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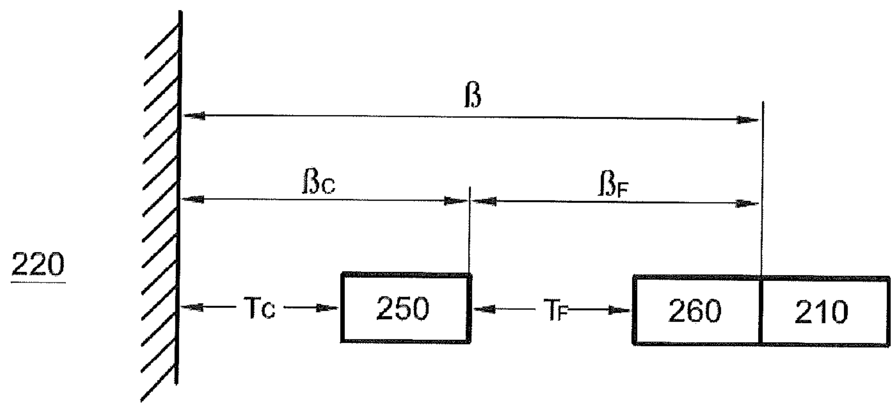

(57) Abstract: Pitch drive system for actively adjusting a pitch angle of a wind turbine blade (210) relative to a wind turbine hub (220), the system comprising a fine pitch drive and a coarse pitch drive, characterized in that the fine pitch drive comprises a first bearing arrangement (260) and first actuation means (T_F), for rotationally supporting and driving the blade through a relatively small range of angular motion, and in that the coarse pitch drive comprises a second bearing arrangement (250) and second actuation means (T_C) for rotationally supporting and driving the blade through a relatively large range of angular motion.

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PITCH DRIVE SYSTEM AND METHOD

TECHNICAL FIELD

The present invention relates to a system and a method for adjusting the pitch angle of a wind turbine blade that is rotationally supported relative to a wind turbine hub.

BACKGROUND ART

Wind turbines are designed to convert wind into electricity, by turning a generator positioned in a wind turbine housing, also known as a nacelle. The rotation of the generator is achieved by wind turbine blades, normally three, that rotate by the wind. In order to optimize the output power of the wind turbine, the blades may be rotated around their longitudinal axis. In this way, the blades can be used to control the amount of wind power transferred from the wind to the generator.

To generate a high torque in low-to-medium wind conditions, the turbine blades are pitched into the wind, to catch as much wind as possible. If the wind speed increases and the generator is in danger of being overloaded, the blade angle of attack is altered. Stall control may be applied, whereby the angle of attack of each blade is increased. In a fully stalled condition, a flat side of the blade faces directly into the wind. The range of blade angular motion that is required to stall the blades, if necessary, is approximately 30 degrees. In other words, 15 degrees in each direction, relative to a rotational midpoint.

Pitch control may also be applied, whereby the blade angle of attack is decreased. If the wind speed becomes too high, or if the hub rotor is to be shut down due to a failure or in order to perform maintenance, the blades are rotated to a “parked” position. In this position, the edge of each blade faces the wind. The required range of blade angular motion in is this instance is approximately 90 degrees.

During operation, once the blades have been rotated to the appropriate angle for the wind conditions, the pitch angle of each blade is finely adjusted, to compensate for the different wind load acting on each blade as it rotates around a main shafts axis of the hub. As a result of fine pitch adjustment, the power output of the generator can be maintained in an optimal range. In the fine adjustment range, the blades are rotatable relative to the hub through an angle of approximately 10 degrees. In other words, 5 degrees in each direction, relative to the rotational midpoint.

Thus, two types of angular adjustment can be identified with respect to blade pitching: fine pitch adjustment and coarse pitch adjustment.

For fine pitch adjustment, the pitch angle is small and pitching speed can be high. For example, the blade may be rotated through an angle of 5 degrees in one second. For coarse pitch adjustment, the pitch angle is relatively large (up to approximately 90 degrees) and the pitching speed relatively slow. For example, each blade may be rotated through an angle of up to 90 degrees in 15 - 20 seconds.

When the wind turbine is in use, fine pitch adjustment occurs much more frequently than coarse adjustment. Typically, fine adjustment takes place more or less continuously, while the larger, positional adjustments occur e.g. once very few minutes. Fine pitch adjustment may therefore be viewed as a high-frequency, short-stroke angular adjustment, while coarse pitch adjustment may be seen as a semi-static, long-stroke angular adjustment.

In conventional wind turbines, the same drive apparatus is used for performing fine and coarse pitch adjustments. For example, a geared motor may be coupled between the hub and each blade, whereby each blade is typically mounted to the hub via a slewing bearing. The slewing bearing may have a ring gear on its inner circumference, which is then driven by a pinion on the motor, to produce a torque at the blade root.

In US6604907, an example of a pitch drive apparatus is disclosed in which each blade is driven by two linear actuators, which are joined to a moveable rocker arm. A regulating cylinder adjusts the rotor blade only in the angular range necessary for power and speed regulation. A disconnection cylinder moves the regulating cylinder by means of an adjustment mechanism into the regulation or disconnection position. Thus, each cylinder may be optimised for its specific function.

There is room for improvement, however.

DISCLOSURE OF INVENTION

The present invention is based on the understanding that the different types of rotational motion which a blade undergoes can benefit not only from a dedicated actuation solution, but also from a dedicated bearing solution.

Accordingly, a pitch drive system according to the invention comprises a fine pitch drive and a coarse pitch drive, whereby the fine pitch drive comprises a first actuation means and a first bearing arrangement for respectively driving and rotationally supporting a wind turbine blade relative to a wind turbine hub. The coarse pitch drive comprises second actuation means and a second bearing arrangement for respectively driving and rotationally supporting the wind turbine blade relative to the wind turbine hub.

Thus, a pitch drive system according to the invention splits pitch adjustment into two degrees of freedom: fine adjustment and coarse adjustment. This enables optimization of each pitch drive, which is especially important for the fine pitch drive, given that the large majority of angular adjustments are fine adjustments.

Suitably, the first bearing arrangement (fine pitch bearing) is a type of bearing that is optimally adapted for high-frequency short-stroke adjustments, and which generates a relatively low friction torque. The second bearing arrangement (coarse pitch bearing) is a different type of bearing, which is adapted for long-stroke angular adjustments. Thus, the first actuation means (fine pitch actuator) can be optimised not only in terms of the speed and range of angular motion, but also in terms of the power required to drive the fine pitch bearing. When a single bearing arrangement is used, as in conventional pitch drive systems, a fine pitch actuator needs to be as powerful as a coarse pitch actuator.

The system preferably comprises an intermediate ring, whereby the blade is mounted to the intermediate ring via the fine pitch bearing. The intermediate ring is then mounted to the hub via the coarse pitch bearing. In one embodiment, the coarse pitch actuator couples the hub and the intermediate ring. The fine pitch actuator may then be mounted between the intermediate ring and the blade, or between the hub and the blade. In a further embodiment, the fine pitch actuator couples the hub and the blade and the coarse pitch actuator is mounted between the blade and intermediate ring.

In one example of the further embodiment, the fine pitch actuator (first actuation means) also serves as the coarse pitch actuator (second actuation means). Suitably, the fine pitch bearing permits a degree of relative rotation that is mechanically limited. Thus, when the fine pitch actuator is operated, the blade is rotated until the mechanical limit of the fine pitch bearing is reached. Further torque then causes rotation of the intermediate ring via the coarse pitch bearing. Such a configuration has the advantage of reducing the number of system components, but has the drawback that the actuator cannot be optimised for fine pitch adjustments only.

In some embodiments of the invention, the fine pitch bearing comprises an elastomeric bearing, whereby a first part of the elastomeric bearing is connected to the intermediate ring and a second part of the elastomeric bearing is connected to the blade. Such a bearing has high axial and radial stiffness, but a low torsional stiffness, thereby permitting the high-frequency, short-stroke adjustments of up to approx. 5 degrees which is required for fine pitch adjustment.

In other embodiments, the fine pitch bearing comprises at least three rods, whereby a first end of each rod is mounted to the intermediate ring by means of a first swivel joint and a second end of each rod of mounted to the blade by means of a second swivel joint. A swivel joint is to be understood as a joint with two degrees of rotational freedom, which allows rotation around the two axes perpendicular to the blade rotation axis. A rod end with spherical plain bearing, or a ball joint are examples of a suitable swivel joint.

The rods have a length and diameter that are suitable for supporting the blade, and the swivel joints allow a back and forth angular rotation of up to at least 5 degrees, relative to a neutral midpoint. Depending on the design of the swivel joints, the rod connections may permit a greater range of angular rotation than 10 degrees.

As will be understood, the rods are particularly well suited for transmitting axial loads and for carrying the large bending moment due to the blade. Furthermore, the sliding contact which takes place in the first and second rod ends and the first and second swivel joints takes place over a relatively small surface area. This reduces friction torque..

The rods take up the axial forces and the bending moment of the blade. For supporting the radial load of the blade, the assembly in this embodiment further comprises a first radial bearing. Since the radial bearing has no need to support bending moment, it is possible to use a radial bearing which has a diameter much smaller than the diameter of the blade root.

Suitably, the hub comprises a central shaft extension and the blade comprises an appropriate mounting structure. The mounting structure may be an integral part of the blade, or may be a separate part to which the blade root is fixedly connected by means of e.g. bolts. The mounting structure preferably has a conical shape, and comprises a small-diameter ring part and a large-diameter ring part which are joined by a plurality of spokes. Suitably, the large-diameter ring part is provided with attachment heads for the second end of each rod. The small-diameter ring part is mounted to the to the central shaft extension of the hub via the first radial bearing.

A mounting platform for an actuator may also be provided at the small-diameter ring part of the conical mounting structure. In one example, the fine pitch actuator is mounted on the platform. Preferably, the actuator is a linear actuator, whereby the output piston is coupled to e.g. a stud on the intermediate ring.

In a further development of the invention, the fine pitch actuator is an electrical or hydraulic linear actuator with a non-linear output force. This is advantageous in embodiments where the amount of torque needed to increase the angle of relative rotation of the fine pitch bearing increases as the angle increases. Thus, the force profile of the fine pitch actuator can be tuned to the torque profile of the fine pitch bearing.

The coarse pitch bearing may be a slewing bearing. The intermediate ring can be mounted to the hub via the slewing bearing, or, to reduce weight, the intermediate ring forms part of the slewing bearing. For example, the intermediate ring can comprise a raceway on a radially outer surface for e.g. two rows of rolling elements, and thus acts as the bearing inner ring. The bearing outer ring is then bolted to the hub in a conventional manner.

In a further embodiment, the coarse pitch bearing comprises a radial bearing for supporting an inner annular section of the intermediate ring, and comprises an axial plain bearing provided at an outer annular section of the intermediate ring. The axial plain bearing comprises first and second sliding surfaces which are clamped to the hub by first and second clamping members.

The coarse pitch bearing has a relatively large diameter (approximately equal to the blade root diameter). The large diameter means that a relatively large friction torque is generated. Consequently, the coarse pitch actuator may comprise a first actuator and a second actuator which act simultaneously on the intermediate ring. In one example, the intermediate ring is provided with a ring gear and the coarse pitch actuator comprises a first motor and pinion which engage with a first segment of the ring gear, and further comprises a second motor and pinion that engages with a second segment of the ring gear. The fine pitch actuator may also be a (short-stroke) motor with a pinion that engages with a third segment of the ring gear.

Because the rotational support of the blade comprises two bearing arrangements, the pitch angle of the blade relative to the hub comprises two components: a fine pitch angle and a coarse pitch angle. The fine pitch angle is the angle of the fine pitch bearing (and blade) relative to the coarse pitch bearing (and intermediate ring). The coarse pitch angle is the angle of the coarse pitch bearing (and intermediate ring) relative to the hub.

The present invention also defines a method of actively adjusting the pitch angle of a wind turbine blade, relative to a wind turbine hub, to a pitch setpoint β. The method comprises steps of:

Splitting the rotational support of the blade into two degrees of freedom via a fine pitch bearing for fine pitch angle adjustments and via a coarse pitch bearing for coarse pitch angle adjustments;

Operating a fine pitch drive, comprising the fine pitch bearing and a fine-pitch actuator, to obtain a fine pitch angle of the blade β_F;

Operating a coarse pitch drive, comprising a coarse pitch bearing and a coarse pitch actuator, to obtain a coarse pitch angle of the blade β_C,

wherein $\beta = \beta_F + \beta_C$.

A number of control and actuation strategies are possible. For example, the pitch setpoint may be split into a coarse pitch setpoint and a fine pitch setpoint, whereby the fine pitch drive and the coarse pitch drive are operated separately and controlled by an independent control loop. An advantage of this method is that a number of system constraints can be defined within an algorithm that determines the setpoint for the fine pitch angle and the coarse pitch angle. For example, a maximum value for fine pitch angle can be defined. Further, a pitch angle range can be specified, which defines a deadzone for the coarse pitch drive. As a result, operation of the coarse pitch drive can be minimized, which is beneficial in terms of minimizing friction torque.

In an alternative control strategy, a master loop controls the fine pitch drive, while a slave loop controls the coarse pitch drive. In one example, the fine pitch bearing is driven directly to the pitch angle setpoint and the coarse pitch drive follows the fine pitch drive, to keep the fine pitch angle close to a neutral position. When the fine pitch bearing comprises rods, the rotation of the rods around the joints causes an axial displacement, which increases with the square of the rotation angle. An axial force associated with the axial displacement is directed towards the hub, in a direction opposite from the centrifugal force. Keeping the fine pitch bearing close to its neutral position is therefore beneficial in terms of minimising disturbance forces within the system.

The algorithm used to determine the setpoint for fine pitch angle and the coarse setpoint angle may also be configured to keep the fine pitch bearing close to its neutral position.

In short, the actuation and control strategy may be optimised in terms of energy management and/or long-term system health. Other advantages of the present invention will become apparent from the detailed description and accompanying figures.

BRIEF DESCRIPTION OF DRAWINGS

The invention will be described in greater detail in the following, with reference to the embodiment shown in the attached drawing, where

Fig. 1a	shows a cross-sectional view of a pitch drive system according to the invention for driven rotation of a wind turbine blade relative to a hub.
Fig. 1b	shows a perspective view of the system of Fig. 1a, without the blade.
Fig. 2	is a schematic representation of the system of Figs. 1a and 1b.
Fig. 3	is a flow diagram of a method according to the invention.
Fig. 4	shows a cross-sectional view of a further example of a system according to the invention

MODES FOR CARRYING OUT THE INVENTION

The embodiments of the invention with further developments described in the following are to be regarded only as examples and are in no way to limit the scope of the protection provided by the patent claims.

Fig. 1 and Fig. 2 show different views of an example of a system according to the invention, adapted for driven rotational support of a wind turbine blade 110, relative to a wind turbine hub 120. In Fig. 1a, a part of one blade 110 is shown mounted to an arm 124 of the hub 120. The hub itself is mounted on a main shaft, which has a main shaft axis perpendicular to an axis 105 of the rotational support. The generator of the wind turbine is centred on the main shaft axis, which is driven when the hub 120 is caused to rotate by wind striking blades attached to the hub. Typically, a wind turbine comprises three blades.

The assembly is configured for active pitch control, and the angle of each blade is adjustable relative to the hub. As explained previously, high-frequency, short stroke angular adjustments (up to approx. five degrees back and forth) are designated as fine pitch adjustments. Large angular adjustments (through a maximum range of approx. 90 degrees) are designated as coarse pitch adjustments.

In a system according to the invention, fine pitch adjustments are made using a fine pitch drive, which comprises a fine pitch bearing. Coarse adjustments are made using a coarse pitch drive, which comprises a different type of bearing (coarse pitch bearing). Suitably, the fine pitch bearing is optimally adapted for the high-frequency, short stroke adjustments, while the coarse pitch bearing is adapted for long-stroke adjustments. The blade 110 is mounted to the hub 120 via a series arrangement of the fine pitch bearing and the coarse pitch bearing, which allows the pitch motions to be split into two degrees of freedom.

The system suitably comprises an intermediate ring 140, mounted between the hub arm 124 and the blade 110. In the depicted example, the intermediate ring has an outer annular section 144, with a diameter essentially equal to the blade root diameter and the diameter of the hub arm 124. The blade is mounted to the intermediate ring via the fine pitch bearing, which comprises three rods 160. A first end 161 of each rod is attached to an inner circumference of the annular section 144 of the intermediate ring, by means of a first swivel joint 163. A second end 162 of each rod is attached to a blade mounting structure by means of a second swivel joint 164. The blade 110 is fixed to the mounting structure by means of e.g. 80 bolts.

In the depicted example, the first and second swivel joints 163, 164 are spherical plain bearings, which are provided at an inner circumference of each first rod end 161 and each second rod end 162. The first spherical plain bearings 163 are then mounted to a corresponding set of first attachment heads 165 on the intermediate ring and the second spherical plain bearings 164 are mounted to a corresponding set of second attachment heads 166 on the blade mounting structure. Suitably, the three first swivel joints and the three second swivel joints are spaced at equal intervals on the intermediate ring 140 and blade mounting structure respectively. The radius of contact in each swivel joint is small in relation to rod length, which has the advantage that a low friction torque is generated.

The first and second swivel joints 163, 164 allow rotation of the rods 160 in two degrees of freedom, meaning that the blade 110 is able to rotate relative to the intermediate ring by a limited amount. In some applications, three rod connections are preferred, as this arrangement is statically determinate. A greater number of swivelling rod connections is also possible (See Figure 4). Typically, the joints are designed to allow a back-and-forth angular adjustment of approx. 5 degrees in each direction. The relative angular displacement also causes an axial displacement of the blade relative to the intermediate ring. Suitably, the blade is mounted to the intermediate ring with a certain axial gap 170 in between, to allow for this axial displacement. A gap of e.g. 10 mm is sufficient when the rods 160 have a length of approximately two metres.

The axial forces acting on the turbine blade and the bending moment are transferred to the intermediate ring 140 via the rod connections, which are excellently suited for taking up tensile and compressive loads (axial forces) and the blade bending moment. The axial forces are transmitted from the intermediate ring to the hub via an axial bearing 150, which forms part of the coarse bearing, as will be described later.

The radial loads on the blade are transferred to the hub by a radial bearing. The radial bearing supports radial load only, which allows the use of a radial bearing with a relatively small diameter. Suitably, the hub comprises a central, shaft-like extension 122, which is joined to the hub arm 124 by a plurality of hub spokes 125: e.g. three equally spaced spokes. Suitably, the blade mounting structure has a small-diameter ring part 112 that is joined to a large diameter ring part by a plurality of blade spokes (not shown). The mounting structure is thus essentially conical shape, whereby the second attachment heads 166 are provided on the large-diameter ring part. The small-diameter ring part 112 is mounted to the hub extension 122 via the radial bearing 130. In the depicted example, the radial bearing is a plain bearing. Due to the relatively small diameter of the plain bearing, a low friction torque is generated by this component.

The fine pitch drive further comprises a fine pitch actuator. In the depicted example, the fine pitch actuator is a short-stroke motor 180 with a first pinion 182 on the output shaft. In Fig. 1b, which shows a perspective view of the assembly without the blade, the motor 180 should be imagined as being mounted to a platform on e.g. the blade mounting structure. An inner circumference of the intermediate ring is provided with a ring gear 190, whereby the first pinion 182 meshes with teeth on a first section of the ring gear. Thus, fine pitch adjustments are made by rotating the fine pitch bearing (and blade) relative to the coarse pitch bearing (and intermediate ring)

For coarse pitch adjustment, the intermediate ring is rotated relative to the hub, and forms part of the rotational support of the blade relative to the hub. The intermediate ring 140 comprises an inner annular section 142, which is joined to the outer annular section 144 by a plurality of ring spokes 145; e.g. three ring spokes (see Fig. 1b). The inner section 142 of the intermediate ring is mounted to the hub shaft 122 on the same radial plain bearing 130 that supports the small-diameter part 112 of the blade mounting structure. It is also possible to use a dedicated bearing for radial support of the intermediate ring 140. The intermediate ring 140 is additionally mounted to the hub 120 via the thrust bearing 150.

In the depicted example, an end of the hub arm 124 is provided with an inwardly extending flange 127. The intermediate ring 140 comprises a U-shaped section, adjacent to the outer annular section 144, whereby the flange 127 is retained between a first leg 147 and a second leg 148 of the U-shaped section. The thrust bearing 150 is provided on the U-shaped section 145, and comprises a first sliding surface 151 on the first leg 147 and a second sliding surface 152 on the second leg 148, which sliding surfaces 151 and 152 are in contact with the hub flange 127.

The first and second sliding surfaces may be provided on a first and second set of individual sliding pads, as best shown in Fig. 1b. In this figure, a side 155 of the first pads, opposite from the first sliding surface 151 is visible. The first pads are mounted through openings in the first leg 147 of the U-shaped section; the second pads are mounted through openings in the second leg. The advantage of individual sliding pads is that the pads can be replaced if the sliding surface becomes worn.

The second leg 148 is a separate part that is connected to the intermediate ring 140, after the blade and intermediate ring have been mounted over the hub extension 122. The second leg can be connected with a suitable preload or clearance, which is sufficient to axially retain the flange 127 between the legs of the U-section, but which allows rotation of the intermediate ring 140 (together with the blade) relative to the hub 120.

The coarse pitch drive further comprises a coarse pitch actuator. In the depicted example, the coarse pitch actuator is a long-stroke motor 185 with a second pinion 187 on its output shaft. The long-stroke motor is mounted to the hub, on e.g. a hub spoke 125. The second pinion meshes with teeth on a second section of the ring gear 190, which is preferably substantially opposite from the first section. Thus, coarse pitch adjustments are made by rotating the coarse bearing (and intermediate ring 140) relative to the hub 120.

A schematic representation of the system is shown in Fig. 2, in which, for simplicity, rotations are represented as translations.

When the coarse actuator is activated, a torque T_C acts on the coarse bearing 250, producing a coarse pitch angle $\beta_{C,}$ which is the angle of the coarse pitch bearing relative to the hub 220. When the fine pitch actuator is activated, a torque T_F acts on the fine pitch bearing 260, producing a fine pitch angle $\beta_{F,}$ which is the angle of the fine pitch bearing relative to the coarse pitch bearing 250. Thus, the pitch angle β of the blade 210 relative to the hub 220 is given by:

$$\beta = \beta_C + \beta_F$$

In order to control the pitch angle adjustments, the system is therefore provided with means for measuring at least two of the blade pitch angle β, the fine pitch angle β_F and the coarse pitch angle β_C.

An example of a method according to the invention, for setting the blade pitch angle to a setpoint value β_{SET} will now be described with reference to the flow diagram in Figure 3.

In a first step 31, the pitch angle setpoint β_{SET} is split into two new setpoints. A setpoint for the coarse pitch angle $\beta_{C,\ SET}$ is determined and a setpoint for the fine pitch angle $\beta_{F,\ SET}$ is determined. Both the coarse and the fine pitch drive may then have their own independent control loops. In a second step, the actual coarse pitch angle is determined, and a coarse pitch controller 32 outputs a torque demand T_C for the coarse pitch bearing, in order to achieve the coarse setpoint $\beta_{C,\ SET}$. In a third step 33, the coarse pitch drive is operated to set the coarse pitch angle β_C at the coarse setpoint angle. The second and third steps are repeated until $\beta_C = \beta_{C,\ SET}$. In a fourth step, the actual fine pitch angle is determined and a fine pitch controller 34 outputs a torque demand T_F for the fine pitch bearing. The fourth step may be performed concurrently with the second step. In a fifth step, the fine pitch drive is operated to set the fine pitch angle $\beta_{F,}$ at the fine setpoint angle. The fourth and fifth steps are repeated until $\beta_F = \beta_{F,\ SET}$. As a result, the blade adopts a pitch angle β that is equal to the setpoint β_{SET}.

In the first step 31 of splitting the pitch setpoint, a number of algorithms may be used in which system constraints are defined. For example, the fine pitch bearing has a limited mechanical range. A maximum value (saturation value) for the fine pitch angle may therefore be defined.

Further, since the coarse pitch bearing generates more fiction torque, a control strategy may be designed to minimise use of the coarse pitch drive by defining e.g. a suitable deadzone. However, the friction torque depends on the load on the coarse bearing. Therefore, the method may include a step of measuring the load on the coarse bearing and the application of the deadzone may be made dependent on the measured load exceeding a predetermined value.

Further, if the coarse bearing has a limited achievable pitch rate, a rate limiter may be used in the algorithm. Filtering may also be employed, to ensure smooth transitions are made between coarse and fine pitch adjustment.

A further example of a pitch drive system according to the invention is depicted in Fig. 4. In this example, the coarse pitch bearing again comprises a plain thrust bearing. The intermediate ring 440 is mounted on the hub extension 422 via a bushing 432. An outer annular portion of the intermediate ring has a ring flange, on which the first and second sliding surfaces 451, 452 of the thrust bearing are provided. The ring flange is clamped to the hub 420 by first and second clamping members 457, 458.

The blade (not shown) is mounted to the hub and intermediate ring via a conical mounting structure 470. The small diameter end of the mounting structure 470 is mounted to the hub extension via a radial bearing 430, which is a non-located spherical plain bearing in this example. The large-diameter end of the mounting structure 470 comprises a series of attachment heads 466 for the second end of each rod 460, while the intermediate ring is provided with a series of attachment heads 465 for the first end of each rod.

The fine pitch bearing in this example comprises 24 rods which interconnect the blade mounting structure 470 and intermediate ring 440 via first and second swivel joints. The advantage of using more than three rod supports is that each rod 460 and swivel joint may have a smaller diameter, which allows the use of standard components. Further, the load on each joint is lower, which reduces friction. A disadvantage of more than 3 connections is that the arrangement is over determined, meaning that there is a risk that the load will not be evenly distributed over each rod. To counteract this drawback, the length of each rod is adjustable, which helps ensure that when the blade is attached, each rod takes up a share of the load.

The fine pitch actuator is a linear actuator in this example. Suitably, the conical mounting structure 470 has a platform on which the linear actuator 480 is received. An output piston of the fine pitch actuator 480 is coupled to a stud on the intermediate ring. The advantage of a linear actuator and corresponding connection is that the connection is less prone to wear than engaging gear teeth.

Further, the system comprises means for measuring at least two of the blade pitch angle β, the fine pitch angle β_F and the coarse pitch angle β_C. In this example, the pitch drive control is configured to enable simultaneous operation of the coarse pitch drive and the fine pitch drive. The fine pitch angle is controlled by a master control loop and the coarse pitch angle is controlled by a slave control loop. Specifically, the fine pitch angle is driven directly towards the pitch angle setpoint and the coarse pitch drive follows the fine pitch drive, to keep the fine pitch angle within its mechanical limits and, preferably, close to its neutral position.

The invention is not to be regarded as being limited to the embodiments described above, a number of additional variants and modifications being possible within the scope of the subsequent patent claims.

CLAIMS

1. Pitch drive system for actively adjusting a pitch angle of a wind turbine blade (110) relative to a wind turbine hub (120, 220, 420), the system comprising a fine pitch drive and a coarse pitch drive, **characterized in that** the fine pitch drive comprises a first bearing arrangement (260) and first actuation means (180, 182, 480), for rotationally supporting and driving the blade through a relatively small range of angular motion, and in that the coarse pitch drive comprises a second bearing arrangement (250) and second actuation means (185, 187) for rotationally supporting and driving the blade through a relatively larger range of angular motion.

2. Pitchdrive system according to claim 1, wherein the first bearing arrangement permits a limited range of relative angular rotation of no more than 30 degrees.

3. Pitch drive system according to claim 1 or 2, wherein the first bearing arrangement comprises an elastomeric bearing.

4. Pitch drive system according to claim 1 or 2, further comprising an intermediate ring (140, 440), wherein the blade (110) is mounted to the intermediate ring via the first bearing arrangement and the intermediate ring is mounted to the hub (120, 220, 420) via the second bearing arrangement.

5. Pitch drive system according to claim 4, wherein the first bearing arrangement comprises at least three rods (160, 460), whereby a first end (161) of each rod is in connection with the intermediate ring (140, 440) via a first swivel joint (163) and a second end (162) of each rod is in connection with the blade (110) via a second swivel joint (164).

6. Pitch drive system according to claim 5, wherein the first bearing arrangement comprises more than three rods (160, 460), and wherein at least one of the rods is adjustable in length.

7. Pitch drive system according to any of claims 4 to 6, wherein the first bearing arrangement comprises a first radial bearing (130, 430) mounted on a shaft-like extension (122, 422) of the hub.

8. Pitch drive system according to any preceding claim, wherein the first actuation means comprises at least one short-stroke motor (180) and the second actuation means comprises at least one long-stroke motor (185)

9. Pitch drive system according to any preceding claim, wherein the fine pitch actuator is a linear actuator (480) which couples the first bearing arrangement (260) and the second bearing arrangement (250).

10. Pitch drive system according to any of claims 4 to 9, wherein the intermediate ring (140, 440) comprises a toothed section 190, and the second actuation means comprises at least one pinion drive (185, 187).

11. Pitch drive system according to any preceding claim, wherein the second bearing arrangement comprises a slewing bearing.

12. Pitch drive system according to any of claims 4 to 10, wherein the second bearing arrangement comprises an axial bearing (150), with first (151, 451) and second (152, 452) sliding surfaces provided on the intermediate ring (140, 440).

13. A method of method of actively adjusting the pitch angle of a wind turbine blade (110, 210) that is rotationally supported relative to a wind turbine hub (120, 220, 420) to a blade pitch setpoint β, the method comprising steps of:

Splitting the rotational support of the blade into two degrees of freedom via a fine pitch bearing (260) for fine pitch angle adjustments and via a coarse pitch bearing (250) for coarse pitch angle adjustments;

Operating a fine pitch drive, comprising the fine pitch bearing (260) and a fine-pitch actuator (180, 182, 480), to obtain a fine pitch component β_F of the blade pitch setpoint;

Operating a coarse pitch drive, comprising the coarse pitch bearing (250) and a coarse pitch actuator (185, 187), to obtain a coarse pitch component β_C of the blade pitch setpoint,

wherein $\beta = \beta_F + \beta_C$.

14. The method of claim 13, further comprising a step of determining a setpoint for the fine pitch component $\beta_{F,\ SET}$ and a setpoint for the coarse pitch component $\beta_{C,\ SET}$, wherein the fine pitch drive and the coarse pitch drive are controlled by an individual control loop.

15. The method according to claim 14, further comprising a step of measuring a load on the coarse pitch bearing, wherein the coarse pitch setpoint $\beta_{F,\ SET}$ is determined partly in dependence on the measured load.

16. The method according to claim 14 or 15, wherein the step of determining is based on an algorithm in which one or more system constraints are defined, the constraints being selected from: a maximum angle for the fine pitch component β_F, a deadzone for the coarse pitch drive which minimizes use of the coarse pitch drive, a rate limit for a pitch rate of the coarse pitch bearing.

17. The method according to claim 13, wherein the steps of operating the fine pitch drive and the coarse pitch drive are performed simultaneously.

18. The method according to claim 17, wherein the fine pitch drive is controlled by a master control loop and the coarse pitch drive is controlled by a slave control loop.

19. The method according to any of claims 13 to 18, wherein a control algorithm is used which keeps the fine pitch bearing close to a rotational midpoint.

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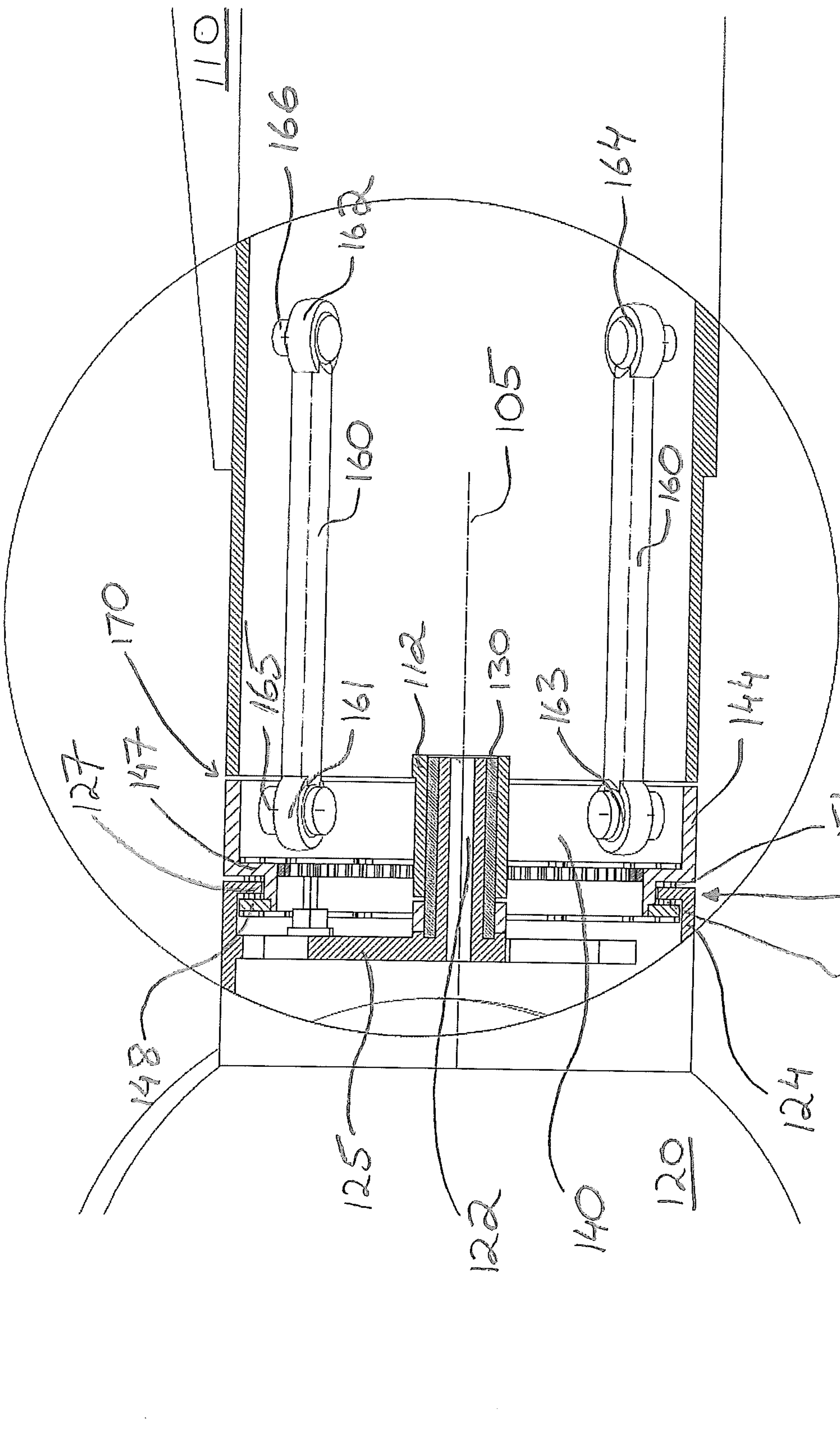
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Fig. 1a

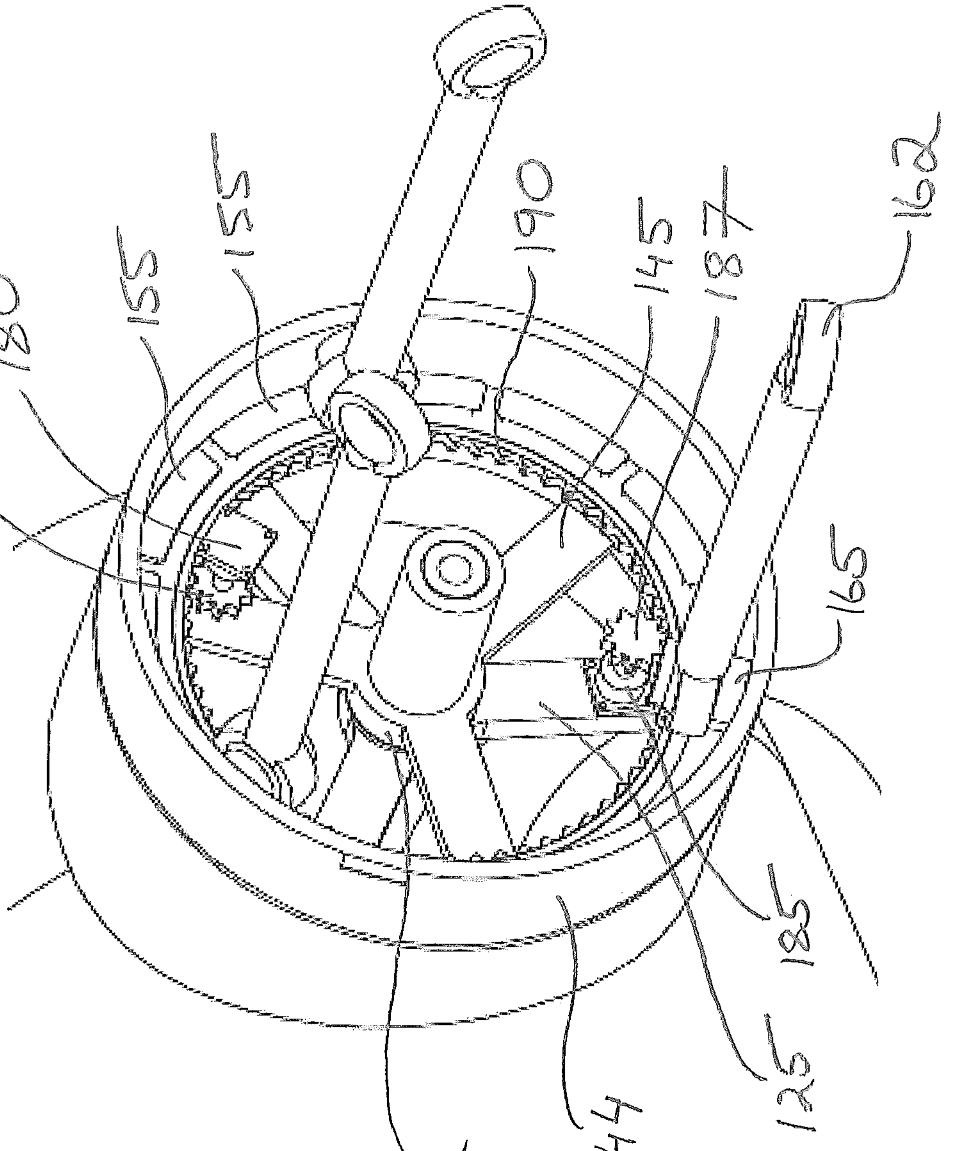
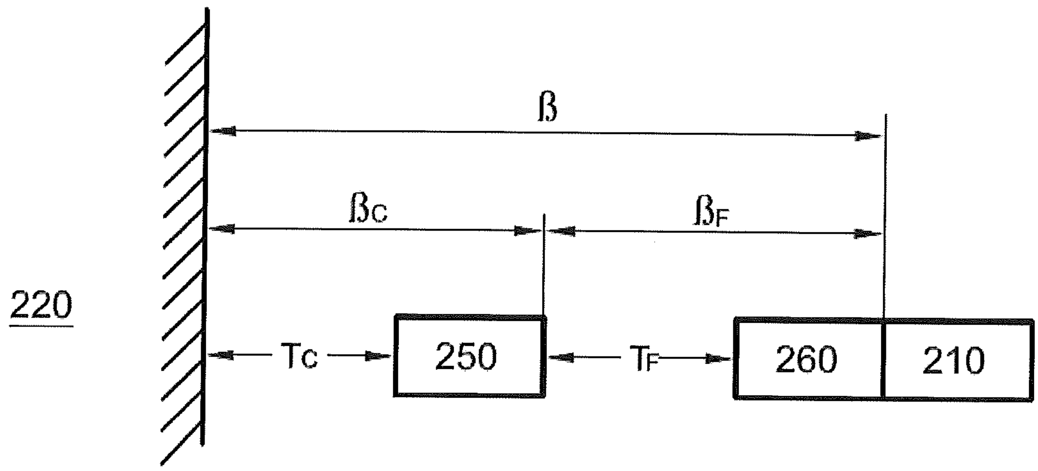


Fig. 6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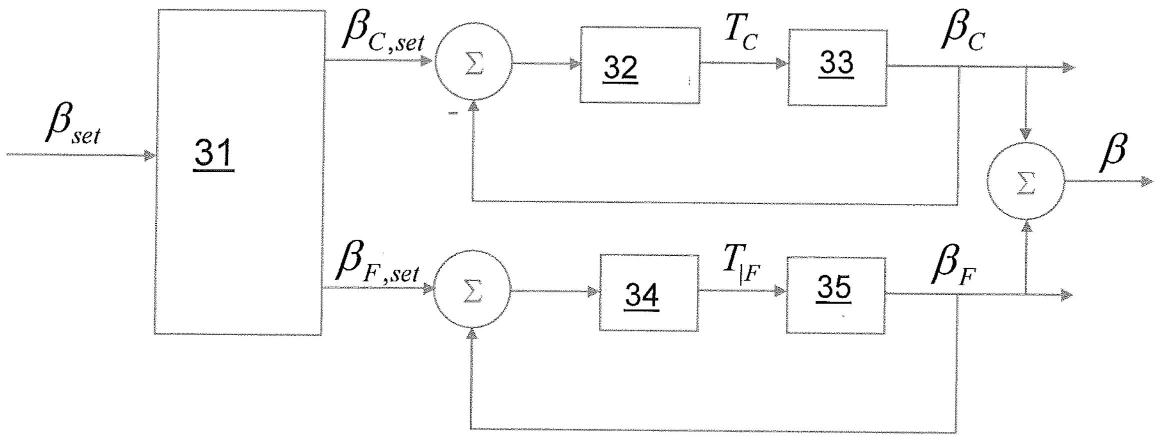
220
Tc
250
TF
260
210

Fig. 2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β
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Fig. 3

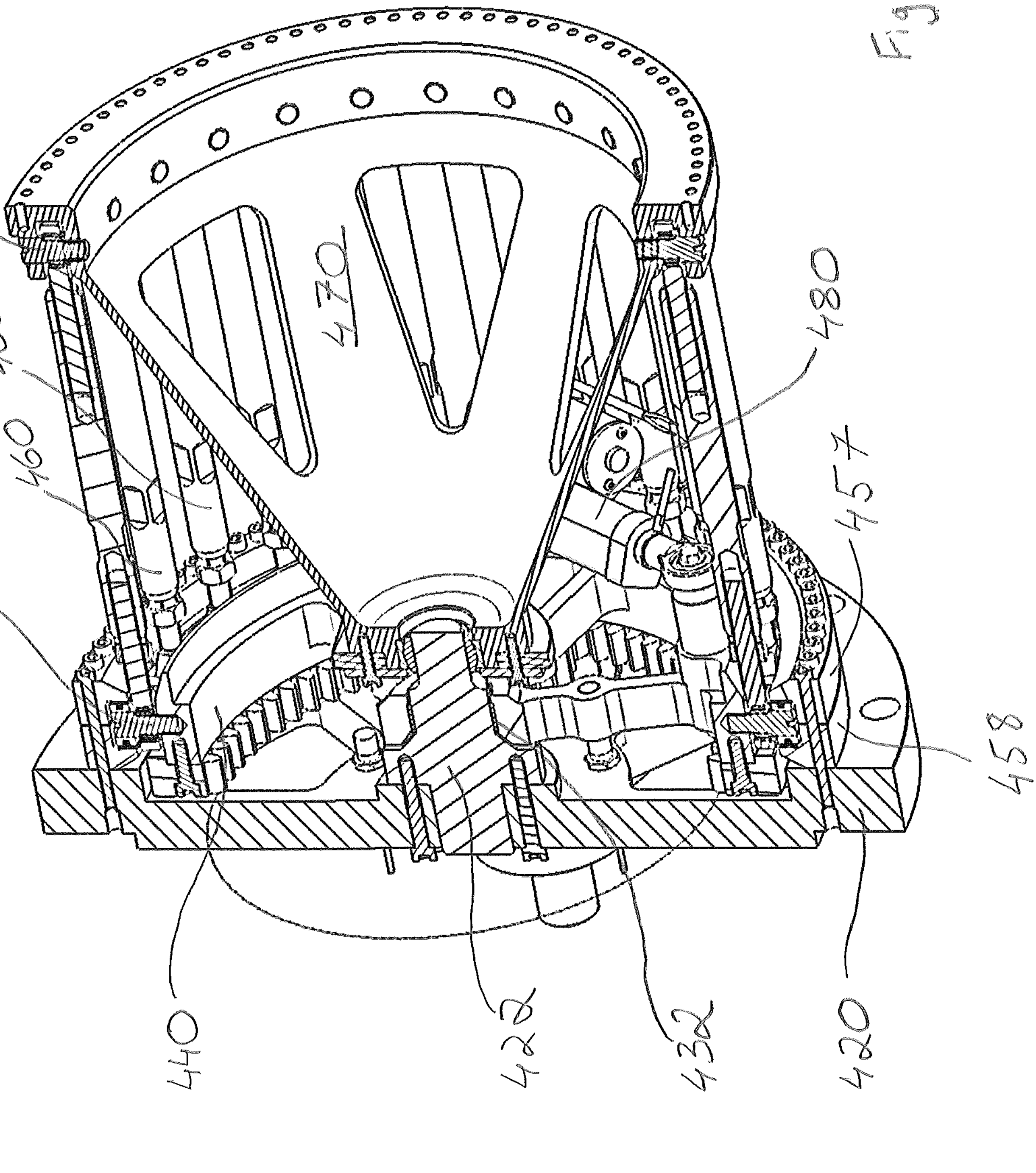

Fig. 4