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(54) **CONTROL METHOD, PROGRAM AND SYSTEM FOR CONTROLLING THE BEARING PRELOAD OF A WIND TURBINE AND WIND TURBINE COMPRISING SUCH CONTROL SYSTEM**

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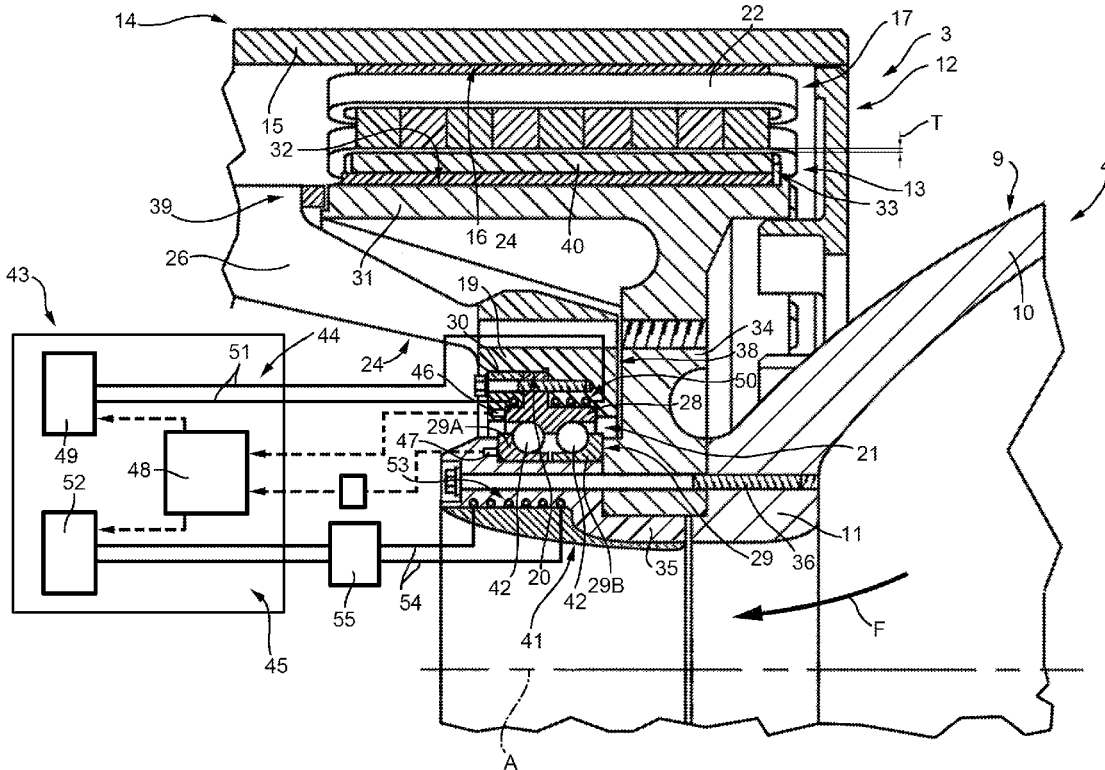
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(57) **ABSTRACT**

A control method configured to control the preload of a bearing includes estimating the preload on the bearing; comparing the estimated preload with a predetermined acceptance range; and correcting the preload on the bearing when the preload is outside the acceptance range.

FIG. 1

FIG. 2

FIG. 6

FIG. 3

FIG. 4

FIG. 5

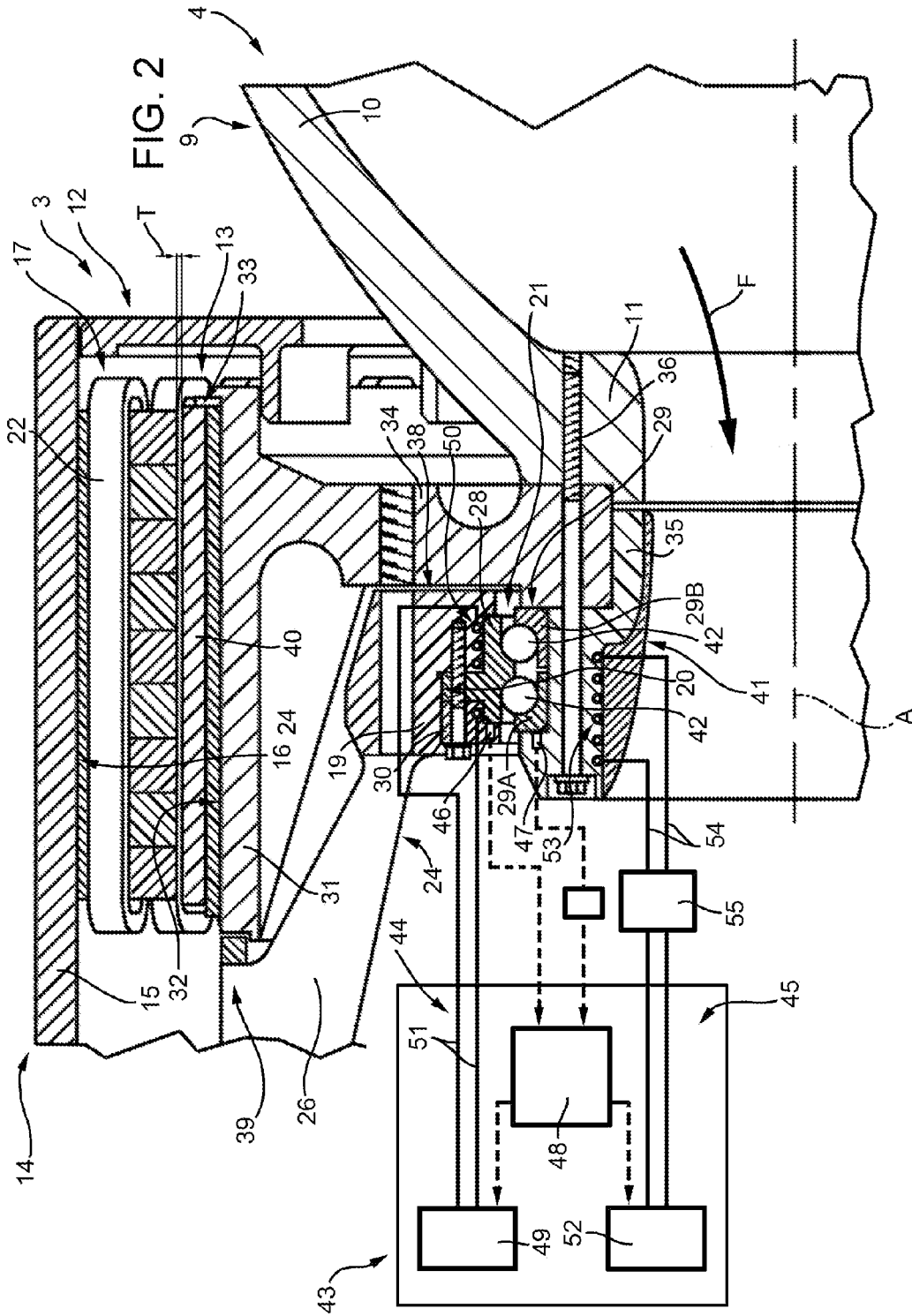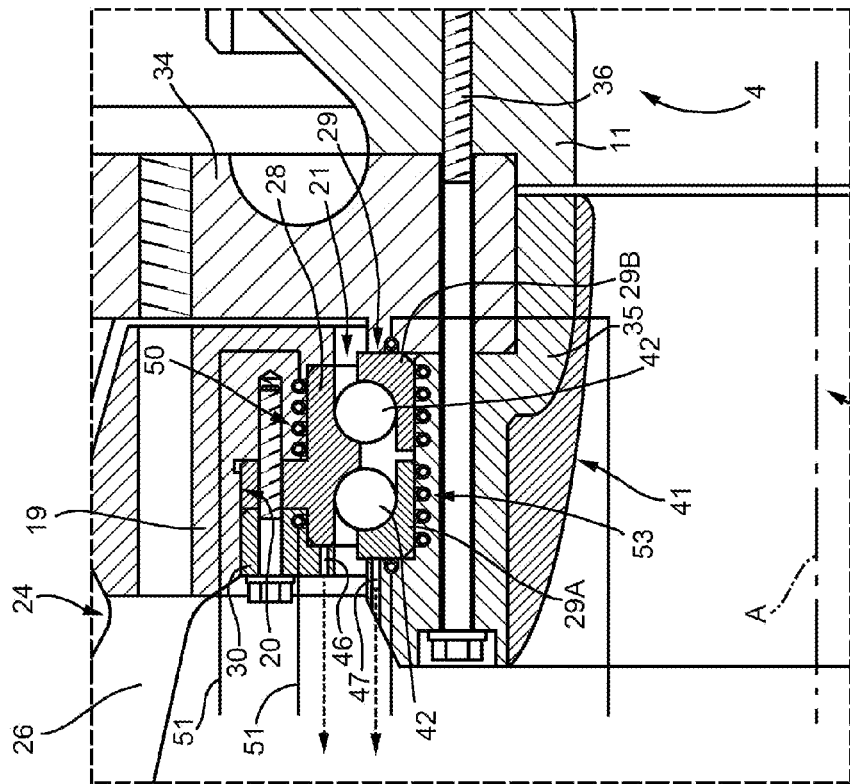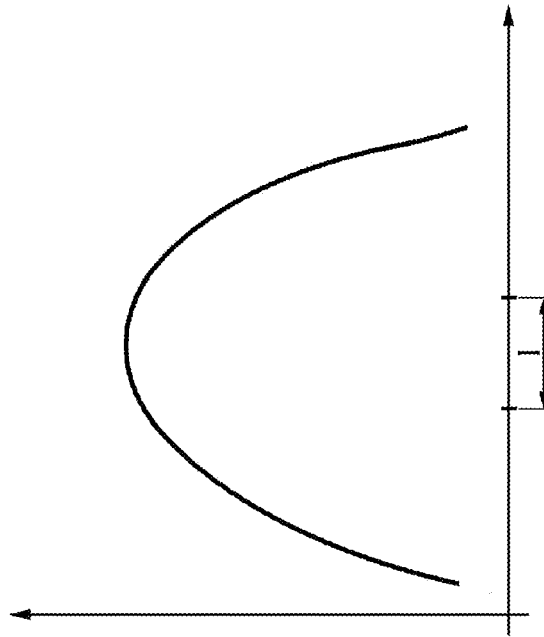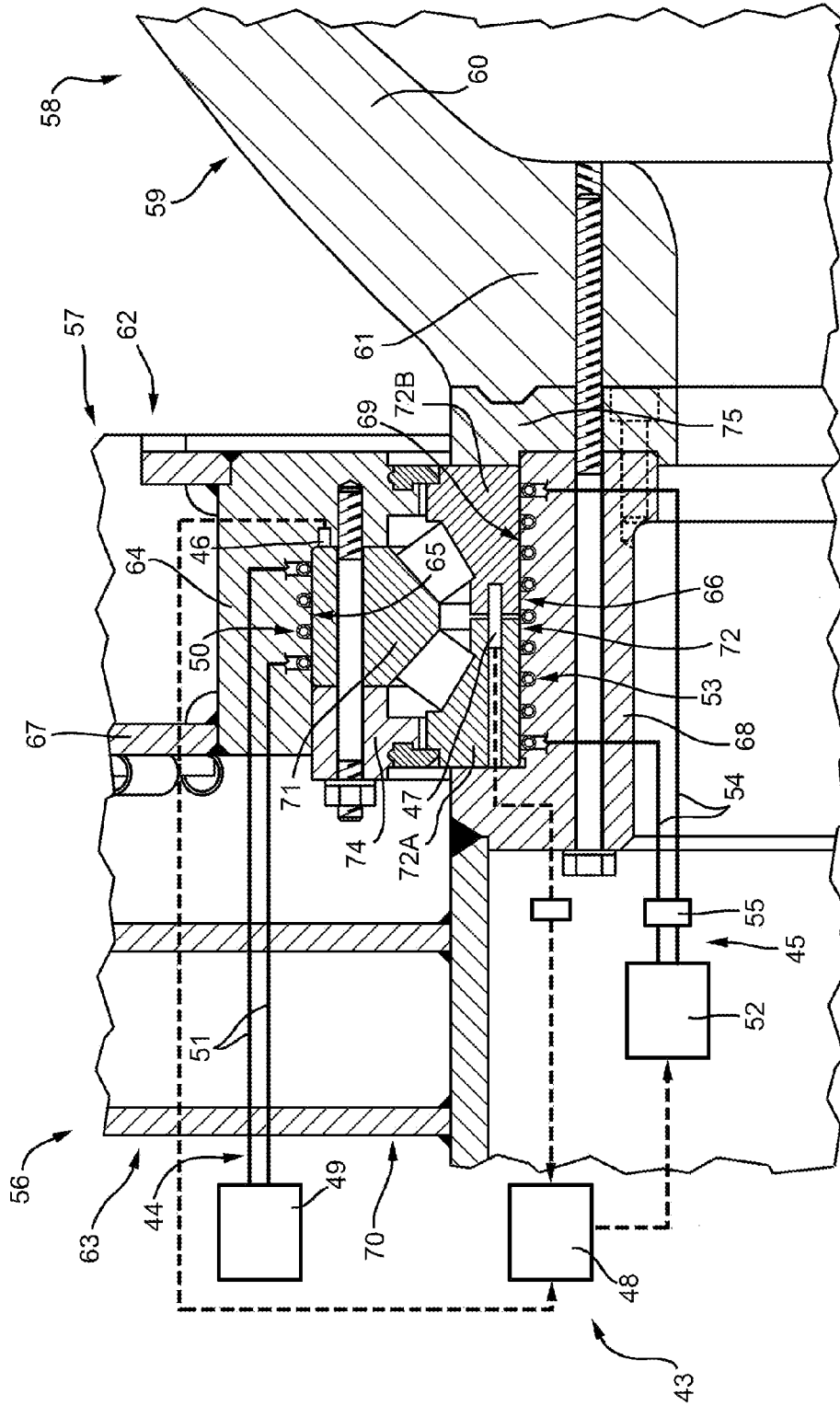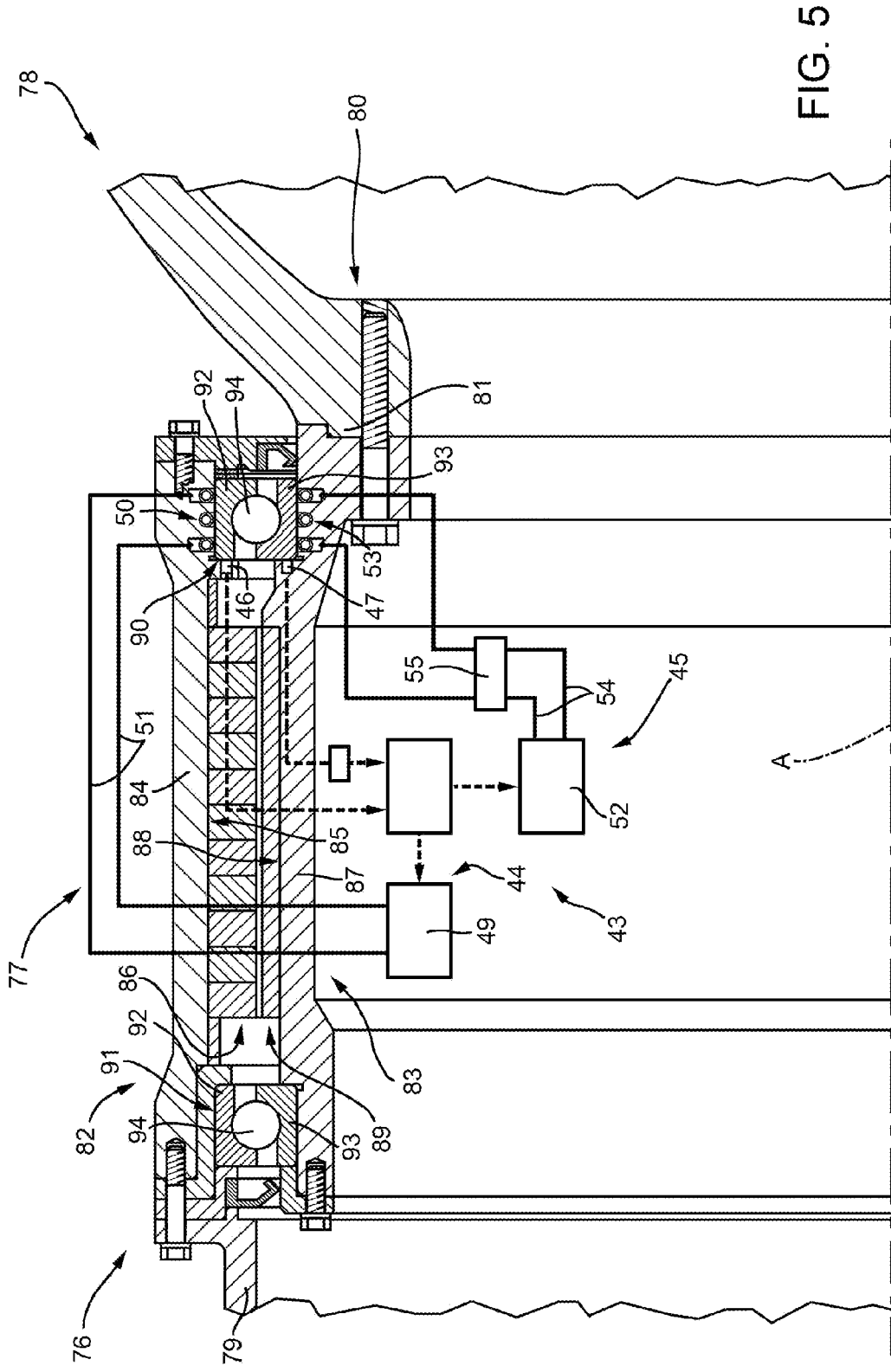# CONTROL METHOD, PROGRAM AND SYSTEM FOR CONTROLLING THE BEARING PRELOAD OF A WIND TURBINE AND WIND TURBINE COMPRISING SUCH CONTROL SYSTEM

PRIORITY CLAIM

[0001] This application is a national stage application of PCT/IB2013/056443, filed on Aug. 6, 2013, which claims the benefit of and priority to Italian Patent Application No. MI2012A 001395, filed on Aug. 6, 2012, the entire contents of which are each incorporated by reference herein.

BACKGROUND

[0002] Certain known wind turbines for producing electric energy normally comprise a main frame that rotates about a vertical axis; a blade assembly, which comprises a hub fitted with at least two blades, and is connected to the main frame by at least one bearing to permit rotation of the blade assembly about an axis of rotation; and a rotary electric machine, which is rotated by the blade assembly, and comprises a stator connected to the main frame, and a rotor connected to the blade assembly. Normally, the stator comprises a tubular first active part, and the rotor comprises a tubular second active part facing, and separated by an air gap from, the tubular first active part. The efficiency of a rotary electric machine is known to be affected significantly by the size of the air gap: the smaller the air gap, the greater the efficiency of the electric machine.

[0003] On direct-drive wind turbines, the blade assembly is connected rigidly to the rotor, and the bearing serves to support both the rotor and the blade assembly for rotation about the axis of rotation; and a fairly common practice is to employ one bearing designed to absorb radial and axial forces and tipping moments. Other wind turbine configurations employ two coaxial bearings.

[0004] The bearings used between the blade assembly and main frame of wind turbines are normally rolling bearings. A rolling bearing comprises an outer ring and an inner ring; and at least one ring of rolling bodies equally spaced about the axis of rotation, between the outer and inner rings. On wind turbines, it is generally good practice to assemble the rolling bearings with a relatively small amount of interference between the inner ring on one side, the outer ring on the other side, and the rolling bodies between the inner ring and outer ring. In other words, the bearing can be assembled to achieve a relatively small amount of both radial and axial interference. Rolling bearings may normally be assembled with interference or clearance; and in the following description, the term 'preload' is used to describe both interference and clearance configurations.

[0005] The set preload on the bearing at the installation stage may vary widely over time, depending on the temperature range at the wind turbine installation site, and on operating conditions, such as the heat generated by the rotary electric machine, friction in the bearing, and the efficiency of the cooling system. Changes in the preload of the bearing may produce relatively severe stress on the bearing, wear affecting the working life of the bearing, or slack which equally impairs the working life of the bearing and also alters the size of the air gap. Changes in the preload of the bearing therefore have a particularly harmful effect on the working life of the bearing and, in some situations, also on the efficiency of the electric machine.

[0006] These drawbacks are further compounded by the current trend towards relatively large-diameter rotary electric machines.

[0007] European Patent No. 2,290,250 discloses a method for controlling the temperature of a sleeve supporting two bearing at its opposite ends for a cartridge of drive-train of a geared wind turbine.

[0008] European Patent No. 1,992,829 discloses a method for controlling the temperature of bearing in machine tool.

[0009] Any one of these documents offers solutions that are not fully satisfactory for a direct drive wind turbine.

SUMMARY

[0010] The present disclosure relates to a method of controlling the preload of a wind turbine bearing.

[0011] It is an advantage of the present disclosure to provide a control method configured to control the preload of a wind turbine bearing, and which provides for achieving a relatively small air gap and, at the same time, ensuring a relatively long working life of the bearing.

[0012] According to the present disclosure, there is provided a control method configured to control the preload of a wind turbine bearing, the method comprising the steps of estimating the preload on the bearing at least as a function of the temperature of the outer ring and the inner ring; comparing the estimated preload with a predetermined acceptance range; and correcting the preload on the bearing when the preload is outside the acceptance range; detecting the temperature of the outer ring; detecting the temperature of the inner ring; calculating the temperature difference between the outer ring and the inner ring; controlling the temperature of the outer ring and the inner ring as a function of the temperature difference between the outer ring and the inner ring so as to keep the preload within the predetermined acceptance range.

[0013] In this way, it is possible to optimize both the working life of the bearing and the efficiency of the electric machine.

[0014] In certain embodiments, the step of estimating the preload comprises calculating the preload on the basis of the structural, dimensional, and assembly characteristics, and the temperature of the bearing.

[0015] In this way, it is possible to achieve a reliable estimate of the preload on the bearing.

[0016] In certain embodiments, the step of correcting the preload on the bearing comprises directly or indirectly heating or cooling the outer ring and/or inner ring.

[0017] This enables full active control of the preload of the bearing.

[0018] In certain embodiments, the control method comprises determining the temperature of the outer ring and the inner ring, or of the supporting structures close to them. In this way, it is possible to implement a closed-cycle control algorithm.

[0019] The temperature of the outer ring and the inner ring is, in certain embodiments, closed-cycle controlled by determining the temperature of the outer ring and the inner ring, or the temperature close to them, but open-cycle controls are not excluded.

[0020] The present disclosure also relates to a program configured to control the preload of a bearing.

[0021] According to the present disclosure, there is provided a computer program loadable directly into a memory of a control unit to perform the steps in the method according to the present disclosure when the program is implemented by the control unit.

[0022] The program may also be stored in a mobile memory on a readable medium on which the program is stored.

[0023] The present disclosure also relates to a control system configured to control the preload of a wind turbine bearing.

[0024] According to the present disclosure, there is provided a control system configured to control the preload of a wind turbine bearing, the control system comprising a control unit configured to estimate the preload on the bearing at least as a function of the temperature of the outer ring and the inner ring; compare the estimated preload with a predetermined acceptance range; and correct the preload on the bearing when the preload is outside the acceptance range; at least one first sensor configured to detect the temperature of the outer ring; at least one second sensor configured to detect the temperature of the inner ring, wherein the control unit is configured to calculate the temperature difference between the outer ring and the inner ring and to control a first and a second control device to adjust the temperature of the outer ring and the inner ring respectively as a function of the temperature difference between the outer ring and the inner ring so as to keep the preload within the predetermined acceptance range.

[0025] The control system provides for optimizing the working life of the bearing and the efficiency of the wind turbine electric machine relatively cheaply and relatively easily. In certain embodiments, the control unit is configured to calculate the preload on the basis of the structural, dimensional, and assembly characteristics, and the temperature of the bearing.

[0026] The control unit is, in certain embodiments, programmable, has a memory in which to store bearing data, is configured to receive outside information, such as the detected temperatures of the outer ring and inner ring, and is configured to emit control signals to control a first and second control device.

[0027] The control unit is also configured to emit alarm signals in the event of anomalous operating situations with respect to recorded history data.

[0028] The present disclosure also relates to a wind turbine.

[0029] According to the present disclosure, there is provided a wind turbine configured to produce electric energy, the wind turbine comprising a blade assembly rotatable about an axis of rotation; a rotary electric machine comprising a stator, and a rotor connected to the blade assembly; a bearing configured to support the blade assembly about the axis of rotation; and a control system configured to control the preload of the bearing and in accordance with the present disclosure.

[0030] The above configuration provides for achieving a relatively small air gap, and improving the efficiency, of the rotary electric machine.

[0031] Additional features and advantages are described in, and will be apparent from the following Detailed Description and the figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032] A non-limiting embodiment of the present disclosure will be described by way of example with reference to the attached drawings, in which:

[0033] FIG. 1 shows a longitudinal section, with parts removed for clarity, of a wind turbine in accordance with the present disclosure;

[0034] FIG. 2 shows a larger-scale longitudinal section, with parts removed for clarity, of the FIG. 1 wind turbine equipped with a bearing preload control system in accordance with the present disclosure;

[0035] FIG. 3 shows a larger-scale longitudinal section, with parts removed for clarity, of a detail of a variation of the present disclosure;

[0036] FIG. 4 shows a longitudinal section, with parts removed for clarity, of a wind turbine in accordance with a further embodiment of the present disclosure;

[0037] FIG. 5 shows a longitudinal section, with parts removed for clarity, of a wind turbine in accordance with a further embodiment of the present disclosure; and

[0038] FIG. 6 shows a working life versus preload graph of the bearing.

DETAILED DESCRIPTION

[0039] Referring now to the example embodiments of the present disclosure illustrated in FIGS. 1 to 6, number 1 in FIG. 1 indicates as a whole a wind turbine configured to produce electric energy. Wind turbine 1 is a direct-drive type. In the example shown, wind turbine 1 comprises a main frame 2; a rotary electric machine 3; and a blade assembly 4 which rotates about an axis of rotation A. Rotary electric machine 3 is located between main frame 2 and blade assembly 4 and, in addition to producing electric energy, serves to support blade assembly 4 and to transmit forces and moments induced by blade assembly 4 and rotary electric machine 3 itself to main frame 2.

[0040] In the example shown, main frame 2 is defined by a curved, tubular nacelle 5 comprising a circular end flange 6 for connection to rotary electric machine 3; an end flange 7 configured to house a pivot (not shown in the drawings) for connection to a vertical support (not shown in the drawings); and an opening 8 in the wall of nacelle 5, through which to insert and remove relatively large component parts. In certain embodiments, opening 8 is substantially aligned with end flange 6.

[0041] Blade assembly 4 comprises a hub 9 connected to rotary electric machine 3; and a plurality of blades (not shown in the drawings). Hub 9 comprises a hollow member 10 configured to support the blades (not shown in the drawings); and a flange 11 for connection to rotary electric machine 3.

[0042] Rotary electric machine 3 extends about axis of rotation A, and is substantially tubular, so as to form a passage between the hollow main frame 2 and hollow hub 9.

[0043] Rotary electric machine 3 comprises a stator 12; a rotor 13 located inside stator 12 and which rotates with respect to stator 12 about axis of rotation A. Rotary electric machine 3 comprises a frame 14 configured to connect rotary electric machine 3 to main frame 2, and configured to support blade assembly 4, stator 12, and rotor 13.

[0044] Frame 14 extends about axis of rotation A, and comprises a tubular structure 15, which has a cylindrical face 16 and is configured to support a tubular active part 17 along cylindrical face 16; an annular flange 18 configured to con-

nect rotary electric machine **3** to main frame **2** of wind turbine **1**; and a ring **19** having an annular seat **20** for at least partly housing a bearing **21**. In the example shown, one bearing **21** supports blade assembly **4** and rotor **13** integral with blade assembly **4**.

[0045] In other words, frame **14** forms part of tubular stator **12**, since tubular structure **15** forms part of tubular stator **12**. Accordingly, tubular stator **12** comprises tubular structure **15** and active part **17**.

[0046] Tubular active part **17** is divided into a plurality of axial active segments **22**, each of which, in the example shown, has electric windings fitted to a ferromagnetic, substantially prismatic core extending predominantly parallel to axis of rotation A.

[0047] Tubular structure **15** is cylindrical and extends about axis of rotation A. Annular flange **18** is coaxial with tubular structure **15** and smaller in diameter than cylindrical face **16**. And ring **19** is coaxial with tubular structure **15** and smaller in diameter than annular flange **18**.

[0048] Annular flange **18** is located inside the end of tubular structure **15**, along axis of rotation A.

[0049] Ring **19** is located inside the central area of tubular structure **15**, along axis of rotation A.

[0050] Tubular structure **15**, annular flange **18** and ring **19** are connected rigidly to one another by arms **23** and **24**. More specifically, tubular structure **15** is connected to annular flange **18** by arms **23**, which extend predominantly radially with a relatively small axial component; and annular flange **18** is connected to ring **19** by arms **24**, which extend predominantly axially with a relatively small radial component.

[0051] Each arm **23** comprises two plates **25** parallel to each other and to axis of rotation A. And similarly, each arm **24** comprises two plates **26** also parallel to each other and to axis of rotation A.

[0052] Annular flange **18** has a seat **27** for connection to main frame **2** of wind turbine **1**. Frame **14** and main frame **2** are, in certain embodiments, connected by a bolted joint (not shown in the drawings) between annular flange **18** and end flange **6**, and by which the forces and moments induced by rotary electric machine **3** and blade assembly **4** are transmitted to main frame **2**.

[0053] In certain embodiments, rotary electric machine **3**, (i.e., wind turbine **1**) has only bearing **21** to withstand the radial and axial loads transmitted from tubular rotor **13** and blade assembly **4** to main frame **2**.

[0054] With reference to FIG. 2, bearing **21** is a rolling bearing, comprises an outer ring **28** and an inner ring **29**, and is housed in annular seat **20** of ring **19**. More specifically, outer ring **28** is housed in annular seat **20**, and inner ring **29** is connected to tubular rotor **13**. Annular seat **20** has a step profile, with cylindrical faces alternating with annular supporting faces. More specifically, outer ring **28** of bearing **21** is housed inside annular seat **20** and locked in place by a lock ring **30** bolted to ring **19** and outer ring **28**.

[0055] Tubular rotor **13** comprises a tubular structure **31** with a cylindrical face **32**; a tubular active part **33**; and a radial structure **34** located inside tubular structure **31** and connected to bearing **21**, more specifically to inner ring **29** of bearing **21**. In other words, radial structure **34** is fixed, on one side, to bearing **21** and, on the opposite side, to hub **9**, more specifically to flange **11** of hub **9**.

[0056] Radial structure **34** is fixed to bearing **21** and hub **9** by two independently releasable bolted joints. Radial struc-

ture **34** is fixed using a lock ring **35** configured to partly house inner ring **29** of bearing **21**, and the end of radial structure **34** with flange **11** of hub **9**.

[0057] Tubular active parts **17** and **33** are separated radially by an air gap T.

[0058] One bolted joint comprises bolts, one of which, indicated **36** (in FIGS. **1** and **2**), engages lock ring **35**, radial structure **34** of rotor **13**, and flange **11** of hub **9**. The other bolted joint comprises bolts **37**, which only engage radial structure **34** of rotor **13**, and flange **11** of hub **9** (FIG. **1**).

[0059] Radial structure **34** is also connectable by a joint, in particular a bolted joint, directly to ring **19**. Radial structure **34** is located close to a face **38** of ring **19**, and both radial structure **34** and ring **19** are configured to be connected integrally to each other. Radial structure **34** and ring **19** are connected to connect tubular rotor **13** directly to frame **14** when changing bearing **21**.

[0060] Frame **14** has an emergency bearing **39** located along arms **24** and which is positioned contacting tubular rotor **13**—in the example shown, tubular structure **31**.

[0061] Like active part **17**, active part **33** comprises axial active segments **40**, each of which, in the example shown, has permanent magnets fitted to respective magnetic guides, is prismatic in shape, and extends predominantly parallel to axis of rotation A.

[0062] Tubular rotary electric machine **3** communicates directly with hollow hub **9**, and is traversed by cooling air, which is indicated by arrows F, is appropriately blown inside rotary electric machine **3**, and serves mainly to cool active parts **17** and **33**. Cooling air F sweeps over the area where bearing **21** is assembled, and in particular the inner ring **29** area. To mitigate the effect of cooling air F, wind turbine **1** comprises an insulating cover **41** configured to insulate the area swept by cooling air F. In the example shown, insulating cover **41** is tubular and applied to lock ring **35**. More specifically, insulating cover **41** is also shaped to guide the flow of cooling air F.

[0063] In addition to outer ring **28** and inner ring **29**, bearing **21** also comprises rolling bodies **42** arranged in two rings. More specifically, inner ring **29** comprises two adjacent half-rings **29A** and **29B**. Wind turbine **1** comprises a control system **43** configured to control the preload of bearing **21**. The term 'preload' is a general term relating to interference or clearance between outer ring **28**, inner ring **29** and rolling bodies **42** of bearing **21**. The preload is divided into a radial preload and an axial preload with reference to axis of rotation A. On wind turbines, the bearing is normally assembled with interference. In the example shown, the preload is set at the assembly stage, by hot-fitting, with a relatively small amount of interference, outer ring **28** inside seat **20** on ring **19**, and inner ring **29** inside a seat on lock ring **35**.

[0064] Lock ring **35** is also tightened to radial structure **34** by bolts **36**. Tightening bolts **36** brings half-rings **29A** and **29B** closer together to produce the axial preload.

[0065] Control system **43** comprises a control device **44** configured to control outer ring **28**; a control device **45** configured to control inner ring **29**; a temperature sensor **46** configured to detect the temperature of outer ring **28**; a temperature sensor **47** configured to detect the temperature of inner ring **29**; and a control unit **48** configured to control control devices **44** and **45** on the basis of the detected temperatures of outer ring **28** and inner ring **29**.

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[0066] Outer ring **28** is the stationary part of bearing **21**, while inner ring **29** is integral with rotor **13** and, in use, rotates about axis of rotation A with respect to outer ring **28**.

[0067] Control device **44** comprises a thermostat **49**; a heat exchanger **50** close to outer ring **28**; and connecting lines **51** between thermostat **49** and heat exchanger **50**.

[0068] Similarly, control device **45** comprises a thermostat **52**; a heat exchanger **53** close to inner ring **29**; connecting lines **54** between thermostat **52** and heat exchanger **53**; and a rotary distributor **55** located along connecting lines **54** to connect the stationary part to the rotary part of control device **45**.

[0069] In the example shown, heat exchanger **53** is located along the inner face of lock ring **35**.

[0070] Control devices **44** and **45** are, in certain embodiments, electric, and heat exchangers **50** and **53** are electric resistors located close to, and, in certain embodiments, coiled about, outer ring **28** and inner ring **29**, respectively.

[0071] In a variation of the present disclosure, control devices **44** and **45** are liquid types, so heat exchangers **50** and **53** can cool as well as heat outer ring **28** and inner ring **29**.

[0072] Bearing **21** is selected on the basis of its capacity and other parameters, including operating temperature. And control system **43** provides for maintaining the temperature of outer ring **28** and inner ring **29** so as to keep the preload within a predetermined acceptance range I.

[0073] The algorithm implemented by control system **43** is substantially based on the characteristics and the assembly conditions of bearing **21**, on the thermal deformation of bearing **21** as a function of the temperature of outer ring **28** and inner ring **29**, and on the variations in preload as a function of said thermal deformation. Given this data, it is possible to calculate the preload as a function of the temperature of outer ring **28** and inner ring **29**. And the calculated preload is compared with the predetermined preload acceptance range I shown in FIG. **6**. As shown in FIG. **6**, the preload acceptance range I (x axis) is chosen to ensure a relatively long predicted working life (y axis) of bearing **21**.

[0074] Control unit **48** is programmable, and comprises a memory in which to store the characteristics of bearing **21**. Control unit **48** is configured to calculate the deformation of bearing **21** on the basis of the detected temperatures of outer ring **28** and inner ring **29**, and/or the difference between the detected temperatures of outer ring **28** and inner ring **29**. Control unit **48** is configured to calculate the preload on the basis of the thermal deformation of outer ring **28** and inner ring **29**; and to compare the calculated preload with preload acceptance range I. If the calculated preload does not fall within acceptance range I, the control unit commands thermostats **49** and **52** to heat and/or cool outer ring **28** and/or inner ring **29** to bring the preload back within acceptance range I.

[0075] Control unit **48** is configured to memorize the temperature data of outer ring **28** and inner **29** together with data detected and memorized by the control unit controlling wind turbine **1** as a whole, so as to determine any anomalous behaviour of bearing **21**. For example, for a given or designated external temperature, cooling system efficiency, wind speed, and blade angle, overheating of bearing **21** may be detected, and which may be considered anomalous in the light of other operating conditions. In which case, control unit **48** is configured to emit an alarm signal.

[0076] In relatively very cold climates, and when wind turbine **1** is re-started, the temperatures of outer ring **28** and inner ring **29** are below the optimum operating parameters of bearing **21**, so both rings must be heated.

[0077] Other environmental and operating conditions make it necessary to heat outer ring **28** and inner ring **29** differently. This differential temperature of outer ring **28** and inner ring **29** is made possible by control system **43**.

[0078] In the FIG. **3** variation, heat exchanger **53** is located between lock ring **35** and inner ring **29** of bearing **21**.

[0079] Number **56** in FIG. **4** indicates a wind turbine configured to produce electric energy. Wind turbine **56** is a direct-drive type and, in the example shown, comprises a rotary electric machine **57**; and a blade assembly **58** which rotates about an axis of rotation A. In addition to producing electric energy, rotary electric machine **57** also serves to support blade assembly **58** and to transmit forces and moments induced by blade assembly **58** and rotary electric machine **57** itself to the main frame (not shown in the drawings) of wind turbine **56**.

[0080] Blade assembly **58** comprises a hub **59** connected to rotary electric machine **57**; and a plurality of blades (not shown in the drawings). Hub **59** comprises a hollow member **60** configured to support the blades (not shown in the drawings); and a flange **61** for connection to rotary electric machine **57**.

[0081] Rotary electric machine **57** is substantially tubular, so as to form a space for access to hollow hub **59**.

[0082] Rotary electric machine **57** comprises a stator **62**; and a rotor **63** located inside stator **62**. Stator **62** comprises a ring **64** having an annular seat **65** for at least partly housing a bearing **66**; and a radial structure **67** configured to connect ring **64** to a tubular structure (not shown in the drawings). In the example shown, one bearing **66** supports blade assembly **58** and rotor **63** integral with blade assembly **58**.

[0083] Rotor **63** comprises a ring **68** with an annular seat **69** configured to house bearing **66**; and a radial structure **70** configured to connect ring **68** to a further tubular structure (not shown in the drawings).

[0084] In certain embodiments, rotary electric machine **57** (i.e., wind turbine **56**) has only bearing **66** to withstand radial and axial forces and tipping moments. Bearing **66** is a rolling bearing and comprises an outer ring **71** and an inner ring **72**. In the example shown, bearing **66** is a rolling bearing with two rings of rolling bodies **73**—in the example shown, rollers. More specifically, outer ring **71** is housed in annular seat **65**, and inner ring **72** is housed in annular seat **69** on ring **68** of rotor **63**. Outer ring **71** of bearing **66** is locked inside annular seat **65** by a lock ring **74** bolted to ring **64** and outer ring **71**.

[0085] Inner ring **72** comprises two half-rings **72A** and **72B**, which are arranged axially adjacent inside seat **69**, and are locked axially by a lock ring **75** and by a bolted joint by which to set the axial preload.

[0086] Wind turbine **56** comprises a control system **43** as described with reference to FIG. **2**. Heat exchanger **50** is housed inside grooves formed in ring **64** of stator **62**, at annular seat **65**, so as to directly contact outer ring **71**. Likewise, heat exchanger **53** is housed inside grooves formed in ring **68** of rotor **63**, at annular seat **69**, so as to directly contact inner ring **72**.

[0087] Temperature sensor **46** is located inside a space in ring **64**, between ring **64** and outer ring **71**, and, in certain embodiments, along a front face of outer ring **71**, at a given or designated distance from heat exchanger **50**. And likewise, temperature sensor **47** is located inside a space in ring **68**, such as between ring **68** and inner ring **72**, and in certain

embodiments, facing a front face of inner ring **72**, and at a given or designated distance from heat exchanger **53**.

[0088] Number **76** in the FIG. **5** embodiment indicates an electric energy producing wind turbine. Wind turbine **76** is a direct-drive type and, in the example shown, comprises a rotary electric machine **77**; and a blade assembly **78** which rotates about an axis of rotation A. In addition to producing electric energy, rotary electric machine **77** also serves to support blade assembly **78** and to transmit forces and moments induced by blade assembly **78** and rotary electric machine **77** itself to the main frame **79** of wind turbine **76**.

[0089] Blade assembly **78** comprises a hollow hub **80** connected to rotary electric machine **77**; and a plurality of blades (not shown in the drawings). Hub **80** comprises a flange **81** for connection to rotary electric machine **77**.

[0090] Rotary electric machine **77** extends about axis of rotation A, and is substantially tubular to form a space for access to hollow hub **80**.

[0091] Rotary electric machine **77** comprises a stator **82**; and a rotor **83** located inside stator **62**, and which rotates about axis of rotation A with respect to stator **82**. Stator **82** comprises a tubular structure **84** having a cylindrical face **85** and configured to support a tubular active part **86** along cylindrical face **85**.

[0092] Rotor **83** comprises a tubular structure **87** with a cylindrical face **88**; and a tubular active part **89** fitted to cylindrical face **88** of tubular structure **87**.

[0093] Tubular structures **84** and **87** are connected in rotary manner by two bearings **90** and **91** located at opposite ends of tubular structures **84** and **87**, which have reinforcing rings at the ends, and assembly rings. Each bearing **90**, **91** comprises an outer ring **92**, an inner ring **93**, and a ring of rolling bodies **94**. Bearing **90** is stressed more than bearing **91**, is preloaded with interference, and is actively controlled by control system **43**. In this case, the grooves housing heat exchangers **50** and **53** are formed in tubular structures **84** and **87**, at end seats of bearings **90** and **91**.

[0094] Clearly, changes may be made to the control method and system and the wind turbine according to the present disclosure without, however, departing from the protective scope of the accompanying Claims. In particular, the control method and system described and claimed also apply to wind turbines with overgears and with structures other than those described with reference to the attached drawings, and may also be used to advantage for controlling bearings other than those described. Accordingly, various changes and modifications to the presently disclosed embodiments will be apparent to those skilled in the art. Such changes and modifications can be made without departing from the spirit and scope of the present subject matter and without diminishing its intended advantages. It is therefore intended that such changes and modifications be covered by the appended claims.

1-25. (canceled)

26. A method of controlling a preload of a wind turbine bearing, said method comprising:

detecting a temperature of an outer ring of the wind turbine bearing;

detecting a temperature of an inner ring of the wind turbine bearing;

calculating a temperature difference between the detected temperature of the outer ring of the wind turbine bearing and the detected temperature of the inner ring of the wind turbine bearing;

estimating the preload on the wind turbine bearing as a function of the detected temperature of the outer ring of the wind turbine bearing and the detected temperature of the inner ring of the wind turbine bearing;

comparing the estimated preload with a predetermined acceptance range; and

correcting the preload on the wind turbine bearing when the preload is outside the predetermined acceptance range by controlling the temperature of the outer ring of the wind turbine bearing and the temperature of the inner ring of the wind turbine bearing as a function of the calculated temperature difference between the detected temperature of the outer ring of the wind turbine bearing and the detected temperature of the inner ring of the wind turbine bearing to keep the preload on the wind turbine bearing within the predetermined acceptance range.

27. The method of claim **26**, wherein estimating the preload includes calculating the preload based on at least one of: a structural characteristic of the wind turbine bearing, a dimensional characteristic of the wind turbine bearing, and an assembly characteristic of the wind turbine bearing.

28. The method of claim **26**, wherein correcting the preload on the wind turbine bearing includes heating the outer ring of the wind turbine bearing.

29. The method of claim **26**, wherein correcting the preload on the wind turbine bearing includes cooling the outer ring of the wind turbine bearing.

30. The method of claim **26**, wherein correcting the preload on the wind turbine bearing includes heating the inner ring of the wind turbine bearing.

31. The method of claim **26**, wherein correcting the preload on the wind turbine bearing includes cooling the inner ring of the wind turbine bearing.

32. The method of claim **26**, wherein correcting the preload on the wind turbine bearing includes at least two selected from the group consisting of: heating the outer ring of the wind turbine bearing, cooling the outer ring of the wind turbine bearing, heating the inner ring of the wind turbine bearing, and cooling the inner ring of the wind turbine bearing.

33. The method of claim **26**, which includes controlling the temperature of the outer ring of the wind turbine bearing as a function of the detected temperature of the outer ring of the wind turbine bearing.

34. The method of claim **26**, which includes controlling the temperature of the inner ring of the wind turbine bearing as a function of the detected temperature of the inner ring of the wind turbine bearing.

35. The method of claim **26**, which includes automatically correcting the preload on the wind turbine bearing when the preload is outside the predetermined acceptance range.

36. A non-transitory computer readable medium including a plurality of instructions, which when executed by a control unit cause the control unit to:

detect a temperature of an outer ring of a wind turbine bearing;

detect a temperature of an inner ring of the wind turbine bearing;

calculate a temperature difference between the detected temperature of the outer ring of the wind turbine bearing and the detected temperature of the inner ring of the wind turbine bearing;

estimate a preload on the wind turbine bearing as a function of the detected temperature of the outer ring of the wind turbine bearing and the detected temperature of the inner ring of the wind turbine bearing;

compare the estimated preload with a predetermined acceptance range; and

cause a correction of the preload on the wind turbine bearing when the preload is outside the predetermined acceptance range by controlling the temperature of the outer ring of the wind turbine bearing and the temperature of the inner ring of the wind turbine bearing as a function of the calculated temperature difference between the detected temperature of the outer ring of the wind turbine bearing and the detected temperature of the inner ring of the wind turbine bearing to keep the preload on the wind turbine bearing within the predetermined acceptance range.

37. A wind turbine bearing preload control system comprising:

at least one first sensor configured to detect a temperature of an outer ring of a wind turbine bearing;

at least one second sensor configured to detect a temperature of an inner ring of the wind turbine bearing; and

a control unit configured to:

calculate a temperature difference between the temperature of outer ring of the wind turbine bearing and the temperature of the inner ring of the wind turbine bearing,

estimate a preload on the wind turbine bearing as a function of the temperature of the outer ring of the wind turbine bearing and the temperature of the inner ring of the wind turbine bearing,

compare the estimated preload on the wind turbine bearing with a predetermined acceptance range, and

cause a correction of the preload on the wind turbine bearing when the preload is outside the acceptance range by controlling a first control device and a second control device to adjust the temperature of the outer ring of the wind turbine bearing and the temperature of the inner ring of the wind turbine bearing as a function of the calculated temperature difference between the temperature of the outer ring of the wind turbine bearing and the temperature of the inner ring of the wind turbine bearing to keep the preload on the wind turbine bearing within the predetermined acceptance range.

38. The wind turbine bearing preload control system of claim 37, wherein the control unit is configured to calculate the preload based on at least one of: a structural characteristic of the wind turbine bearing, a dimensional characteristic of the wind turbine bearing, and an assembly characteristic of the wind turbine bearing.

39. The wind turbine bearing preload control system of claim 37, wherein the first control device is configured to heat the outer ring of the wind turbine bearing to correct the preload on the wind turbine bearing.

40. The wind turbine bearing preload control system of claim 37, wherein the first control device is configured to cool the outer ring of the wind turbine bearing to correct the preload on the wind turbine bearing.

41. The wind turbine bearing preload control system of claim 37, wherein the second control device is configured to heat the inner ring of the wind turbine bearing to correct the preload on the wind turbine bearing.

42. The wind turbine bearing preload control system of claim 37, wherein the second control device is configured to cool the inner ring of the wind turbine bearing to correct the preload on the wind turbine bearing.

43. The wind turbine bearing preload control system of claim 37, wherein:

the first control device is configured to at least one of: heat the outer ring of the wind turbine bearing to correct the preload on the wind turbine bearing, and cool the outer ring of the wind turbine bearing to correct the preload on the wind turbine bearing; and

the second control device is configured to at least one of: heat the inner ring of the wind turbine bearing to correct the preload on the wind turbine bearing, and cool the inner ring of the wind turbine bearing to correct the preload on the wind turbine bearing.

44. The wind turbine bearing preload control system of claim 37, wherein the control unit is configured to control the first control device to adjust the temperature of the outer ring of the wind turbine bearing as a function of the detected temperature of the outer ring of the wind turbine bearing.

45. The wind turbine bearing preload control system of claim 37, wherein the control unit is configured to control the second control device to adjust the temperature of the inner ring of the wind turbine bearing as a function of the detected temperature the inner ring of the wind turbine bearing.

46. The wind turbine bearing preload control system of claim 37, wherein the control unit is configured to automatically cause the correction of the preload on the wind turbine bearing when the preload is outside the predetermined acceptance range.

47. An electric energy producing direct drive wind turbine comprising:

a blade assembly rotatable about an axis of rotation;

a rotary electric machine including:

a stator, and

a rotor connected to the blade assembly;

a bearing configured to support the blade assembly about the axis of rotation; and

a control system including:

at least one first sensor configured to detect a temperature of an outer ring of the bearing;

at least one second sensor configured to detect a temperature of an inner ring of the bearing; and

a control unit configured to:

calculate a temperature difference between the temperature of outer ring of the bearing and the temperature of the inner ring of the bearing,

estimate a preload on the bearing as a function of the temperature of the outer ring of the bearing and the temperature of the inner ring of the bearing,

compare the estimated preload on the bearing with a predetermined acceptance range, and

cause a correction the preload on the bearing when the preload is outside the acceptance range by controlling a first control device and a second control device to adjust the temperature of the outer ring of the bearing and the temperature of the inner ring of the bearing as a function of the calculated temperature difference between the temperature of the outer ring of the bearing and the temperature of the

inner ring of the bearing to keep the preload on the bearing within the predetermined acceptance range.

48. The electric energy producing direct drive wind turbine of claim **47**, wherein the bearing is thermally insulated.

49. The electric energy producing direct drive wind turbine of claim **47**, wherein the rotary electric machine is a hollow tubular rotary electric machine, through which cooling air flows along the axis of rotation, and which includes an insulating cover at the inner ring of the bearing.

50. The electric energy producing direct drive wind turbine of claim **47**, wherein:

the outer ring of the bearing is connected to the stator, and

the inner ring of the bearing is connected to the rotor.

51. The electric energy producing direct drive wind turbine of claim **47**, wherein:

the stator includes:

a first tubular structure, and

a tubular first active part connected to the first tubular structure; and

the rotor includes:

a second tubular structure, and

a tubular second active part which:

is connected to the second tubular structure,

faces the tubular first active part, and

is separated from the tubular first active part by an air gap.

52. The electric energy producing direct drive wind turbine of claim **47**, wherein the bearing is a rolling bearing configured to support a radial load and an axial load.

53. The electric energy producing direct drive wind turbine of claim **47**, wherein the bearing includes two rings of rolling bodies.

54. The electric energy producing direct drive wind turbine of claim **53**, wherein the rolling bodies are defined by rollers.

55. The electric energy producing direct drive wind turbine of claim **47**, wherein the control unit is configured to automatically cause the correction of the preload on the bearing when the preload is outside the predetermined acceptance range.

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