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(57) Abstract: An axial flux electrical machine is described in which a modular construction is utilised in order to reduce manufacturing complexity and hence cost.
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AXIAL FLUX ELECTRICAL MACHINES

The present invention relates to axial flux electrical machines.

BACKGROUND OF THE INVENTION

Electrical machines, including motors and generators, are important in a wide range of applications, including vehicle propulsion systems, power generation systems including wind, and water power generation systems, and in industrial applications. One particular application is in hybrid vehicle power systems in which an electric motor is used in combination with an internal combustion engine. Axial flux electrical machines are particularly suited to vehicle applications, due to their relatively high torque density.

However, existing designs of axial flux electrical machines can be difficult and expensive to assemble with a desired high level of quality.

It is therefore desirable to provide a design of axial flux electrical machine which overcomes the drawbacks of the previously-considered designs.

SUMMARY OF THE INVENTION

According to one aspect of the present invention, there is provided an axial flux electrical machine comprising a stator assembly, a shaft that extends through the stator assembly for rotation with respect to the stator assembly, and first and second rotors attached to the shaft so as to be rotatable with respect to the stator assembly, the first and second rotors being arranged to respective sides of the stator assembly, wherein the stator assembly comprises a stator housing that defines a substantially cylindrical aperture therethrough, the shaft extending through the aperture, coaxially therewith, a stator winding assembly located in the aperture, and a bearing located in the aperture for supporting the shaft, the shaft being supported only by the bearing.

According to another aspect of the present invention, there is provided an axial flux electrical machine comprising a stator assembly, a shaft that extends through the stator assembly for rotation with respect to the stator assembly, and first and second rotors attached to the shaft so as to be rotatable with respect to the stator assembly, the first and second rotors being arranged to respective sides of the stator assembly, wherein the stator assembly comprises a stator housing which has first and second ends and which defines a substantially cylindrical aperture that extends from the first end to the second end, a stator winding assembly located in the aperture, and first and second covers which engage with the first
and second ends of the stator housing respectively, so as to close the aperture, the first and second covers defining respective apertures through which the shaft extends, such that the first cover is located between the first rotor and the stator winding assembly, and such that the second cover is located between the second rotor and the stator winding assembly.

The first and second covers may be of a heat insulating material. The covers may of a composite material, and provide a thermal barrier between the stator assembly and the rotors. The covers are of a magnetically inert material.

In one example, the stator winding assembly comprises a plurality of stator pole portions arranged around the shaft, and a plurality of electrical windings arranged around respective stator pole portions. Each such stator pole portion may comprise a pair of interengaged stator pole components.

Each rotor may comprise a rotor disk having first and second substantially planar sides, a plurality of magnets engaged with the first side of the disk, and a plurality of flux conduit portions engaged with the second side of the disk, the magnets and conduit portions being arranged to overlap one another in circumferential direction such that one conduit portion overlaps a pair of adjacent magnets. The conduit portions may be of a grain oriented laminated steel construction.

In an alternative example, each rotor may comprise a steel rotor disk on a first surface of which is mounted a plurality of magnets.

Such a machine may further comprise a fluid conduit that defines a fluid flow path through the stator housing. The fluid conduit may be arranged for the transport of a cooling fluid through the stator housing.

In such a machine, any spare space in the aperture may be filled with a resin, gel or phase-change material.

Such a machine may further comprise a cooling structure located external to the stator housing. The cooling structure may be provided by fins defined by the stator housing.

According to another aspect of the present invention, there is provided a method of manufacturing an axial flux electrical machine comprising the steps of:

a. providing a first cover having a first surface;
b. locating a plurality of first stator pole portion components on the first surface of the first cover;

c. locating a plurality of windings around respective stator pole portion components;

d. engaging a plurality of second stator pole portion components on respective ones of the first stator pole portion components;

e. locating a bearing housing substantially centrally on the first surface of the first cover;

f. locating the first cover on a first end of a stator housing such that the stator pole portions components, the windings, and the bearing housing are located within a substantially cylindrical aperture defined by the stator housing;

g. locating a second cover on a second end of the stator housing, so as to close the aperture, the second cover engaging with the second stator pole portion components and the bearing housing;

h. engaging a first rotor with a shaft;

i. locating the shaft through the stator housing such that it is supported by at least one bearing located in the bearing housing, and such that the first rotor is adjacent the first cover;

j. engaging a second rotor with the shaft such that the second rotor is adjacent the second cover; and

k. providing at least one external cover to enclose the first and second rotors.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an end view of an axial flux electrical machine embodying the present invention;

Figure 2 is a side view of the machine of Figure 1;

Figure 3 is a side cross-sectional side view of the machine of Figure 1;

Figure 4 is a side cross-sectional side view of a stator assembly of the machine of Figure 1;

Figure 5 is an end view of the stator assembly of Figure 4;
Figure 6 is a side view of part of a stator component;

Figure 7 is a perspective view of the part of Figure 6;

Figure 8 is a side view of a rotor assembly of the machine of Figure 1;

Figure 9 is a cross-sectional side view of the rotor assembly of Figure 8;

Figure 10 is a flowchart illustrating steps in a first example manufacturing method;

Figure 11 illustrates a stator component;

Figure 12 is a flowchart illustrating steps in an example method of manufacturing the stator component of Figure 11;

Figure 13 illustrates an example winding component;

Figure 14 is a flowchart illustrating steps in an example method of manufacturing the winding component of Figure 14;

Figure 15 illustrates a double sided stator assembly;

Figure 16 is a flowchart illustrating steps in an example method of manufacturing the stator assembly of Figure 15;

Figure 17 illustrates a single sided stator assembly;

Figure 18 is a flowchart illustrating steps in an example method of manufacturing the stator assembly of Figure 17;

Figure 19 is a flowchart illustrating steps in an example method of manufacturing an electrical machine including a stator assembly as shown in Figure 15.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

An electrical machine embodying the present invention will be described in more detail below. The embodiment to be described is an electric motor, but such a design may also be used as a generator. The principles of construction to be described apply equally to both types of electrical machine.
Figures 1 and 2 show an electric motor 1 embodying one aspect of the present invention, which motor 1 comprises a casing 10 provided with external covers 11a and 11b. An output shaft 13 extends through the first external cover 11a. An electrical terminal housing 12 is provided by the casing 10 and an aperture 14 for electrical connections is provided. The casing 10 is provided with coolant connections 15, and a number of cooling fins 16. It will be readily appreciated that the coolant connection 15 and cooling fins 16 are not essential to the construction of the motor 1.

Figure 3 illustrates a cross-sectional side view of the motor 1 of Figures 1 and 2, and shows a stator assembly 20 through which the shaft 13 extends, and first and second rotors 22 and 23 which are mounted on the shaft 13. As will be described in more detail below, the shaft 13 and rotors 22 and 23 are mounted to be rotatable with respect to the stator assembly 20, and casing 10.

The motor of the Figure 1, 2 and 3 incorporates a single stator assembly and twin rotors, with the rotors being located to opposite sides of the single central stator assembly. In one embodiment of the present invention, the stator assembly incorporates bearings for supporting the shaft 13. These internal bearings provide the only support for the shaft 13 and rotors 22 and 23 inside the motor 1.

The motor 1 shown in Figures 1, 2 and 3 also includes a shaft encoder and processor 24 within the overall casing of the motor 1. The processor 24 receives shaft position information from the encoder for determining shaft speed and position. In addition, the motor 1 includes a number of sensors (not shown for clarity) which operate to produce measurement signals in dependence upon operating characteristics of the motor 1. For example, the sensors may include temperature sensors for determining the temperatures of the stator windings, stator pole positions, rotor components, rotor bearings, and other components of the motor 1.

The processor 24 operates to receive such operating measurement signals and processes those signals to produce operating data which is stored in a memory device within the motor 1. The stored data can be used and processed by the processor to determine possible future wear or failure modes, such as local high temperatures indicative of a decaying electrical connection, and can be output, either fully, or as an alarm condition. Such data processing within the motor can serve to optimise the life of the motor by providing advance notification for servicing and maintenance requirements. The processor is preferably connected to an industry-standard shielded connector, such as a CAN (controller area
network) bus connector, for enabling output of processed data and alarm condition data. The processor may be connected with a second output connector which can be accessed directly by a service technician to provide diagnostic information and servicing inputs. The processor may also be connected to a wireless transmitter/receiver which is operable to transmit and receive data for the processor. In such a manner, the motor 1 can be remotely accessed and can indicate status and alarm conditions remotely.

As will be described in more detail below, a motor embodying the present invention is manufactured as a series of modules, which enable the manufacturing process to be kept straightforward, and hence less expensive than previous designs. A motor embodying the present invention also has the advantage that the manufacturing process works with the high forces provided by the magnets and stator, rather than working against them. Such a design enables the manufacturing process to be kept straightforward.

The stator assembly 20 is shown in more detail in the cross-sectional view of Figure 4. The stator assembly 20 comprises a stator housing 201 (which also provides the motor casing 10, and the electrical connector housing 12 for the motor 1 of Figures 1, 2 and 3). The stator housing 201 defines a cylindrical aperture 202 in which stator components are located. The cylindrical aperture 202 is defined between the casing 201 and first and second stator covers 203 and 213. The first and second stator covers 203, 213 are secured to the stator casing 201 via stator cover fixings 204 and 214 respectively. The fixings 204, 214 may be provided by any suitable means, such as bolts, screws or a bonding material. Located centrally in the cylindrical aperture 202, and attached to the first and second stator covers 203, 213, is a rotor bearing assembly 205. The rotor bearing assembly 205 is attached to the first and second stator covers 203 and 213 via fixing means 206 and 216 respectively. The rotor bearing assembly 205 defines a cylindrical passage therethrough 208 to which the shaft 13 extends when the motor is assembled. Each of the stator covers 203 and 213 defines a circular aperture through which the shaft 13 can pass. The rotor assembly housing 205 defines bearing region 207 and 217 into which support bearings for the rotor are located.

The stator assembly 20 also comprises a plurality of stator pole portions 210 around which stator windings 211 are located.

In line with conventional axial motor construction, the stator is provided with a plurality of windings, which when in use carry electric current to provide a rotating magnetic flux. This magnetic flux is reacted by the magnets on the rotors which causes the rotors and hence the drive shaft, to turn. In order to maximise the effect of the magnetic flux produced in the
stator, the windings are located around central cores (or "stator pole portions"). These stator pole portions can be of an iron-based material. In an embodiment of the present invention are provided by grain oriented laminated steel sheets, or powder iron, or a combination of the two. Such constructions serves to reduce magnetic losses and, therefore, improve efficiency of the machine.

Figures 6 and 7 illustrate a stator pole component 2101 of a stator pole portion 210. The stator pole component 2101 has a body portion 2102 and an enlarged end portion 2103 which extends from the body portion 2102. The body portion 2102 and enlarged end portion 2103 define a winding receiving region 2104 in which the stator windings 211 are located.

The stator pole portion 210 is made up of two such pole components 2101, having their respective body portions 2102 engaged with one another.

Since the stator pole portion is made up from a pair of identical stator pole components 2101, the manufacture of the stator assembly can be simplified, as will be described below. In addition, since a single design of stator pole component is used, the cost of the component can be reduced.

In one example method for manufacture of the stator pole portion 210, a first stator pole component 2101 is located in a suitable jig with its end face 2106 placed against a receiving surface. A pre-wound winding 211 is placed over the part 2101 such that the stator winding is located in the region 2104 and is in contact with the end portion 2103. A second stator pole component 2101 is then placed with its body portion 2102 extending into the winding 211 so as to come into contact with the first pole component 2101. The parts are fixed together, for example using adhesive, or other bonding agent.

In one embodiment, the windings 211 are formed of relatively thick, flat copper bar which is bent into a suitable shape. Alternatively, the windings can be provided by the more conventional multi-wound copper wire type. In any event, in order to allow speedy and efficient manufacturing of the stator part, the windings are pre-wound before being located onto the first part of the stator portions, before attachment of the second half of the stator portion. The required number of stator portions are produced, and can be produced in advance and stored ready for manufacture into a stator assembly, and then into a motor. In one example manufacturing process, the first stator cover 203 is placed in a jig with its inner surface accessible to a worker and/or assembly machine. The rotor bearing assembly 205 is located on the first cover 203 and secured to it using the appropriate fixings or bonding. A
pre-constructed stator pole and winding component are placed in position on the first cover 203 around the bearing assembly 205, and the appropriate electrical connections are made to the windings 211. The first cover 203 is then secured to the stator housing, so that one end of the cylindrical aperture is closed, and so that the stator components and bearing housing are located within the stator housing. The second cover is then located on the casing and secured to the casing 210 using fixings 214 (or suitable bonding material). After the second cover 213 is placed on the assembly, the assembly may be filled with a suitable potting material, such as gel, resin or phase-change material.

In another example manufacturing process, as illustrated in the flow chart of Figure 10, the first stator cover is placed in a jig with its inner surface accessible to a worker and/or assembly machine (step 300). The rotor bearing assembly 205 is located on the first cover 203 and secured to it using the appropriate fixings or bonding (step 302). The required number of stator pole components 2101 are secured in position on the first cover 203 (step 304). The stator housing is located on the first cover (step 306), so that one end of the cylindrical aperture is closed, and so as to provide a volume in which the stator components are located.

A winding component is pre-formed (step 307), and is then placed over the first stator pole portion components in place on the first cover within the stator housing (step 308). The winding assembly is pre-assembled, so that all of the electrical and mechanical connections between the sets of windings are made. In one particular example, the winding component is a single continuous winding component as described below. In this way the manufacturing process can be simplified. Following location of the winding assembly, the second stator pole components 2101 are located in contact with the first components so as to extend into respective apertures provided in the winding assembly (step 310). The second cover is then located on the casing and secured to the casing 210 using fixings 214 (or suitable bonding material) (step 312). After the second cover 213 is placed on the assembly, the assembly may be filled with a suitable potting material, such as gel, resin or phase-change material.

As an alternative, the first cover may be secured to the housing after location of the stator pole portions or first stator pole portion components.

The first and second covers 203, 213 are of a heat insulating material in order to provide a thermal barrier to reduce heat transfer to and from the stator assembly. Reducing heat transfer serves to help maintain the components within an appropriate temperature range.
An optional feature of a motor embodying the present invention is the provision of a fluid conduit located in the stator housing. The conduit may be provided by a suitable flexible tube, for example of glass fibre. The conduit defines a fluid flow path around the internal space of the stator housing 201 through which cooling fluid, such as water, can be pumped. The fluid conduit is in fluid communication with the coolant connections 15, for transfer of cooling fluid in and out of the motor housing 10.

The stator assembly is then ready for the introduction of the rotor assembly, which includes the first and second rotors 22 and 23 and the shaft 13.

The rotor assembly is illustrated in Figures 8 and 9, and comprises the shaft 13 onto which the first rotor 22 and the second rotor 23 are mounted. The first and second rotors 22 and 23 are fixed to the shaft 13 and rotatable with the shaft 13. In Figure 8, the rotor assembly is shown mounted on the rotor bearing assembly housing 205, which is shown in the stator assembly described previously. Figure 9 shows a cross-sectional view of the rotor assembly of Figure 8.

The shaft 13 extends through the rotor shaft bearing housing 205 and is supported by bearings 226 and 236. The shaft is solely supported by the internal bearings in the motor. The first rotor 22 comprises a rotor disk 221 and a plurality of magnets 222 mounted on a surface of the rotor disk 221. Mounted on a reverse surface of the rotor disk 221 is a plurality of magnetic flux conduit portions. Each such conduit portion overlaps a pair of magnets, and provides a flux path between the magnets, thereby increasing the efficiency of the rotor. In one example, the rotor disk is of a composite material, such as carbon fibre composite. The second rotor 23 is attached to the shaft 13 using fixing means 235 and 235, spaced apart from the first rotor, to the opposite side of the bearing housing 205. The second rotor assembly 23 also comprises a rotor disk 231, a plurality of magnets 232, and a plurality of flux conduit portions 233 attached to the disk.

In an alternative example, each rotor may comprise a steel rotor disk on a first surface of which is mounted a plurality of magnets.

In order to assemble the motor, bearings 226 and 236 are inserted into the bearing locating regions 207 of the rotor bearing housing 205 in the stator assembly 20. The first rotor assembly 22 is attached to the shaft 13, and then the shaft 13 is inserted into the stator assembly through the cylindrical aperture 208. The drive shaft 13 is supported in the stator assembly by the bearings 226 and 236, and enables the fitting of the second rotor assembly.
23 to the shaft 13. The fixings in Figures 8 and 9 are illustrated as being provided by a bolt 234 and locking nut 235. Any suitable means for attaching the second rotor assembly to the shaft can be provided.

Such a motor design enables the shaft 13 to be located in the bearing in an accurate manner. In addition, provision of the internal bearing enables the shaft insertion to be completed without the need for complex manipulation tools, since the magnetic forces exerted between the rotor magnets and the stator assembly serve to pull the rotor and shaft into position. Any off centre forces are resisted by the shaft in the bearing.

In order to complete the motor, the first and second external covers 11a and 11b are attached to the casing 10.

A further example manufacturing method will now be described with reference to Figures 11 to 19. The principle of this further example method is to enable a modular process, in order that desirably high quality of manufacture can be achieved.

Figure 11 illustrates a stator cover 203,213 having stator pole components 2101 integrated therein, and Figure 12 illustrates steps in a method of manufacturing such a stator cover 203,213. The stator cover 203,213 is manufactured so as to secure the stator pole components 2101 into the cover.

In order to manufacture the integrated stator cover 203,213 of Figure 11, a predetermined number of stator pole components 2101 are arranged in a predetermined pattern in a jig (Figure 12, step 400). Composite fibre material, for example carbon fibre, is layed up around the positioned stator pole components 2101(step 402), to provide the cover 203,213. The fibre lay-up is undertaken in such a manner as to provide the final cover with sufficient stiffness and strength. The fibre lay-up also provides the cover 203,213 with a bearing receiving feature 207,217, and defines a shaft aperture 208. The bearing receiving feature 207,217 is adapted to receive a bearing for carrying the rotor shaft of the machine.

The composite material is then completed by injection of a suitable resin, vacuum, heating and curing steps in accordance with well-known and understood practice (step 404).

A bearing is then bonded into the bearing receiving feature (step 406) using a bonding agent. The bearing bonding agent may be thermally activated, such that the bearing can be removed from the cover by application of heat to the bonding agent. Preferably, the choice
of bonding agent is made so that the bonding agent is released at a lower temperature than the composite material resin.

The stator cover with integrated pole components is then ready for use in the manufacture of the stator assembly, as will be described below.

In one particular example, the stator windings are provided by a single pre-wound assembly, for example as illustrated in Figure 13. In such an example, the pre-wound assembly is manufactured from a continuous piece of winding material, such as copper bar, and provides a continuous winding assembly having a series of interlinked windings 2018, one for each stator pole. The windings 2018 are interlinked by connecting portions 2019.

Providing a pre-manufactured single piece continuous winding assembly greatly reduces the complexity of manufacturing a motor embodying an aspect of the present invention.

Figure 14 illustrates steps in an example method of manufacturing the winding component of Figure 13. The winding material is prepared (step 410), and then a single continuous winding component is wound (step 412), in one example using a computer controlled winding machine. The winding component is then ready (step 414) for use in the manufacture of a stator assembly, as described below.

Figure 15 illustrates a double sided stator assembly, and Figure 16 shows steps in a method of manufacturing the same. A first previously-manufactured integrated stator cover 203 is located on a jig (step 420), and the stator housing 10 is bonded thereto (step 422), such that the stator pole components 2101 of the cover 203 extend axially into an internal volume of the housing 10. In this manner, the cover, and hence pole components can be located accurately within the housing 10.

A pre-manufactured winding component 211 is then inserted into the housing 10 (step 424), such that each pole components 2101 extends at least partially into a winding element 2111 of the winding component 211. A second integrated stator cover 213 is then bonded to the housing 10, on a side opposite to the first integrated cover 203 (step 426). The second integrated stator cover 213 is located such that pole components thereof extend into the internal volume of the housing 10, so as to extend at least partially into the winding elements 2111 of the winding component 211. The stator pole components of the first and second integrated covers 203,213 preferably engage with one another.
Electrical connections 17 are then made with the winding component 211 (step 428). The electrical connection housing 12 can then be completed.

In such a manner, a double sided stator assembly 210 is then available for manufacture into an electrical machine, as will be described below. This double sided stator assembly 210 can then be considered as a pre-manufactured module, and can be manufactured independently of other components of the machines.

A single sided stator assembly 20A is illustrated in Figure 17, and Figure 18 illustrates steps in an example method of manufacturing the same. Similarly to the method of manufacturing the double sided stator assembly described above, a previously-manufactured integrated stator cover 203 is located on a jig (step 430), and the stator housing 10 is bonded thereto (step 430), such that the stator pole components 2101 of the cover 203 extend axially into an internal volume of the housing 10. In this manner, the cover, and hence pole components can be located accurately within the housing 10.

A pre-manufactured winding component 211A is then inserted into the housing 10 (step 434), such that each pole components 2101 extends at least partially into a winding element 2111A of the winding component 211A. In contrast to the double-sided stator assembly of Figure 15, the winding component 211A is dimensioned such that it extends only partially into the internal volume of the housing, and so that the pole components of the integrated cover 203 extend substantially fully into respective winding elements 2111A.

A magnetic return path 240, in this example in the form of and annular ring, is then located (step 236) in the internal volume of the housing 10, and the open end of the housing is closed with a cover 242 (step 438). The cover 242 may be secured with bolts, or by bonding with an appropriate bonding material. The return path 240 may be attached, by bonding or other means, to the cover 242, such that the cover 242 and return path 240 are located on the housing in the same single step.

Electrical connections 17 are then made to the windings (step 440), as before. The single sided stator assembly is then available for manufacture into an electrical machine, as will be described below. This single sided stator assembly 210 can then be considered as a pre-manufactured module, and can be manufactured independently of other components of the machines.
The double-sided and single sided stator assemblies make use of the same integrated stator covers - the only difference being that the double sided assembly uses a pair of cover, whilst the single sided assembly uses a single integrated cover. This use of a common integrated cover component reduces manufacturing complexity, and enables component cost to be reduced.

Figure 19 illustrates steps in an example manufacturing method for a twin rotor electrical machine that makes use of the double-sided stator assembly described above. At step 450, the stator assembly is located in a jig. The rotor shaft is then located in the shaft bearings of the integrated covers (step 452), and the first rotor fixed to the shaft (step 454) to one side of the stator assembly. The air gap between the rotor and stator assembly is set appropriately. The second rotor is then fixed to the shaft, to the side of the stator assembly opposite to that of the first rotor (step 456). The sir gap between the second rotor and the stator assembly is set at an appropriate distance.

Finally, external covers are attached to the housing (step 458). The covers protect the rotors, and allow the shaft to extend from at least one side of the machine. The machine is then ready for use in an application.

In this way, an axial flux motor is able to be manufactured in a simple, straightforward and modular manner, which reduces complexity and cost.
CLAIMS:

1. An axial flux electrical machine comprising a stator assembly, a shaft that extends through the stator assembly for rotation with respect to the stator assembly, and first and second rotors attached to the shaft so as to be rotatable with respect to the stator assembly, the first and second rotors being arranged to respective sides of the stator assembly, wherein the stator assembly comprises a stator housing which has first and second ends and which defines a substantially cylindrical aperture that extends from the first end to the second end, a stator winding assembly located in the aperture, and first and second covers which engage with the first and second ends of the stator housing respectively, so as to close the aperture, the first and second covers defining respective apertures through which the shaft extends, such that the first cover is located between the first rotor and the stator winding assembly, and such that the second cover is located between the second rotor and the stator winding assembly.

2. An axial flux electrical machine comprising a stator assembly, a shaft that extends through the stator assembly for rotation with respect to the stator assembly, and a first rotor attached to the shaft so as to be rotatable with respect to the stator assembly, wherein the stator assembly comprises a stator housing which has first and second ends and which defines a substantially cylindrical aperture that extends from the first end to the second end, a stator winding assembly located in the aperture, and first and second covers which engage with the first and second ends of the stator housing respectively, so as to close the aperture, the first and second covers defining respective apertures through which the shaft extends, such that the first cover is located between the first rotor and the stator winding assembly.

3. A machine as claimed in claim 1, wherein the first and second covers include respective bearing housings in which are located respective bearing for supporting the shaft, and wherein the shaft is supported by only such bearings.

4. A machine as claimed in claim 1 or 2, wherein the first and/or second covers include a plurality of stator pole components which extend axially within the housing.

5. A machine as claimed in claim 4, wherein the stator pole components are at least partially encapsulated in the cover concerned.
6. A machine as claimed in any one of the preceding claims, wherein the first and second covers are of a heat insulating material, such as a composite material, thereby to provide a thermal barrier between the rotors and the stator assembly.

7. A machine as claimed in any one of the preceding claims, wherein the stator winding assembly comprises a plurality of stator pole portions arranged around the shaft, and a plurality of electrical windings arranged around respective stator pole portions.

8. A machine as claimed in claim 7, wherein each stator pole portion comprises a pair of interengaged pole components.

9. A machine as claimed in any one of the preceding claims, wherein the or each rotor comprises a rotor disk having first and second substantially planar sides, a plurality of magnets engaged with the first side of the disk, and a plurality of flux conduit portions engaged with the second side of the disk, the magnets and conduit portions being arranged to overlap one another in circumferential direction such that one conduit portion overlaps a pair of adjacent magnets.

10. A machine as claimed in claim 9, wherein the conduit portions are of grain oriented laminated steel, or of powder iron, or of a combination of grain oriented laminated steel and powder iron.

11. A machine as claimed in any one of the preceding claims, further comprising a fluid conduit that defines a fluid flow path through the stator housing.

12. A machine as claimed in claim 11, wherein the fluid conduit is arranged for the transport of a cooling fluid through the stator housing.

13. A machine as claimed in any one of the preceding claims, wherein any spare space in the aperture is filled with a resin, gel or phase-change material.

14. A machine as claimed in any one of the preceding claims, further comprising a cooling structure located external to the stator housing.

15. A machine as claimed in claim 14, wherein the cooling structure is provided by fins defined by the stator housing.

16. A machine as claimed in any one of the preceding claims, further comprising a shaft encoder connected with the shaft, at least one sensor operable to produce an output signal indicative of an operating parameter of the machine, or of a component of the machine, and a processor located within the machine, and operable to receive signals
from the encoder, and from the sensor, to process such received signals to produce
operating data for the machine, and to store such operating data.

17. A machine as claimed in claim 16, wherein the processor is operable to output such
stored data when requested by a user input.

18. A machine as claimed in claim 16 or 17, comprising a plurality of temperature sensors
operable to generate respective signal indicative of temperatures of associated
components of the machine.

19. A machine as claimed in claim 18, wherein the processor is operable to generate such
operating data from the plurality of temperature signals, and to compare such data with
store model data, thereby to provide output data indicative of wear or failure of the
machine.

20. A method of manufacturing an axial flux electrical machine comprising the steps of:
   a. providing a first cover having a first surface;
   b. locating a plurality of first stator pole portion components on the first surface
      of the first cover;
   c. locating a plurality of windings around respective pole portion components;
   d. engaging a plurality of second stator pole portion components on respective
      ones of the first stator pole portion components;
   e. locating a bearing housing substantially centrally on the first surface of the
      first cover;
   f. locating the first cover on a first end of a stator housing such that the stator
      pole portions components, the windings, and the bearing housing are located
      within a substantially cylindrical aperture defined by the stator housing;
   g. locating a second cover on a second end of the stator housing, so as to close
      the aperture, the second cover engaging with the second stator pole portion
      components and the bearing housing;
   h. engaging a first rotor with a shaft;
i. locating the shaft through the stator housing such that it is supported by at least one bearing located in the bearing housing, and such that the first rotor is adjacent the first cover;

j. engaging a second rotor with the shaft such that the second rotor is adjacent the second cover; and

k. providing at least one external cover to enclose the first and second rotors.

21. A method as claimed in claim 17, further comprising injecting a resin, gel or phase-change material into the aperture.

22. A method of manufacturing a stator assembly for an axial flux electrical machine comprising the steps of:

a. producing an integrated stator cover using the steps of:
   i. locating a plurality of stator pole components in a predetermined pattern a jig;
   ii. creating a substantially planar stator cover using composite fibre material, the stator cover encapsulating part of each of the pole components so that the components are held in place with respect to the cover, and defining a bearing housing;

b. producing a single continuous winding component by winding elongate conductive material to form a series of winding elements;

c. attaching such an integrated stator cover to a housing, such that the pole components extend into an inner volume defined by the housing;

d. locating such a winding component in the housing, such that the pole components extend at least partially into respective winding elements;

e. attaching a second cover to the housing, on a side opposite to that to which the integrated stator cover is attached, thereby substantially closing the inner volume of the housing.

23. A method as claimed in claim 19, wherein attaching a second cover to the housing comprises attaching a second integrated stator cover to the housing, such that pole
components of the second stator cover extend at least partially into respective winding elements of the winding component.

24. A method as claimed in claim 19, wherein attaching a second cover to the housing comprises attaching a cover including a magnetic flux conductor to the housing.

25. A stator assembly for an axial flux electrical machine the stator assembly comprising a stator housing that defines a substantially cylindrical volume therein, an integrated stator cover affixed to a first end of the housing, thereby to close that first end of the volume, the integrated stator cover including a plurality of stator pole components which extend from the cover into the volume, and a bearing for supporting a shaft, a stator winding assembly located in the volume, and arranged such that the stator pole components extend at least partially into respective winding elements of the winding assembly, and a second cover affixed to the housing, so as to close a second end of the volume, the second cover including a bearing for supporting such a shaft.

26. A stator assembly as claimed in claim 25, wherein the second cover is a second integrated stator cover which includes a plurality of stator pole components arranged to extend at least partially into respective winding elements of the winding assembly.

27. A stator assembly as claimed in claim 26, wherein the pole components of the first cover engage with the pole components of the second cover.

28. A stator assembly as claimed in any one of claims 25 to 27, wherein each pole component is encapsulated at least partially by the cover from which that pole component extends.

29. An axial flux electrical machine as claimed in any one of claims 1 to 19, and comprising a stator assembly as claimed in any one of claims 25 to 28.
locate first cover

locate rotor bearing assembly

locate first pole elements

manufacture winding assembly

locate housing

locate winding element

locate second pole elements

attach second cover

Figure 10
locate stator pole components

lay-up fibre material

complete composite material

insert and bond bearings

ready for further processing

Figure 12
410 prepare winding material

412 wind component

414 ready for further processing

Figure 14
locate first integrated stator cover

bond housing to first cover

insert and locate winding

locate and bond second cover to housing

complete electrical connections

Figure 16
430 locate integrated stator cover

432 bond housing to stator cover

434 insert and locate winding

436 insert and locate conductor component

438 locate and secure second cover

440 complete electrical connections

Figure 18
locate stator assembly

locate shaft

fix first rotor

fix second rotor

locate and attach outer covers