Axial flux machine

An axial flux machine which can be used as a gearless mill drive (GMD) comprises a rotor disk (10) mounted about an axis of rotation and having first and second axial faces (14, 16). A first stator ring (20) is positioned on one side of the rotor disk (10) adjacent to the first axial face (14) of the rotor disk (10) to define a first air gap (8) between the first stator ring (20) and the first axial face (14) of the rotor disk (10). The first stator ring (20) is formed by a plurality of circumferentially adjacent wedge-shaped first stator ring segments (32a) each having a radially inner edge (36a) and a radially outer edge (42a). A second stator ring (26) is positioned on the other side of the rotor disk (10) adjacent to the second axial face (16) of the rotor disk (10) to define a second air gap (9) between the second stator ring (26) and the second axial face (16) of the rotor disk (10). The second stator ring (26) is formed by a plurality of circumferentially adjacent wedge-shaped second stator ring segments (32b) each having a radially inner edge (36b) and a radially outer edge (42b) and being circumferentially aligned with a corresponding wedge-shaped first stator ring segment (32a). The first and second stator ring segments (32a, 32b) are deflectable in the axial direction in response to axial deflection of the rotor disk (10) to maintain the first and second air gaps (8, 9) and a link element (40) extends between the radially outer edge regions (42a, 42b) of each circumferentially aligned pair of first and second stator ring segments (32a, 32b) so that they deflect together in unison in the axial direction.
The present disclosure relates to an axial flux machine and in particular a stator construction for an axial flux machine. The axial flux machine any be an axial flux motor which may operate as a gearless drive for a grinding mill such as an autogenous (AG) mill or a semi-autogenous (SAG) mill.

SUMMARY OF THE DISCLOSURE

According to one aspect of the present disclosure, there is provided an axial flux machine comprising:

- a rotor mounted about an axis of rotation and having first and second axial faces;
- a first stator ring positioned on one side of the rotor adjacent to the first axial face of the rotor to define a first air gap between the first stator ring and the first axial face of the rotor, the first stator ring being formed by a plurality of circumferentially adjacent wedge-shaped first stator ring segments each having a radially inner edge and a radially outer edge; and
- a second stator ring positioned on the other side of the rotor adjacent to the second axial face of the rotor to define a second air gap between the second stator ring and the second axial face of the rotor, the second stator ring being formed by a plurality of circumferentially adjacent wedge-shaped second stator ring segments each having a radially inner edge and a radially outer edge and being circumferentially aligned with a corresponding wedge-shaped first stator ring segment; wherein the first and second stator ring segments are deflectable in the axial direction in response to axial deflection of the rotor and a link element extends between the radially outer edge regions of each circumferentially aligned pair of first and second stator ring segments so that they deflect together in unison in the axial direction.

TECHNICAL BACKGROUND

Grinding mills are widely used in mineral processing applications and the most common types are the autogenous (AG) grinding mill in which the feed material itself acts as the grinding medium and the semi-autogenous (SAG) grinding mill in which supplementary grinding material, typically steel balls, is added to the feed material.

Grinding mills are often subjected to transient loads in the radial, axial and circumferential directions, particularly during start-up if the material in the mill has settled and formed what is commonly referred to as a 'frozen charge'.

Gearless mill drives can be implemented in the form of an axial flux machine comprising a rotor disk and an axially adjacent stator. Particular difficulties can, however, arise due to the aforementioned transient loads which cause axial deflections of the rotor disk and therefore affect the air gap between the rotor disk and the axially adjacent stator. Unwanted vibration, fatigue and transient event damage can all result from the transient loads.

There is, therefore, a need for an improved axial machine which overcomes the aforementioned difficulties and which can be used as a gearless drive for a rotating electrical machine, and in particular a gearless mill drive for a grinding mill.

The axial flux machine according to the present disclosure compensates for local deflections and changes of axial position of the rotor. In particular, when the axial flux machine is subjected to transient loads which cause axial deflection of the rotor, the magnetic forces acting between the rotor and the first and second stator rings cause the first and second stator rings to deflect axially. Because the axial deflection of each circumferentially aligned pair of first and second stator ring segments is coordinated by the link elements, the first and second stator rings deflect together in unison in the axial direction and follow the local deflections of the rotor, thereby maintaining the first and second air gaps.

When the axial flux machine according to the present disclosure is used as a gearless mill drive in a grinding mill, the structural arrangement is simplified significantly when compared to a more conventional radial flux gearless mill drive in the form of a ring motor, in which the mill barrel acts as the rotor and a stator circumferentially surrounds the rotor. This leads to a more robust but lightweight machine. For example, the first and second stator support rings are of significantly lighter construction than the equivalent component of a radial flux gearless mill drive, since the torque forces can be transferred to ground at a much smaller diameter. In addition, the stress reduction provided by the present arrangement means that although the preload (or dc) forces are the same as a radial flux gearless mill drive, the alternating loads are much lower because the restraining spring stiffness is low.

The rotor may comprise a rotor disk.

Each link element may extend substantially axially between the radially outer edge regions of each circumferentially aligned pair of first and second stator ring segments. This provides for effective force transfer between the first and second stator ring segments and ensures that they deflect in unison in the axial direction in response to local axial deflections of the rotor.

Two of said link elements may extend substantially axially between the radially outer edge regions of each circumferentially aligned pair of first and second stator ring segments. Each link element may extend substantially axially between circumferentially outermost positions on the radially outer edge regions.
link elements may advantageously enhance the deflection of the first and second stator ring segments in response to local axial deflections of the rotor.

Each link element may be pivotally connected at its opposite ends to the radially outer edge regions of each circumferentially aligned pair of first and second stator ring segments, for example about a pivot axis which is circumferentially tangential to the radially outer edge of the respective first or second stator ring segment. This may enhance the co-ordinated deflection of the first and second stator ring segments.

The axial flux machine may include first and second stator supports, for example in the form of stator support disks, which may be statically positioned on axially opposite sides of the rotor to support respectively the first and second stator rings. The stator supports can be of a relatively lightweight construction thereby simplifying the construction of the axial flux machine.

The first stator ring segments may be supported at or close to their radially inner edge on the first stator support so that they are located between the first stator support and the first axial face of the rotor. The second stator ring segments may be supported at or close to their radially inner edge on the second stator support so that they are located between the second stator support and the second axial face of the rotor.

Each of the first and second stator ring segments may be supported at or close to its radially inner edge for movement in the generally axial direction to mimic any local axial deflections of the rotor.

Each of the first and second stator ring segments may be supported at or close to its radially inner edge by a pair of circumferentially spaced support links. The support links may be positioned at circumferentially outermost positions of each respective first or second stator ring segment. Such an arrangement, using a pair of circumferentially spaced support links, provides a structurally simple but at the same time effective way of deflectably mounting the first and second stator ring segments on the respective first and second stator supports.

In one arrangement, each support link may be a hinged support link which may be pivotally connected at one end at or close to the radially inner edge of the first or second stator ring segment and may be pivotally connected at the other end to an axially inner face of the respective first or second stator support. In another arrangement, each support link may comprise a plurality of link elements which are positioned at or close to the radially inner edge of the first or second stator ring segment to permit substantially axial movement of the first or second stator ring segments relative to the first or second stator support. In the latter arrangement, the link elements may take the form of a parallelogram linkage. The arrangement of link elements that is ultimately selected to support the radially inner edge of each first stator ring segment on the first stator support and to support the radially inner edge of each second stator ring segment on the second stator support can be adapted to suit the size of the axial flux machine, with multiple link elements being used to obtain the desired stator ring movement path.

A coupling element may extend between at least one of the first stator ring segments and the first stator support to transfer torque between the first stator ring and the first stator support. A coupling element may extend between at least one of the second stator ring segments and the second stator support to transfer torque between the second stator ring and the second stator support. One of said coupling elements may extend between each of the plurality of first stator ring segments and the first stator support and between each of the plurality of second stator ring segments and the second stator support. The use of a plurality of coupling elements may be useful to improve torque transfer and hence machine stability.

Each coupling element may extend in a substantially circumferential direction between the respective first stator ring segment and the first stator support and between the respective second stator ring segment and the second stator support. Each coupling element may be pivotally connected about radial and axial axes at one end at or close to the radially outer edge of the first or second stator ring segment and may be pivotally connected about radial and axial axes at the other end at or close to a radially outer edge of the of the respective first or second stator support. Such multi-axis mounting, for example provided by a universal joint, ensures that the first and second stator ring segments can deflect independently relative to the respective first and second stator supports in the axial and radial directions in response to transient loads and thereby follow the local axial deflections of the rotor.

The first stator support may include a support arm which may project axially from a position at or close to its radially outer edge towards the radially outer edge of the axially adjacent first stator ring, said other end of the coupling element being pivotally connected about radial and axial axes to the support arm. The second stator support may include a support arm which may project axially from a position at or close to its radially outer edge towards the radially outer edge of the axially adjacent second stator ring, said other end of the coupling element being pivotally connected about radial and axial axes to the support arm. The provision of support arms ensures that the coupling elements can be arranged to extend in the substantially circumferential direction to thereby maximise torque transfer.

**BRIEF DESCRIPTION OF THE DRAWINGS**

Figures 1 and 2 are diagrammatic perspective views of an axial flux machine according to the present disclosure; Figure 3 is a partially cut-away perspective view of
the machine shown in Figures 1 and 2;
Figure 4 is an enlarged view of the region labelled A in Figure 1;
Figure 5 is an enlarged view of the region labelled B in Figure 1; and
Figure 6 is an enlarged view of the region labelled C in Figure 2.

DETAILED DESCRIPTION OF EMBODIMENTS

[0022] Embodiments will now be described by way of example only and with reference to the accompanying drawings.

[0023] An axial flux machine comprises a rotor disk 10 mounted on a shaft 12 for rotation with the shaft 12 about its axis of rotation. The rotor disk 10 has first and second axial faces 14, 16 on which circumferentially arranged permanent magnets 17 are mounted towards its outer periphery.

[0024] A first stator support disk 18 is mounted on one side of the rotor disk 10 adjacent to the first axial face 14 and a first stator ring 20 is mounted on an axially inner face 22 of the first stator support disk 18 between the first stator support disk 18 and the first axial face 14 of the rotor disk 10. A second stator support disk 24 is mounted on the other side of the rotor disk 10 adjacent to the second axial face 16 and a second stator ring 26 is mounted on an axially inner face 28 of the second stator support disk 24 between the second stator support disk 24 and the second axial face 16 of the rotor disk 10. The first and second stator support disks 18, 24 are statically mounted with respect to the shaft 12 by bearings 30.

[0025] Each of the first and second stator rings 20, 26 is formed by a plurality of wedge-shaped respective first and second stator ring segments 32a, 32b each of which carries suitably arranged stator windings 34. A first air gap 6 is formed between the first stator ring 20 and the permanent magnets 17 on the first axial face 14 of the rotor disk 10. A second air gap 9 is formed between the second stator ring 26 and the permanent magnets 17 on the second axial face 16 of the rotor disk 10. The first and second stator ring segments 32a, 32b are aligned circumferentially to form pairs of first and second stator ring segments 32aN, 32bN, where N = 1 to n; for example circumferentially aligned pairs 32a1, 32b1; 32a2, 32b2; 32a3, 32b3; etc.

[0026] Referring in particular to Figures 1, 2 and 6, each of the first stator ring segments 32a is pivotally supported at its radially inner edge 36a on the inner face 28 of the first stator support disk 18 by a hinged link arrangement comprising a pair of circumferentially spaced hinged support links 38 positioned at the circumferential extremities of each first stator ring segment 32a. The hinged support links 38 are pivotally connected at one end to the radially inner edge 36a of each first stator ring segment 32a and at the other end to the inner face 28 of the first stator support disk 18. Similarly, each of the second stator ring segments 32b is pivotally supported at its radially inner edge 36b on the inner face 28 of the second stator support disk 24 by a hinged link arrangement comprising a pair of circumferentially spaced hinged support links 38 positioned at the circumferential extremities of each second stator ring segment 32b. The hinged support links 38 are pivotally connected at one end to the radially inner edge 36b of each second stator ring segment 32b and at the other end to the inner face 28 of the second stator support disk 24. It will thus be understood that the first and second stator ring segments 32a, 32b are capable of pivotally deflecting in the substantially axial direction about their radially inner edges 36a, 36b.

Each first stator ring segment 32a can deflect in the substantially axial direction about its radially inner edge 36a independently of the other first stator ring segments 32a. Each second stator ring segment 32b can likewise deflect in the substantially axial direction about its radially inner edge 36b independently of the other second stator ring segments 32b.

[0027] A rigid link element 40 extends axially between the radially outer edges 42a, 42b of each circumferentially aligned pair of first and second stator ring segments 32aN, 32bN. The link elements 40 coordinate any deflection in the axial direction of each pair of stator ring segments 32aN, 32bN so that they move together in unison in the axial direction. In the illustrated embodiment, two link elements 40 connect each pair of first and second stator ring segments 32aN, 32bN, with the link elements 40 being positioned at the circumferential extremities of each stator ring segment 32. As most clearly seen in Figure 4, the opposite end of each link element 40 is pivotally connected to the radially outer edge 42a, 42b of the respective first or second stator ring segment 32a, 32b about a pivot axis which is circumferentially tangential to the radially outer edge 42a, 42b of the respective first or second stator ring segment 32a, 32b.

[0028] Referring in particular to Figures 1 and 5, in order to transfer torque between the first and second stator rings 20, 26 and the respective first and second stator support disks 18, 24, a coupling element 44 connects each of the first stator ring segments 32a to the first stator support disk 18 and each of the second stator ring segments 32b to the second stator support disk 24. Each coupling element 44 extends in the substantially circumferential direction and is connected at one end to the radially outer edge 42a, 42b of each of the first and second stator ring segments 32a, 32b by a universal joint. The other end of each coupling element 44 is connected to a respective support arm 46 which projects axially from the inner face 22, 28 of each of the respective first and second stator support disks 18, 24, at a position adjacent to the radially outer edge, in a direction towards the rotor disk 10. Again the pivotal connection is provided by a universal joint. The universal joints provide pivotal connections of the ends of each coupling element 44 about radial and axial axes so that local axial and radial deflections of the individual first and second stator ring segments 32a, 32b can be accommodated.
During operation of the axial flux machine, in the event that the rotor disk 10 deflects axially, the magnetic forces cause a corresponding deflection of the first and second stator rings 20, 26. Because the stator rings 20, 26 are composed of individual first and second stator ring segments 32a, 32b, with the first stator ring segments 32a being able to deflect independently of each other and the second stator ring segments 32b likewise being able to deflect independently of each other, the first and second stator rings 20, 26 are individually guided in the axial direction to follow the local axial deflections of the rotor disk 10. Moreover, the link elements 40 ensure that any local axial deflections of the circumferentially arranged pairs of first and second stator ring segments 32aN, 32bN are coordinated so that they move in unison in the axial direction. This arrangement ensures that the first and second air gaps 8, 9 are maintained during transient loading of the axial flux machine.

The axial flux machine is particularly suitable for operation as a motor or generator in any large diameter rotating machine. As indicated above, the axial flux machine could usefully operate as a gearless drive for a grinding mill. It could also be implemented as a generator in a wind turbine. In the illustrated embodiment, the shaft 12 includes a connecting flange 48 via which it may be connected to a component to be driven by the rotor disk 10 (for example a mill barrel in the case of a grinding mill) or that drives the rotor disk 10.

Although exemplary embodiments have been described in the preceding paragraphs, it should be understood that various modifications may be made to those embodiments without departing from the scope of the appended claims. Thus, the breadth and scope of the claims should not be limited to the above-described exemplary embodiments. Each feature disclosed in the specification, including the claims and drawings, may be replaced by alternative features serving the same, equivalent or similar purposes, unless expressly stated otherwise.

Unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise", "comprising", and the like, are to be construed in an inclusive as opposed to an exclusive or exhaustive sense; that is to say, in the sense of "including, but not limited to".

Claims

1. An axial flux machine comprising:-
   a rotor (10) mounted about an axis of rotation and having first and second axial faces (14, 16);
   a first stator ring (20) positioned on one side of the rotor (10) adjacent to the first axial face (14) of the rotor (10) to define a first air gap (8) between the first stator ring (20) and the first axial face (14) of the rotor (10), the first stator ring (20) being formed by a plurality of circumferentially adjacent wedge-shaped first stator ring segments (32a) each having a radially inner edge (36a) and a radially outer edge (42a);
   a second stator ring (26) positioned on the other side of the rotor (10) adjacent to the second axial face (16) of the rotor (10) to define a second air gap (9) between the second stator ring (26) and the second axial face (16) of the rotor (10), the second stator ring (26) being formed by a plurality of circumferentially adjacent wedge-shaped second stator ring segments (32b) each having a radially inner edge (36b) and a radially outer edge (42b) and being circumferentially aligned with a corresponding wedge-shaped first stator ring segment (32a);
   wherein the first and second stator ring segments (32a, 32b) are deflectable in the axial direction in response to axial deflection of the rotor (10) and a link element (40) extends between the radially outer edge regions (42a, 42b) of each circumferentially aligned pair of first and second stator ring segments (32a, 32b) so that they deflect together in unison in the axial direction.

2. An axial flux machine according to claim 1, wherein each link element (40) extends substantially axially between the radially outer edge regions (42a, 42b) of each circumferentially aligned pair of first and second stator ring segments (32a, 32b).

3. An axial flux machine according to claim 2, wherein two of said link elements (40) extend substantially axially between the radially outer edge regions of each circumferentially aligned pair of first and second stator ring segments (32a, 32b), each link element (40) extending substantially axially between circumferentially outermost positions in the radially outer edge regions.

4. An axial flux machine according to any preceding claim, wherein each link element (40) is pivotally connected at its opposite ends to the radially outer edge regions (42a, 42b) of each circumferentially aligned pair of first and second stator ring segments (32a, 32b) about a pivot axis which is circumferentially tangential to the radially outer edge of the respective first or second stator ring segment.

5. An axial flux machine according to any preceding claim, wherein first and second stator supports (18, 24) are statically positioned on axially opposite sides of the rotor (10) to support respectively the first and second stator rings (20, 26).

6. An axial flux machine according to claim 5, wherein the first stator ring segments (32a) are supported at or close to their radially inner edge (36a) on the first stator support (18) between the first stator support and the first axial face (14) of the rotor (10); and the second stator ring segments (32b) are supported at
or close to their radially inner edge (36b) on the second stator support (24) between the second stator support and the second axial face (16) of the rotor (10).

7. An axial flux machine according to claim 6, wherein each of the first and second stator ring segments (32a, 32b) is supported at or close to its radially inner edge by a pair of circumferentially spaced support links (38).

8. An axial flux machine according to claim 7, wherein the support links (38) are positioned at circumferentially outermost positions of each respective first or second stator ring segment (32a, 32b).

9. An axial flux machine according to claim 7 or claim 8, wherein each of the first and second stator ring segments (32a, 32b) is pivotally supported at or close to its radially inner edge by a hinged support link (38) for pivotal movement in the generally axial direction to mimic any axial deflection of the rotor (10).

10. An axial flux machine according to claim 9, wherein each hinged support link (38) is pivotally connected at one end at or close to the radially inner edge of the first or second stator ring segment (32a, 32b) and at the other end to an axially inner face (22, 28) of the respective first or second stator support (18, 24).

11. An axial flux machine according to any preceding claim, wherein a coupling element (44) extends between at least one of the first stator ring segments (32a) and the first stator support (18) and between the second stator ring segments (32b) and the second stator support (24) to transfer torque respectively between the first stator ring (20) and the first stator support (18) and between the second stator ring (26) and the second stator support (24).

12. An axial flux machine according to claim 11, wherein one of said coupling elements (44) extends between each of the plurality of first stator ring segments (32a) and the first stator support (18) and between each of the plurality of second stator ring segments (32b) and the second stator support (24).

13. An axial flux machine according to claim 11 or claim 12, wherein each coupling element (44) extends in a substantially circumferential direction between the respective first stator ring segment (32a) and the first stator support (18) and between the respective second stator ring segment (32b) and the second stator support (24).
### DOCUMENTS CONSIDERED TO BE RELEVANT

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**TECHNICAL FIELDS SEARCHED (IPC)**

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The present search report has been drawn up for all claims.

**Place of search**

The Hague

**Date of completion of the search**

15 April 2013

**Examiner**

Le Chenadec, Hervé
This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on 15-04-2013.

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