the midpoint and downwind measurements 602, 603 consistently show a substantial increase in peak-peak displacement over the upwind measurements 601. Depending on the threshold level chosen, these measurements may cause an alert to be triggered. For Turbine 2, however, all measurements tend to show a lower overall peak-peak displacement, although with increased variation for the upwind and midpoint measurements 701, 702.

Figures 8 and 9 illustrate radial peak-peak measurements for rotor shafts of Turbines 1 and 2 respectively for displacement sensors mounted at the downwind end of the rotor shaft and arranged orthogonally to one another, in this case with one displacement sensor along the side of the rotor shaft and another at the top of the rotor shaft. Figure 8 shows the top 801 and side 802 measurements for Turbine 1. Figure 9 shows the top 901 and side 902 measurements for Turbine 2. Figure 8 also shows a proposed threshold peak-peak amplitude level 803 of around 1.2 mm. In line with the measurements in Figures 6 and 7, the peak-peak displacements for Turbine 1 are substantially higher than those for Turbine 2, indicating a potential issue with the rotor shaft for Turbine 1. The displacement measurements in each case differ between the side and top orientations by around 0.1 mm. It was determined that these differences were real, i.e. indicating increased flexure of the rotor shaft in the vertical direction. This was done through comparing 90 degree phase-shifted versions of the raw displacement data, which indicated a clear correlation between the two signals.

Figure 10 illustrates plots of displacement measured over time by a displacement sensor mounted to measure an axial distance to the rotor flange in comparison to displacement measured by a displacement sensor mounted to measure radial distance to the rotor shaft. The rotor flange displacement 1001 tends to correlate with the rotor shaft displacement 1002, particularly for the period between around 10 and 20 s on the plot. This indicates that the increases in displacement amplitude for the rotor shaft during the period from 15 to 20 s are caused by an increase in bending load on the rotor shaft, rather than by a weakening of the rotor shaft. Measured peak-peak measurements of the rotor flange and rotor shaft are shown over a period of several days in Figure 11, indicating rotor flange measurements 1101 and rotor shaft measurements 1102. These measurements indicate that the rotor flange displacement measurements can be used to rule out high rotor shaft displacement measurements if the rotor flange displacements are also high for the same period. In a general aspect therefore, an alert may be triggered if an amplitude of the measured runout of the rotor shaft exceeds a first predetermined threshold and an amplitude of the measured axial distance to the rotor flange is below a second predetermined threshold. As a result, if a high rotor shaft runout is measured in combination with a low rotor flange displacement, this will tend to indicate a weakening of the rotor shaft rather than high loading that would affect both measurements similarly.

Displacement measurements taken on one or both of the gearbox mounts 203a, 203b (Figure 2) may also be used as validation for rotor shaft measurements. Figure 12 illustrates recorded displacement measurements taken on displacement sensors 204a, 204b positioned to measure an axial distance to first and second gearbox mounts 203a, 203b. The measurements 1201, 1202 are roughly anti-correlated, i.e. for large loadings the displacement from one sensor will tend to move in the opposite direction to the other. The corresponding peak-peak displacements over time 1301, 1302, shown in Figure 13, tend to be of similar magnitudes. A displacement sensor on only one of the gearbox mounts may therefore be sufficient to determine movement of the gearbox. Fracture of the rotor shaft will tend to result in excessive fore-aft movement of the gearbox, so measuring displacement of the gearbox mounts can be used to validate increased rotor shaft runout displacements. In a general aspect therefore, an alert may be triggered if an amplitude of the measured runout of the rotor shaft exceeds a first predetermined threshold and an amplitude of the measured axial distance to a gearbox mount is above a third predetermined threshold.

Figure 14 illustrates schematically a flow diagram of an example method of monitoring a rotor shaft of a wind turbine. The method includes a first step 1401 of measuring runout, using one or more displacement sensors mounted to measure a radial distance to an outer surface of the rotor shaft. The measured runout is recorded at step 1402, which as described above may be carried out periodically and for a preset time limit or a preset number of rotations of the rotor shaft. At step 1403, which may be carried out locally or remotely, the recorded runout measurement is analysed to determine if the runout exceeds a predetermined threshold. An addition step of transmitting the recorded runout to a remote computer may be included between steps 1402 and 1403. If the threshold is exceeded, an alert may be triggered at step 1404. Otherwise, the process repeats with a further measurement at step 1401. If an alert is triggered, this may result in operation of the wind turbine being ceased or derated at step 1405.

Figure 15 illustrates schematically an example system 101 for monitoring a rotor shaft of a wind turbine. The system 101 comprises one or more displacement sensors 109a-g. One or more of the displacement sensors 109a-g are mounted to measure a radial distance to an outer surface of the rotor shaft. Other ones of the displacement sensors may be mounted to measure an axial distance to the rotor flange or to a gearbox mount, as described above. A local computer 110 located on the wind turbine is connected to record displacement signals from each of the displacement sensors 109a-g. The local computer 110 may periodically record and transmit recorded displacement data to a remote computer 116. Transmission of the recorded displacement data may be done via a wireless connection, for example via a mobile data connection, that connects the local computer 110 to the remote computer 116 via the internet 113. Signal processing may be carried out by the remote computer 116, with the local computer 110 performing data gathering and transmission functions. The remote computer 116 may determine if the measured runout exceeds a predetermined threshold.

Operation of the system 101 is as described above, with processing of the recorded displacement signal data typically being carried out by the remote computer 116. The remote computer 116 may for example be a cloud-based computing service and may receive displacement signal data from a plurality of wind turbine monitoring systems.

Referring to Figure 16, an example computer 110 for the system described above includes a non-transitory computer-readable medium with program instructions stored thereon for performing the above-described method. In some embodiments, the computer 110 may include at least one memory 1603, at least one processor 1602, a network interface 1604 and a sensor interface 1606 for receiving signals from one or more displacement sensors. Additionally or alternatively, in other embodiments the computer 110 may include a different type of computing device operable to carry out the program instructions. For example, in some embodiments, the computer 110 may include an application-specific integrated circuit (ASIC) that performs processor operations, or a field-programmable gate array (FPGA).

While the local computer 110 of the system may be included in a single unit and/or provided in a distinct housing 1601, as shown in figure 16, in other embodiments at least some portion of the computer 110 may be separate from the housing 1601. For example, in some embodiments, one or more parts of the computer 110 may be part of a smartphone, tablet, notebook computer, or wearable device. Further, in some embodiments, the computer 110 may be a client device, i.e., a device actively operated by the user, while in other embodiments, the computer 110 may be a server device, e.g., a device that provides computational services to a client device. Moreover, other types of computational platforms are also possible in embodiments of the disclosure.

The memory 1603 is a computer-usable memory, such as random-access memory (RAM), read-only memory (ROM), non-volatile memory such as flash memory, a solid-state drive, a hard-disk drive, an optical memory device, and/or a magnetic storage device. The memory 1603 may be used to store recorded displacement data prior to being transmitted.

The processor 1602 of the computer 110 includes computer processing elements, e.g., a central processing unit (CPU), a digital signal processor (DSP), or a network processor. In some embodiments, the processor 1602 may include register memory that temporarily stores instructions being executed and corresponding data and/or cache memory that temporarily stores performed instructions. In certain embodiments, the memory 1603 stores program instructions that are executable by the processor 802 for carrying out the methods and operations of the disclosure, as described herein.

The network interface 1604 provides a communications medium, such as, but not limited to, a digital and/or an analog communication medium, between the computer 110 and other computing systems or devices. In some embodiments, the network interface 1604 may operate via a wireless connection, such as IEEE 802.11 or BLUETOOTH, using an antenna 1605 to send and receive signals, while in other embodiments the network interface 1604 may operate via a physical wired connection, such as an Ethernet connection. Still in other embodiments, the network interface 1604 may communicate using another convention. The network interface 1604 may also or alternatively operate according to a wireless telecommunications standard, for example a 3G, 4G or 5G standard, to transmit and receive data.

Other embodiments are with the scope of the invention, which is defined by the appended claims.

CLAIMS

1. A method of monitoring a rotor shaft (121) of a wind turbine (100), the method comprising:

measuring a runout of the rotor shaft (121) during operation of the wind turbine (100) using a first displacement sensor (109) mounted to measure a radial distance to an outer surface of the rotor shaft (121);

recording the measured runout over time; and

determining if the measured runout exceeds a predetermined threshold.

2. The method of claim 1, wherein the step of determining if the measured runout exceeds a predetermined threshold comprises:

determining an amplitude of the measured runout; and

determining if the amplitude exceeds a predetermined amplitude threshold.

3. The method of claim 1 or claim 2, comprising triggering an alert if the measured runout exceeds the predetermined threshold.

4. The method of claim 2 or claim 3, wherein the amplitude is a peak amplitude, an RMS amplitude or a peak to peak amplitude of the measured runout.

5. The method of any preceding claim, further comprising:

measuring a runout of the rotor shaft (121) during operation of the wind turbine (100) using a second displacement sensor (109e) mounted to measure a radial distance to an outer surface of the rotor shaft (121) at an angle to the first displacement sensor (109a);

recording the measured runout from the second displacement sensor (109e) over time; and

determining if the measured runout from the second displacement sensor (109e) exceeds the predetermined threshold.

6. The method of claim 5, wherein the second displacement sensor (109e) is mounted orthogonally to the first displacement sensor (109e).

7. The method of claim 1, further comprising measuring an axial distance to a rotor flange (201) connected to a first end of the rotor shaft using a third displacement sensor (109b) mounted to measure a distance to the rotor flange (201) in a direction parallel to a rotational axis (124) of the rotor shaft (121) and recording the measured axial distance to the rotor flange (201) over time.

8. The method of claim 7, further comprising:

determining an amplitude of the measured axial distance to the rotor flange (201); and

triggering an alert if the amplitude of the measured runout exceeds a first predetermined amplitude threshold and an amplitude of the measured axial distance to the rotor flange (201) is below a second predetermined threshold.

9. The method of any preceding claim, comprising:

measuring a runout of the rotor shaft (121) during operation of the wind turbine (100) using a plurality of displacement sensors (109a, 109c, 109d, 109e) including the first displacement sensor (109), the plurality of displacement sensors (109a, 109c, 109d, 109e) mounted to measure a radial distance to an outer surface of the rotor shaft (121) at different positions along the rotor shaft;

recording the measured runout from the plurality of displacement sensors (109a, 109c-e) over time; and

determining if the measured and recorded runout exceeds the predetermined threshold for one or more of the plurality of displacement sensors (109a, 109c-e).

10. The method of claim 9, wherein the plurality of displacement sensors (109a, 109c-e) are positioned around the rotor shaft (121) between first and second bearings (122, 123) within which the rotor shaft (121) is rotatably mounted.

11. The method of claim 1, wherein an end of the rotor shaft is connected to a gearbox (106) comprising a gearbox mount (203a, 203b), the method further comprising measuring an axial distance to the gearbox mount (203a, 203b) using a fourth displacement sensor (109f, 109g) mounted to measure an axial distance to the gearbox mount (203a, 203b) in a direction parallel to a rotational axis (124) of the rotor shaft (121) and recording the measured axial distance to the gearbox mount (203a, 203b) over time.

12. The method of claim 11, further comprising:

determining an amplitude of the measured axial distance to the gearbox mount (203a, 230b); and

triggering an alert if the amplitude of the measured runout exceeds a first predetermined amplitude threshold and an amplitude of the measured axial distance to the gearbox mount (203a, 203b) is above a third predetermined threshold.

13. The method of any one of claims 3, 8 or 12 wherein triggering the alert causes a controller (111) of the wind turbine (100) to cease or derate operation of the wind turbine (100).

14. The method of any preceding claim, wherein the displacement sensor (109a-g) is a non-contact displacement sensor, such as an inductive displacement sensor or an optical displacement sensor.

15. A system (101) for monitoring a rotor shaft (121) of a wind turbine (100), the system (101) comprising:

a first displacement sensor (109) configured to measure a runout of the rotor shaft (121) during operation of the wind turbine (100), the first displacement sensor (109) mounted to measure a radial distance to an outer surface of the rotor shaft (121); and

a computer (110, 116) connected to the first displacement sensor (109), the computer (110, 116) configured to record the measured runout over time and determine if the runout exceeds a predetermined threshold.

16. The system (101) of claim 15, wherein the computer (110, 116) is configured to determine if the measured runout exceeds a predetermined threshold by:

determining an amplitude of the measured runout; and

determining if the amplitude exceeds a predetermined amplitude threshold.

17. The system (101) of claim 15 or claim 16, wherein the computer (110, 116) is configured to trigger an alert if the measured runout exceeds the predetermined threshold.

18. The system (101) of claim 16 or claim 17, wherein the amplitude is a peak amplitude, an RMS amplitude or a peak to peak amplitude of the measured runout.

19. The system (101) of any one of claims 15 to 18, further comprising:

a second displacement sensor (109e) mounted to measure a radial distance to an outer surface of the rotor shaft (121) at an angle to the first displacement sensor (109a),

wherein the computer (110, 116) is configured to:

measure a runout of the rotor shaft (121) from the second displacement sensor (109e) during operation of the wind turbine (100);

record the measured runout from the second displacement sensor (109e) over time; and

determine if the measured runout from the second displacement sensor (109e) exceeds the predetermined threshold.

20. The system (101) of claim 19, wherein the second displacement sensor (109e) is mounted orthogonally to the first displacement sensor (109e).

21. The system (101) of claim 15, further comprising a third displacement sensor (109b) mounted to measure an axial distance to a rotor flange (201) in a direction parallel to a rotational axis (124) of the rotor shaft (121), the rotor flange (201) connected to a first end of the rotor shaft, the computer (110, 116) configured to record the measured axial distance to the rotor flange (201) over time.

22. The system (101) of claim 21, wherein the computer (110, 116) is configured to:

determine an amplitude of the measured axial distance to the rotor flange (201); and

trigger an alert if the amplitude of the measured runout exceeds a first predetermined amplitude threshold and an amplitude of the measured axial distance to the rotor flange (201) is below a second predetermined threshold.

23. The system (101) of any one of claims 15 to 22, wherein the computer (110, 116) is configured to:

measure a runout of the rotor shaft (121) during operation of the wind turbine (100) using a plurality of displacement sensors (109a, 109c, 109d, 109e) including the first displacement sensor (109), the plurality of displacement sensors (109a, 109c, 109d, 109e) mounted to measure a radial distance to an outer surface of the rotor shaft (121) at different positions along the rotor shaft;

record the measured runout from the plurality of displacement sensors (109a, 109c-e) over time; and

determine if the measured and recorded runout exceeds the predetermined threshold for one or more of the plurality of displacement sensors (109a, 109c-e).

24. The system (101) of claim 23, wherein the plurality of displacement sensors (109a, 109c-e) are positioned around the rotor shaft (121) between first and second bearings (122, 123) within which the rotor shaft (121) is rotatably mounted.

25. The system of claim 15, wherein an end of the rotor shaft is connected to a gearbox (106) comprising a gearbox mount (203a, 203b), the system (101) further comprising a fourth displacement sensor (109f, 109g) mounted to measure an axial distance to the gearbox mount (203a, 203b) in a direction parallel to a rotational axis (124) of the rotor shaft (121), the computer (110, 116) configured to measure an axial distance to the gearbox mount (203a, 203b) using the fourth displacement sensor (109f, 109g) and record the measured axial distance to the gearbox mount (203a, 203b) over time.

26. The system (101) of claim 25, wherein the computer (110, 116) is configured to:

determine an amplitude of the measured axial distance to the gearbox mount (203a, 230b); and

trigger an alert if the amplitude of the measured runout exceeds a first predetermined amplitude threshold and an amplitude of the measured axial distance to the gearbox mount (203a, 203b) is above a third predetermined threshold.

27. The system (101) of any one of claims 17, 22 or 26 wherein the computer (110, 116) is configured to cause a controller (104) of the wind turbine to cease or derate operation of the wind turbine if the alert is triggered.

28. The system (101) of any one of claims 15 to 27, wherein the displacement sensor (109a-g) is a non-contact displacement sensor, such as an inductive displacement sensor or an optical displacement sensor.

29. A computer program comprising instructions to cause a computer (110, 116) to perform the method according to any one of claims 1 to 14.

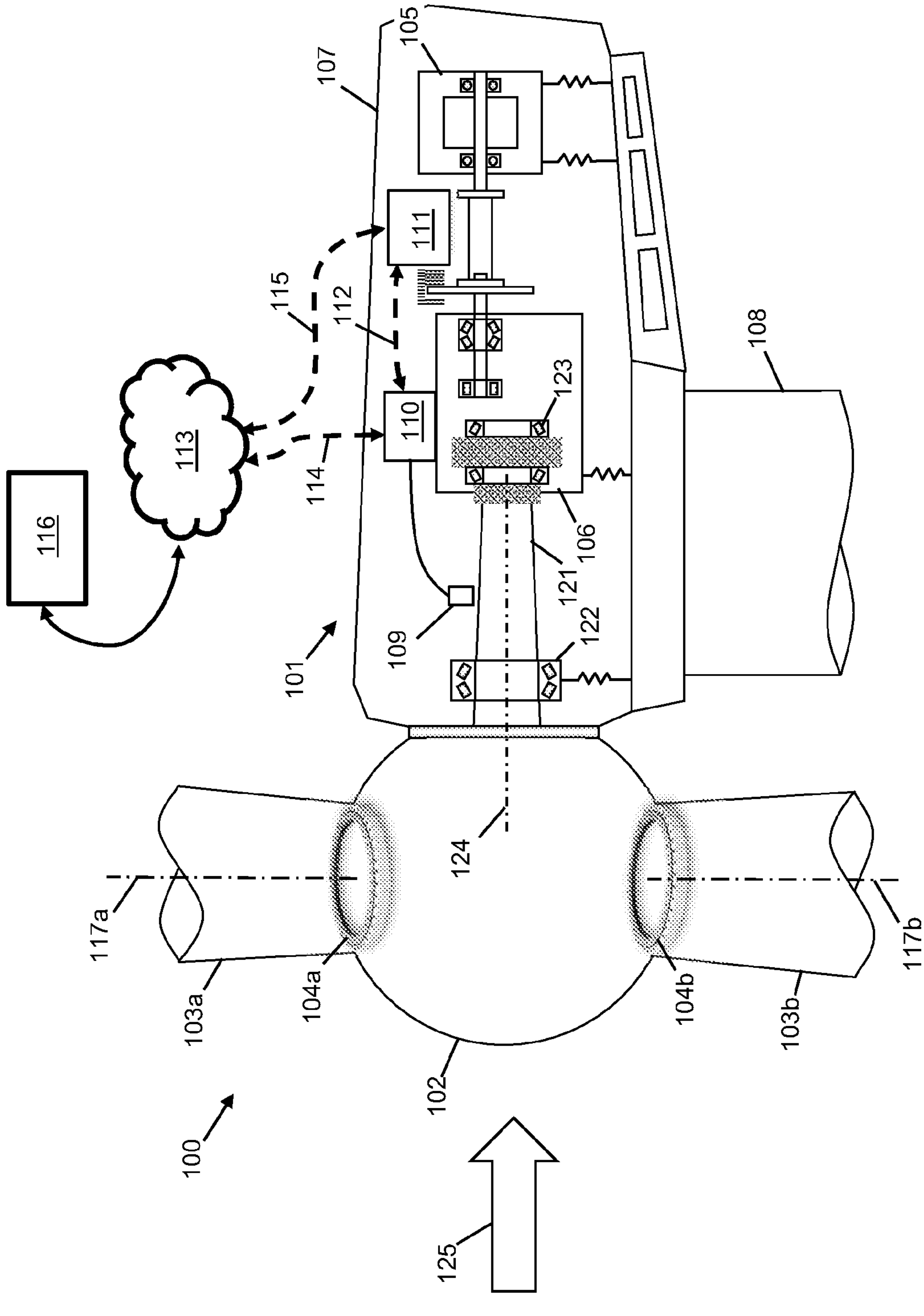
100
101
102
103a
103b
104a
104b
105
106
107
108
109
110
111
112
113
114
115
116
117a
117b
121
122
123
124
125

Fig. 1

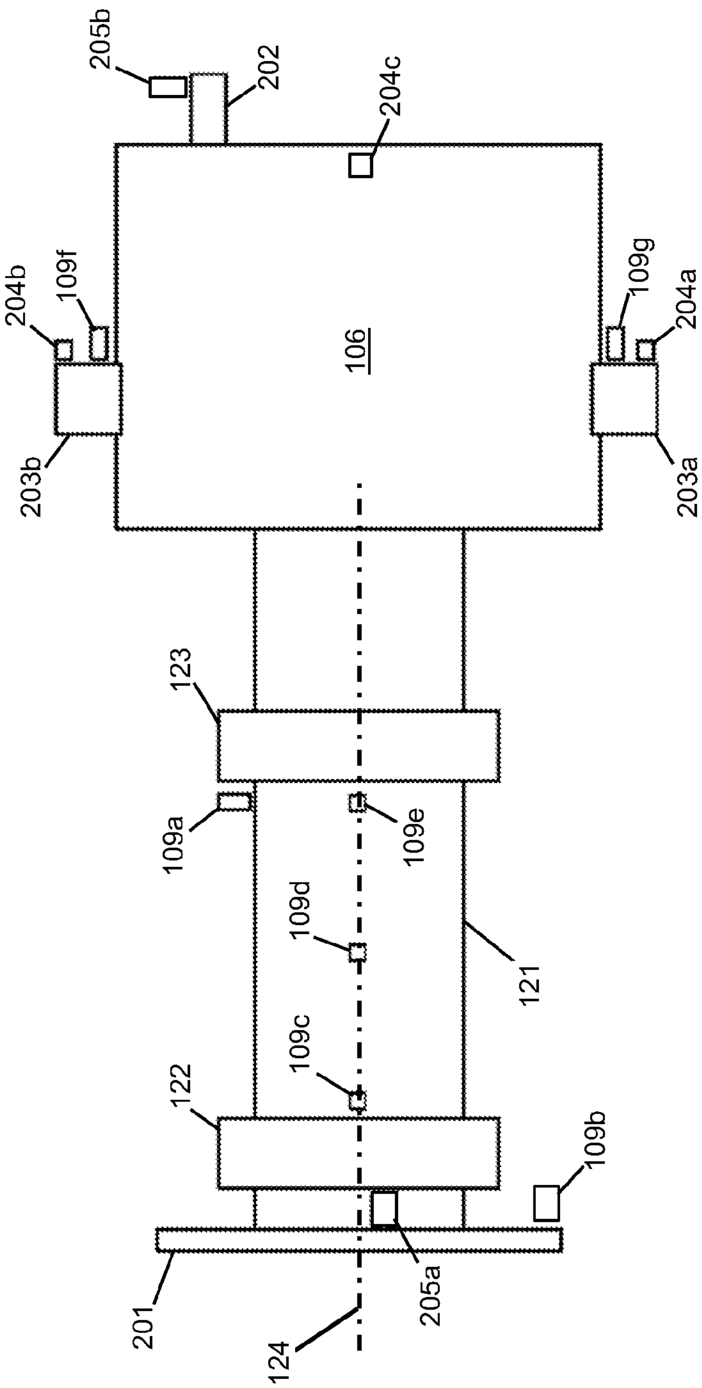
205b
202
204c
204b
109f
109g
204a
106
203b
203a
123
109a
109e
109d
121
109c
122
109b
205a
201
124

Fig. 2

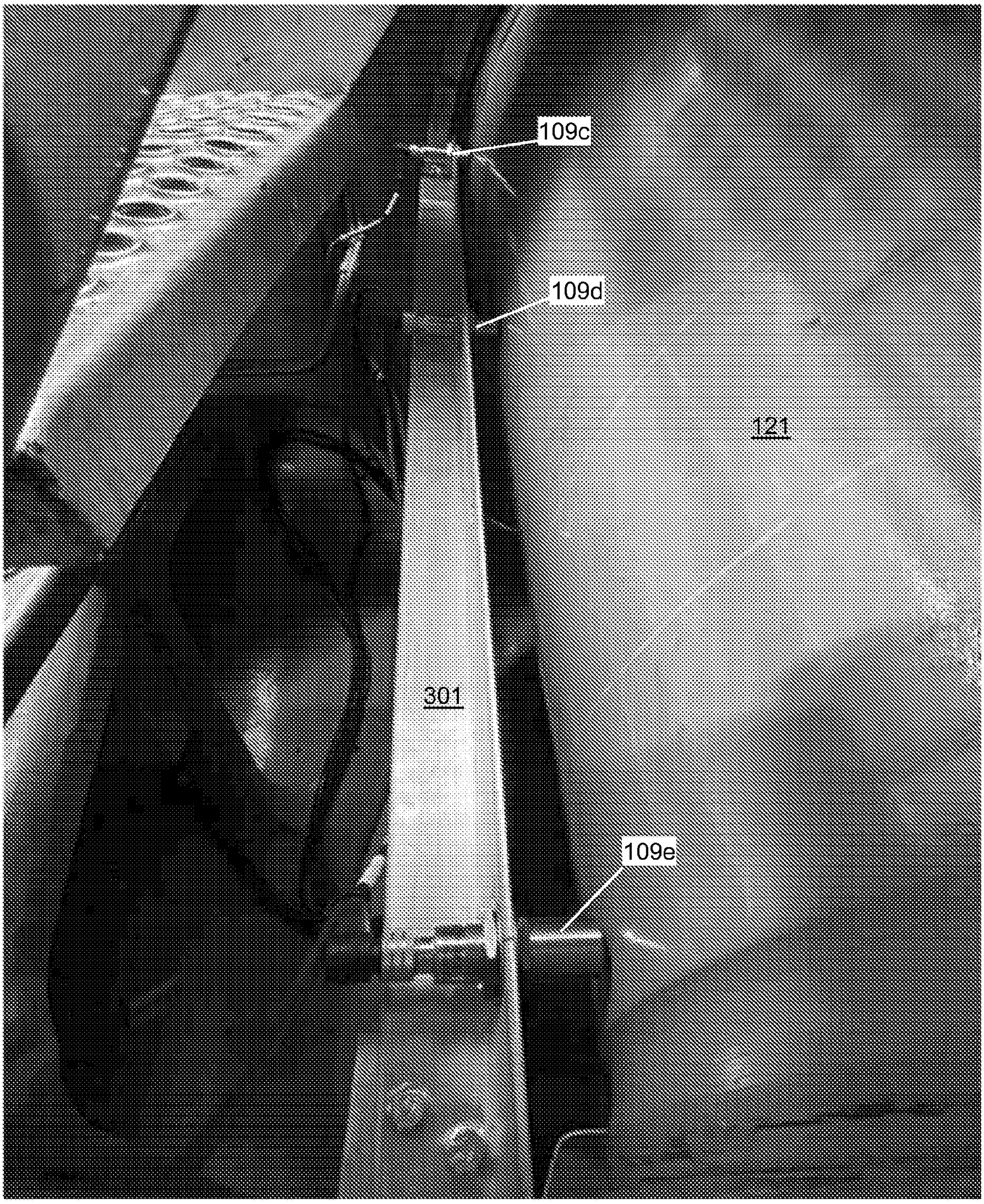

Fig. 3

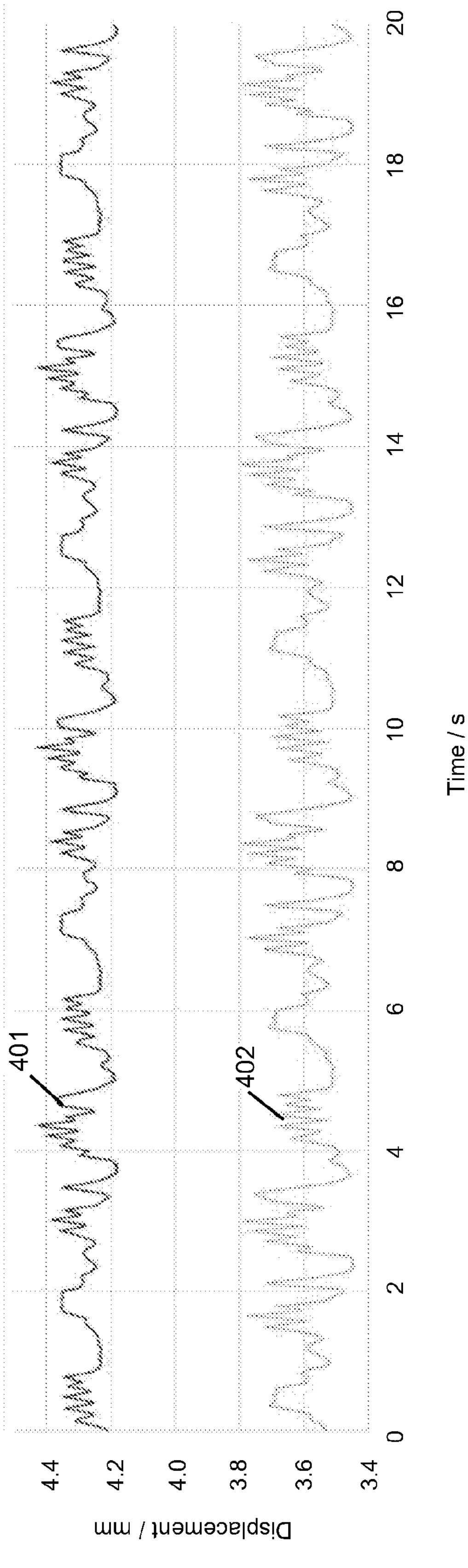
401
402
Displacement / mm
4.4
4.2
4.0
3.8
3.6
3.4
0
2
4
6
8
10
12
14
16
18
20
Time / s

Fig. 4

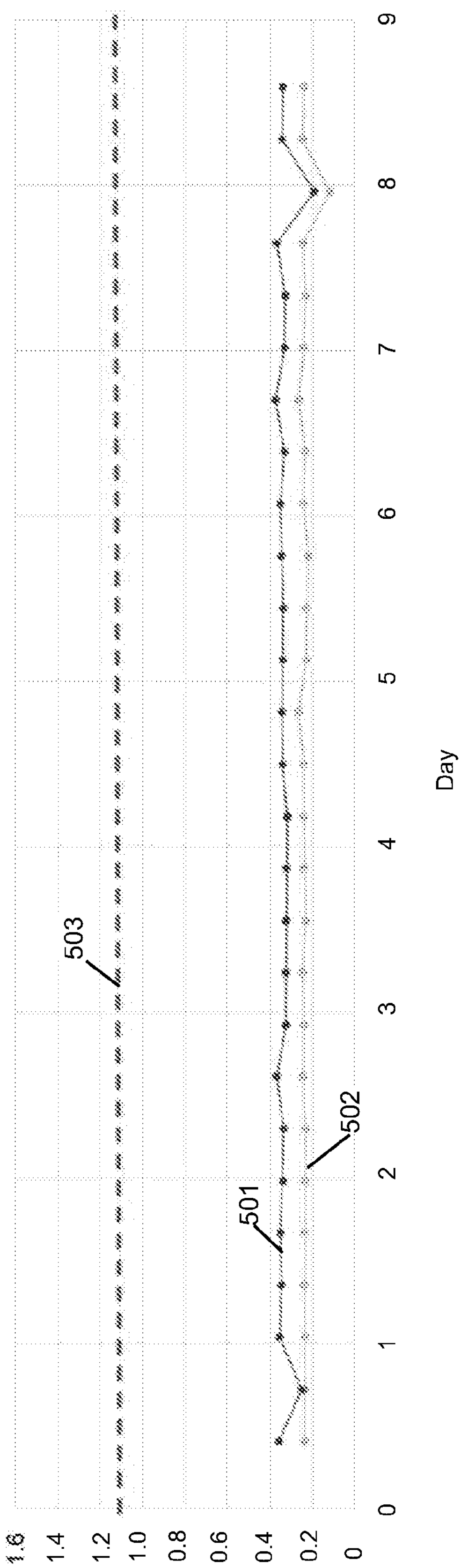
Peak-peak displacement / mm
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
Day
0
1
2
3
4
5
6
7
8
9
501
502
503

Fig. 5

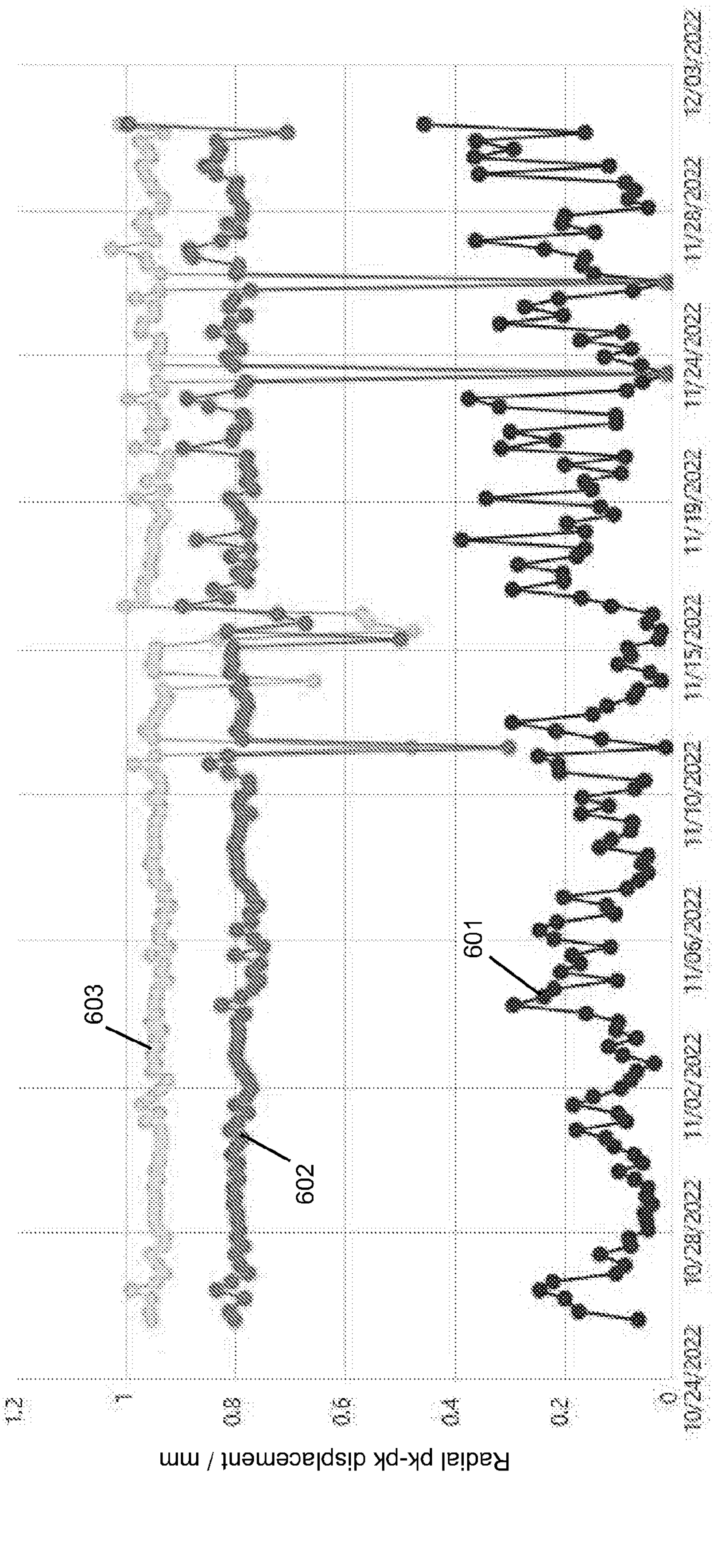
Radial pk-pk displacement / mm
1.2
1
0.8
0.6
0.4
0.2
0
10/24/2022
10/28/2022
11/02/2022
11/06/2022
11/10/2022
11/15/2022
11/19/2022
11/24/2022
11/28/2022
12/03/2022
601
602
603

Fig. 6

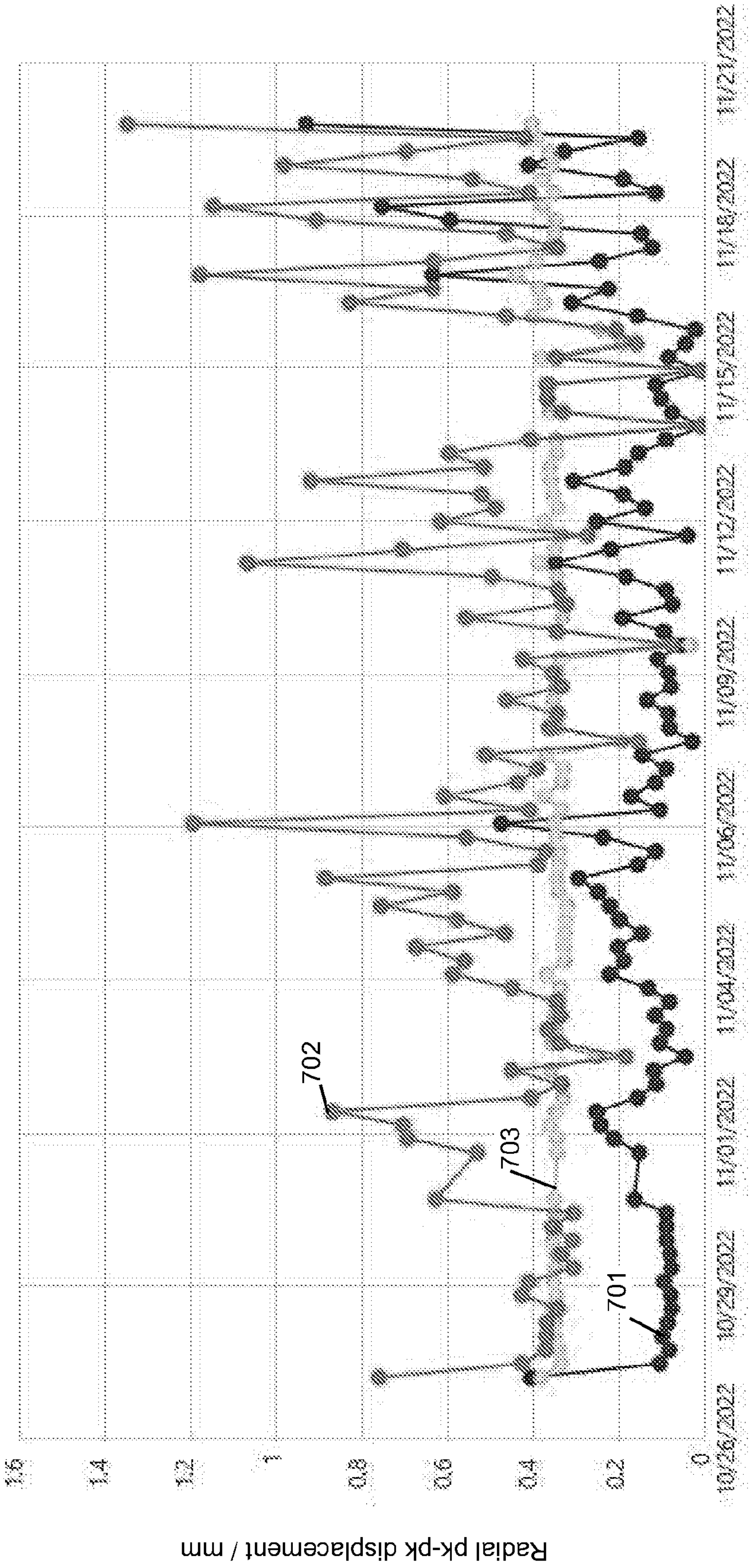
Radial pk-pk displacement / mm
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10/26/2022
10/29/2022
11/01/2022
11/04/2022
11/06/2022
11/09/2022
11/12/2022
11/15/2022
11/18/2022
11/21/2022
701
702
703

Fig. 7

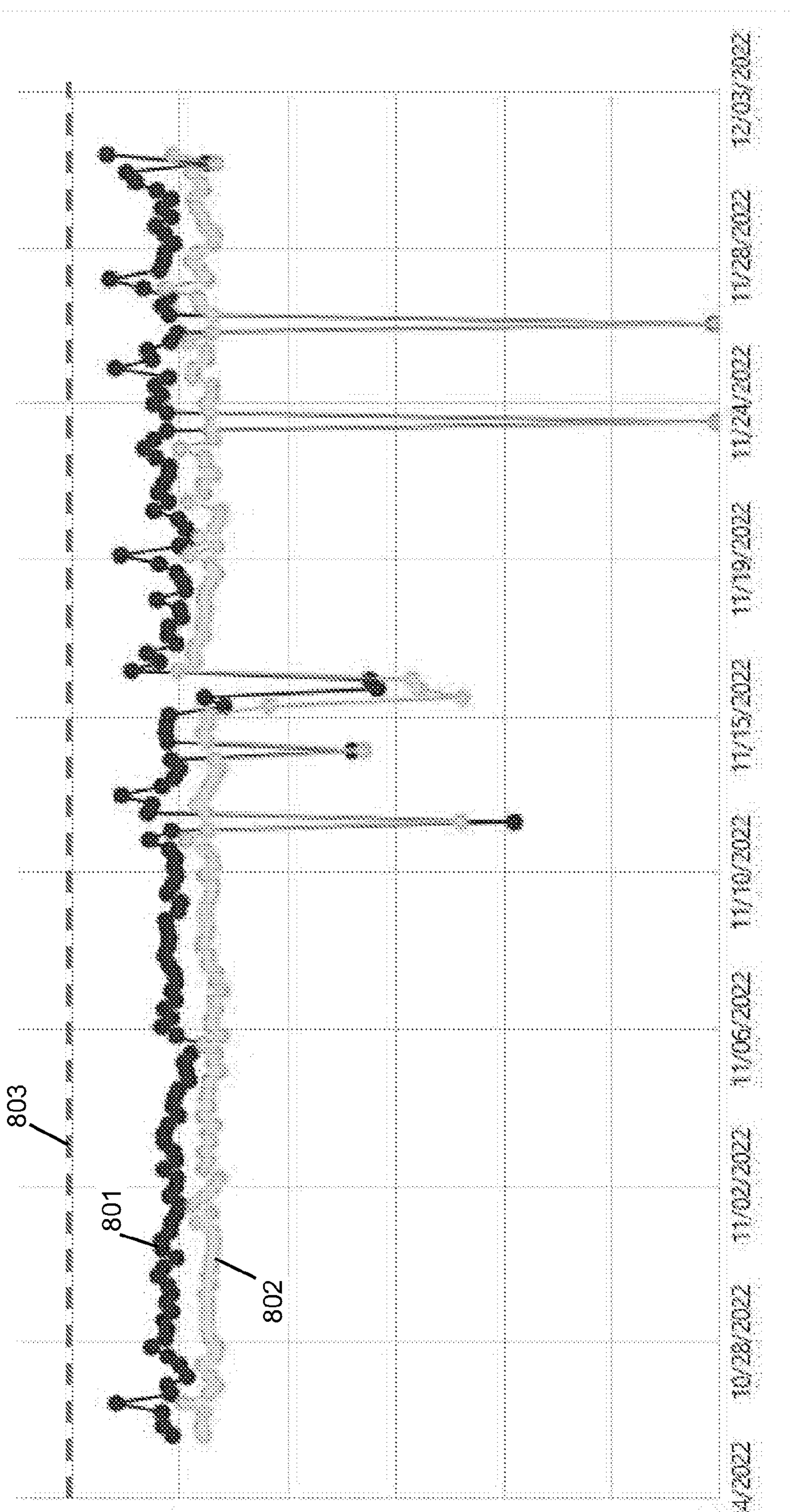
803
801
802
Radial pk-pk displacement / mm
1.2
1
0.8
0.6
0.4
0.2
0
10/24/2022
10/28/2022
11/02/2022
11/06/2022
11/10/2022
11/15/2022
11/19/2022
11/24/2022
11/28/2022
12/03/2022

Fig. 8

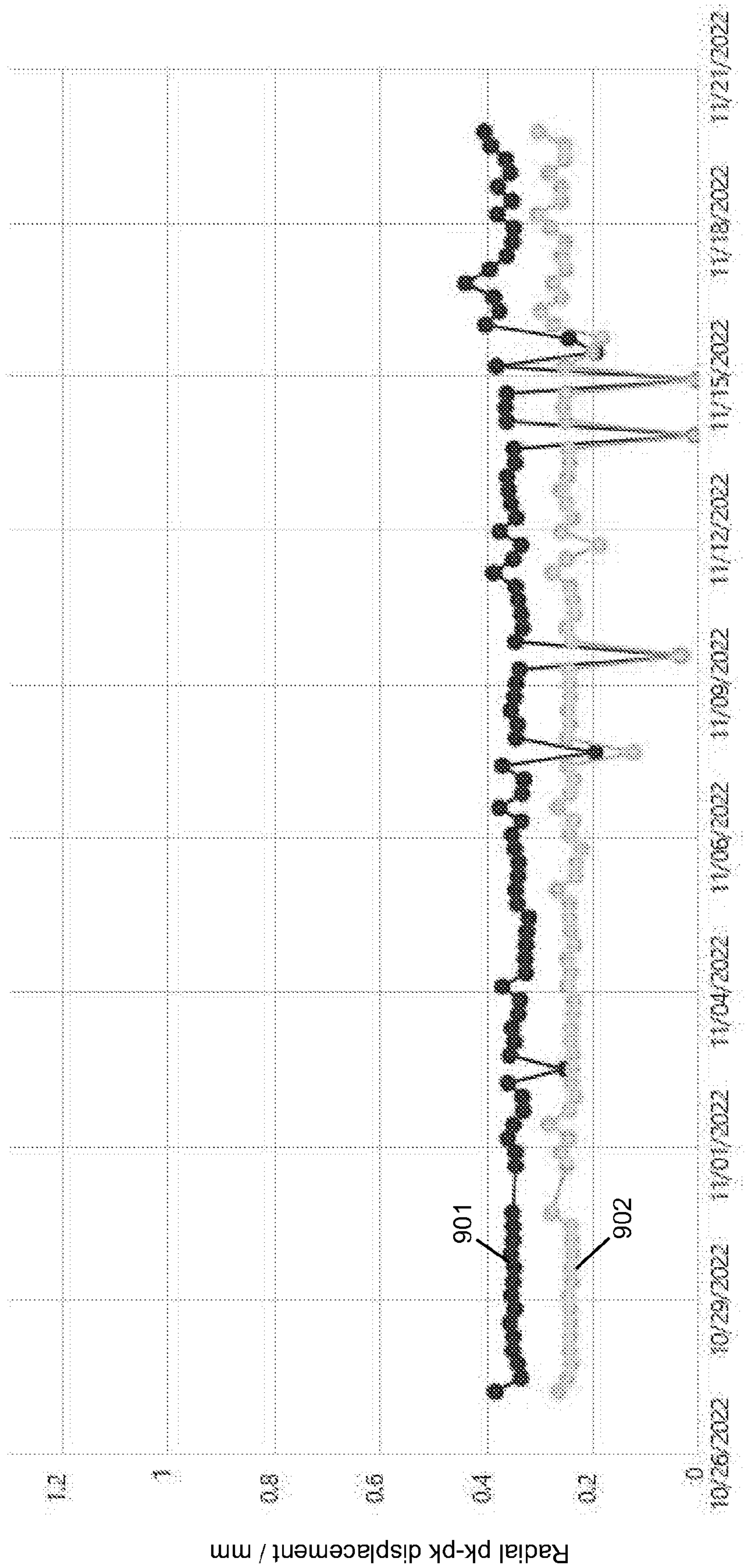
Radial pk-pk displacement / mm
1.2
1
0.8
0.6
0.4
0.2
0
10/26/2022
10/29/2022
11/01/2022
11/04/2022
11/06/2022
11/09/2022
11/12/2022
11/15/2022
11/18/2022
11/21/2022
901
902

Fig. 9

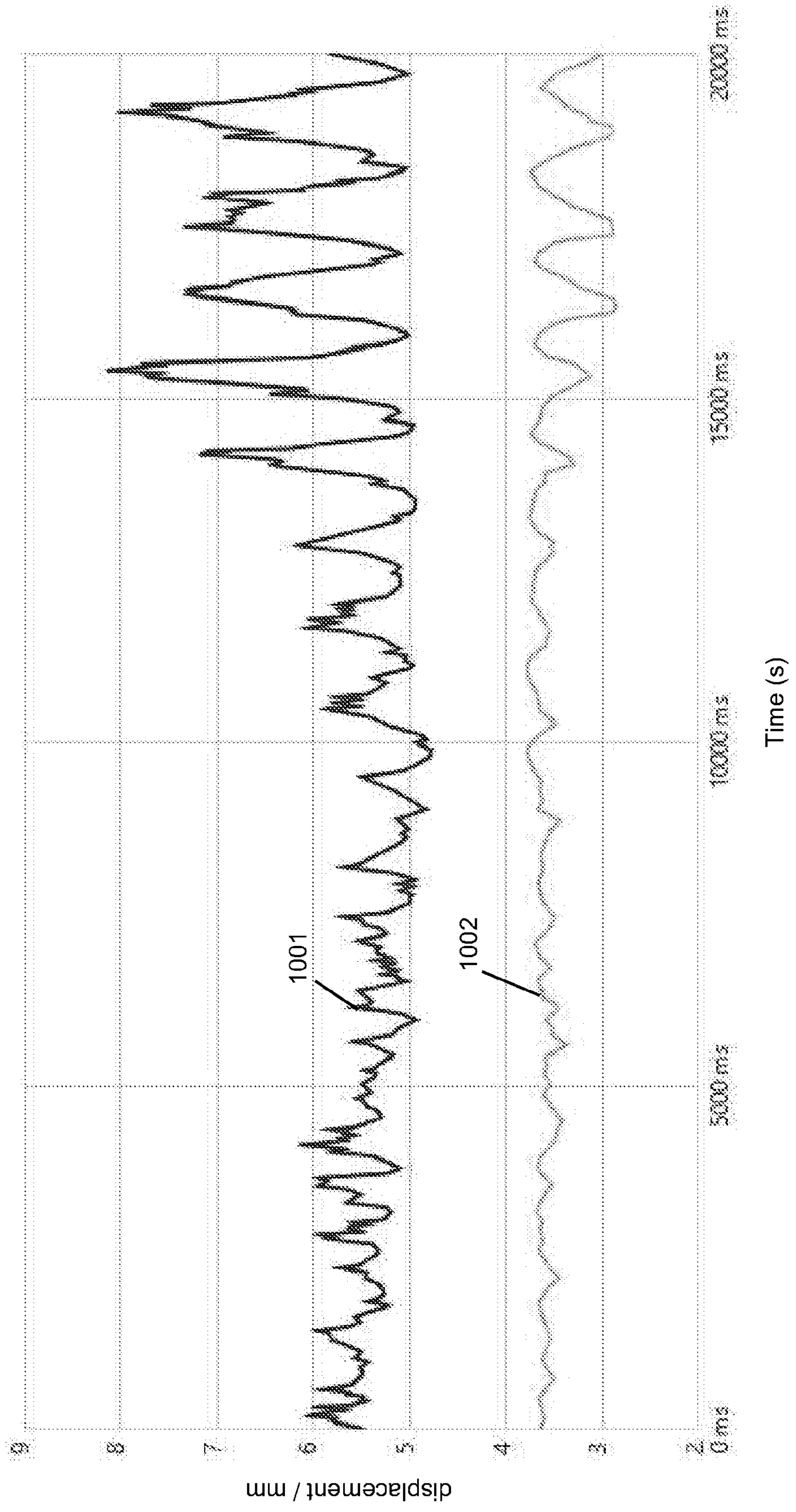
1001
1002
0 ms
5000 ms
10000 ms
15000 ms
20000 ms
Time (s)
2
3
4
5
6
7
8
9
displacement / mm

Fig. 10

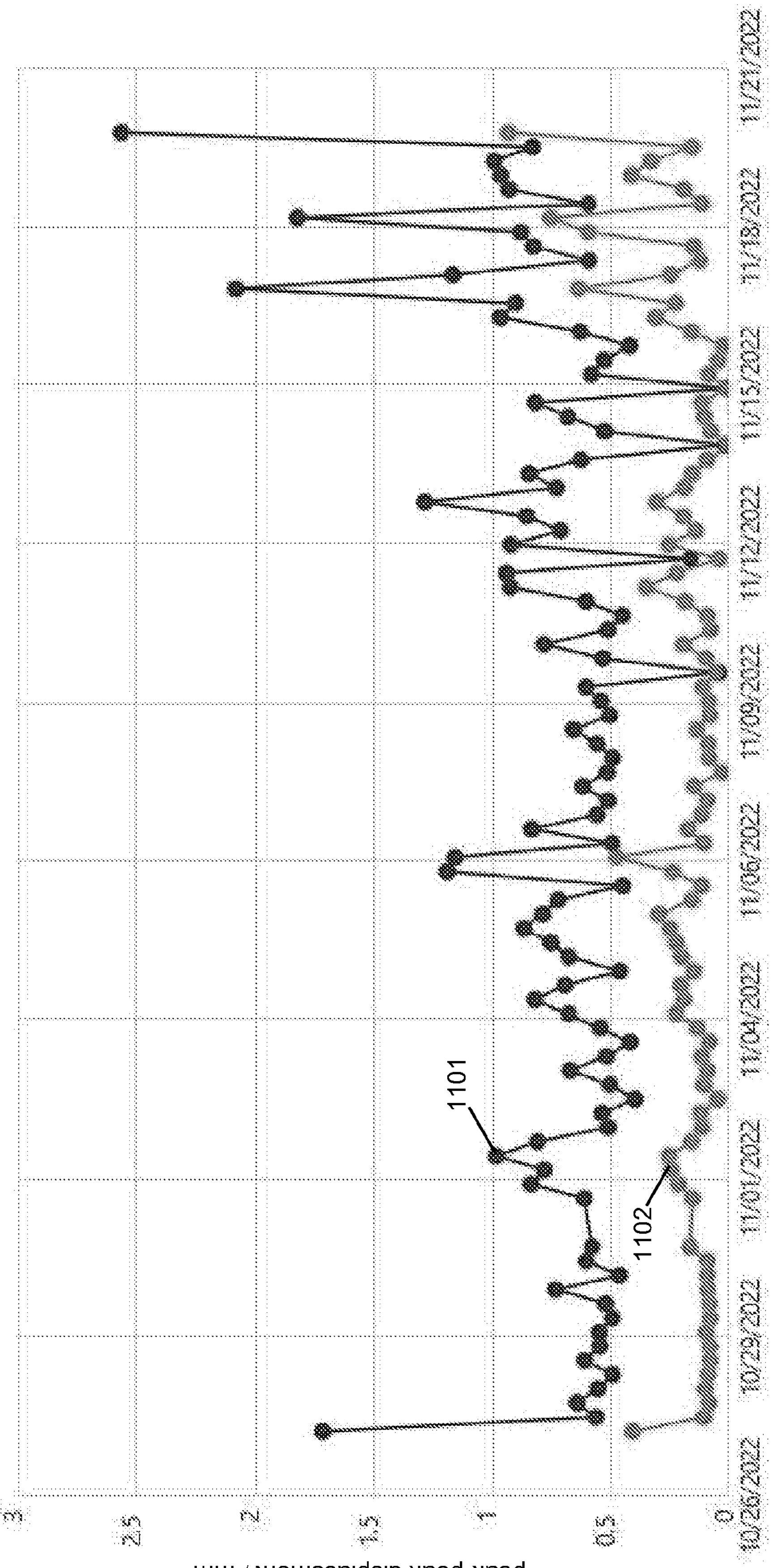
peak-peak displacement / mm
0
0.5
1
1.5
2
2.5
3
10/26/2022
10/29/2022
11/01/2022
11/04/2022
11/06/2022
11/09/2022
11/12/2022
11/15/2022
11/18/2022
11/21/2022
1101
1102

Fig. 11

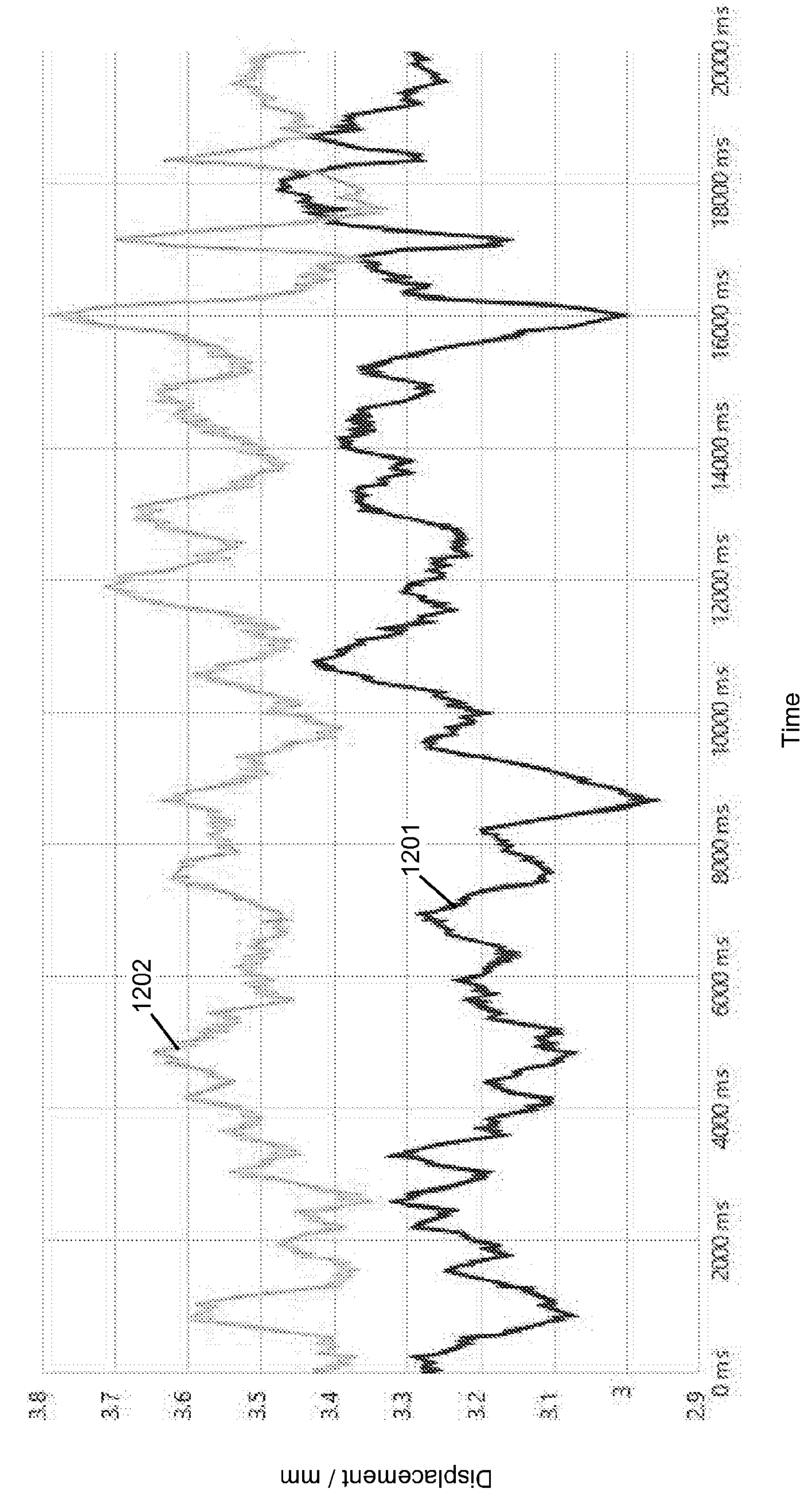
Displacement / mm
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
0 ms
2000 ms
4000 ms
6000 ms
8000 ms
10000 ms
12000 ms
14000 ms
16000 ms
18000 ms
20000 ms
Time
1201
1202

Fig. 12

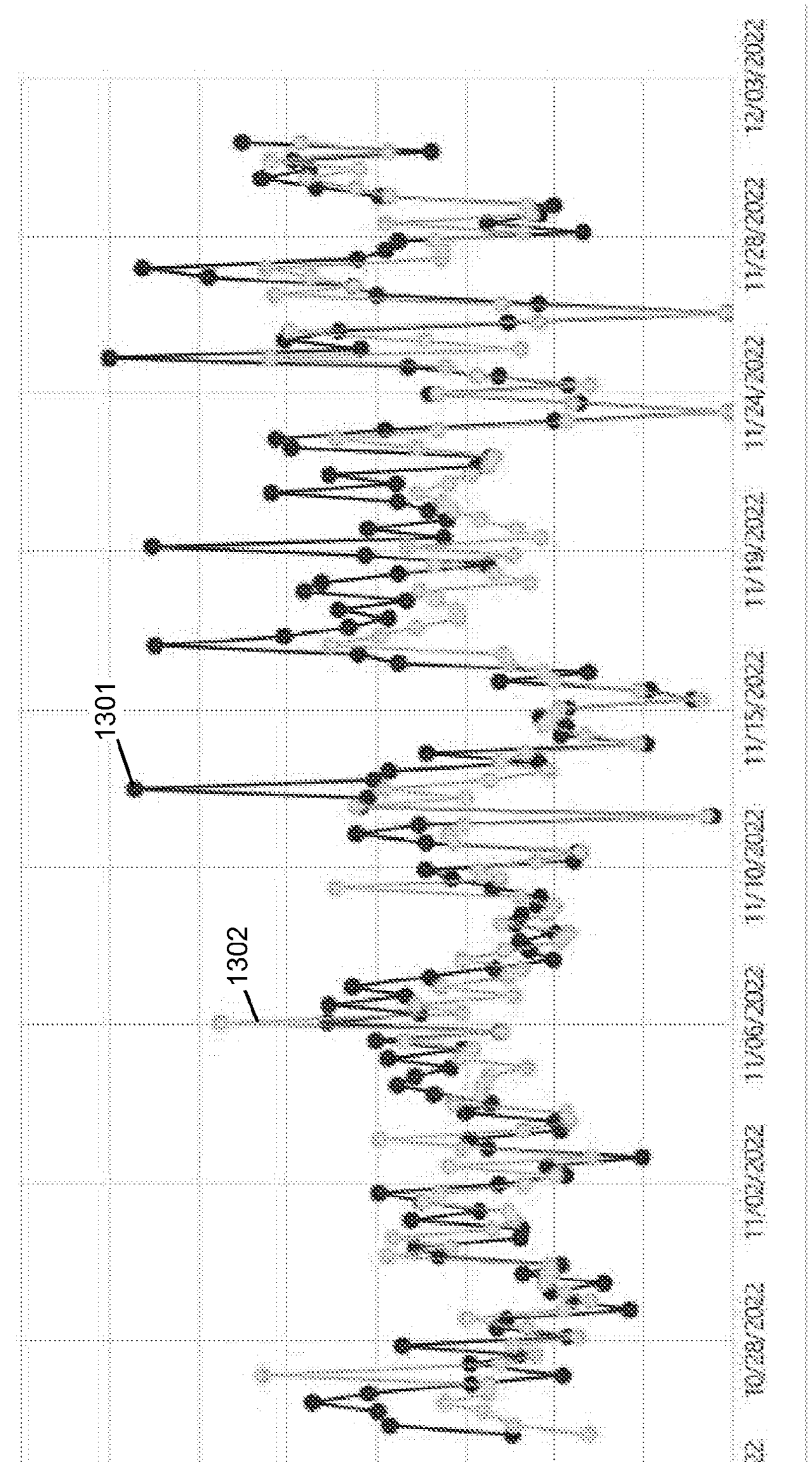
1301
1302
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10/24/2022
10/28/2022
11/02/2022
11/06/2022
11/10/2022
11/15/2022
11/19/2022
11/24/2022
11/28/2022
12/03/2022

Fig. 13

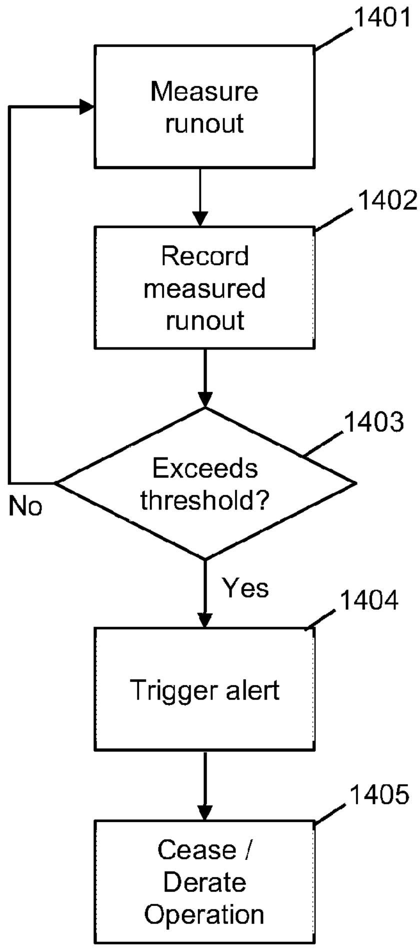
1401
Measure runout
1402
Record measured runout
1403
Exceeds threshold?
No
Yes
1404
Trigger alert
1405
Cease / Derate Operation

Fig. 14

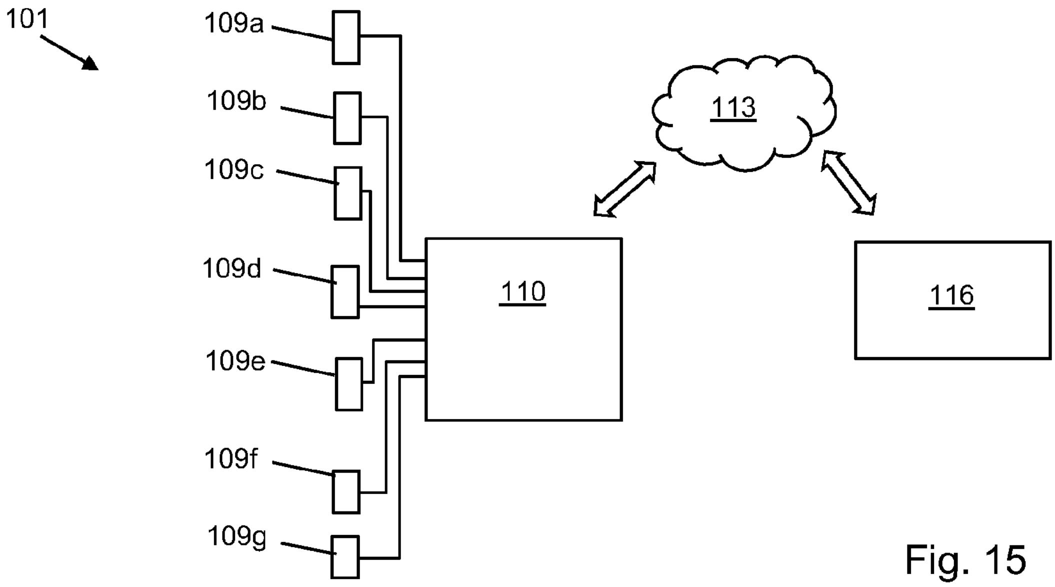
101
109a
109b
109c
109d
109e
109f
109g
110
113
116

Fig. 15

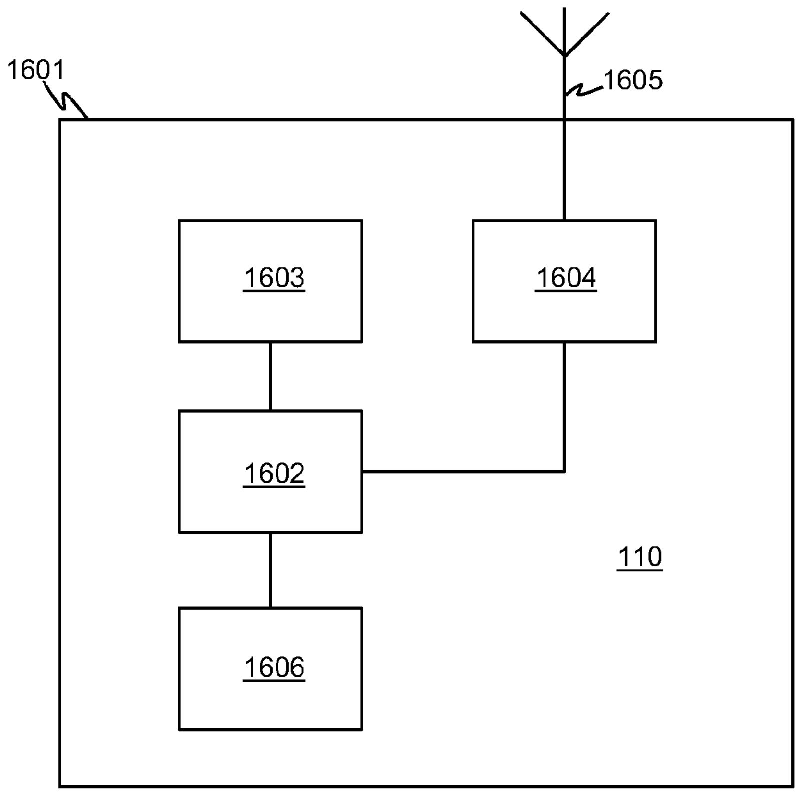
1601
1605
1603
1604
1602
110
1606

Fig. 16

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2024/050408

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D17/00
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F03D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 402 717 A1 (GEN ELECTRIC [US]) 4 January 2012 (2012-01-04)	1-7,9, 10, 12-21, 23,24, 26-29
A	paragraphs [0014], [0015], [0016], [0021], [0028]; claim 1; figures 2-5,9	8,22

X	US 2005/276696 A1 (LEMIEUX DAVID L [US]) 15 December 2005 (2005-12-15)	1-7, 9-21, 23-29
A	paragraphs [0032] - [0035], [0034], [0045]; claim 1; figures 3-7	8,22

	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 April 2024	26/04/2024

Name and mailing address of the ISA/
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer
Król, Marcin

2

International application No
PCT/GB2024/050408

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 2 060 785 A1 (GAMESA INNOVATION & TECH SL [ES]) 20 May 2009 (2009-05-20) paragraphs [0029], [0033]; claim 1; figures 1,3,4 -----	1-6,9, 10, 12-20, 23,24, 26-29

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2024/050408

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 2402717	A1	04-01-2012	CN	102312779	A	11-01-2012
			DK	2402717	T3	19-09-2016
			EP	2402717	A1	04-01-2012
			US	2011140422	A1	16-06-2011
US 2005276696	A1	15-12-2005	CN	1707262	A	14-12-2005
			DE	102005016524	A1	29-12-2005
			DK	177717	B1	07-04-2014
			DK	177769	B1	23-06-2014
			US	2005276696	A1	15-12-2005
EP 2060785	A1	20-05-2009	CN	101435408	A	20-05-2009
			DK	2060785	T3	15-04-2019
			EP	2060785	A1	20-05-2009
			ES	2723877	T3	03-09-2019
			US	2009129924	A1	21-05-2009