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JP 2001211607 A **SU 001101970 A1**
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(54) Abstract Title: **Rotor cooling by inter-winding ducts; Cooling ducts in pole pieces**

(57) A spacing sheet is disclosed for forming cooling ducts between two layers of windings in the rotor of a rotating electrical machine. The spacing sheet comprises a backing layer (52; 115), and a plurality of spacers (54; 114) located on the backing layer. The spacers are discontinuous so as to define a plurality of interconnected cooling ducts. The pole shoes assist in retaining the windings, Figs 5,6 (not shown) illustrate differing lamination layouts. The laminations forming the pole pieces are of different size so as to define a radial exit path by recessing parts of the pole shoe for coolant flow 4 from the cooling ducts which are provided in an area of the winding which is overlapped by the pole shoe.

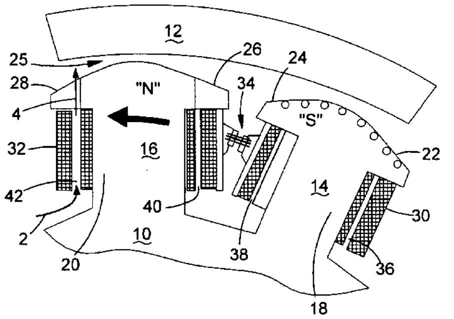

FIG.1

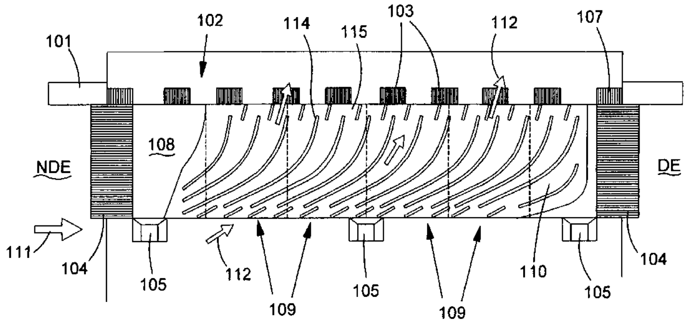

FIG.8

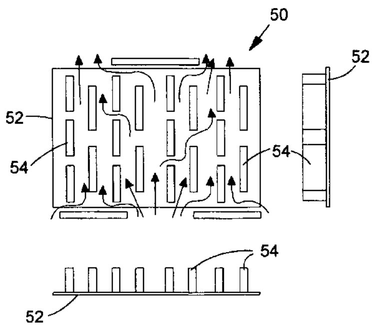

FIG.2

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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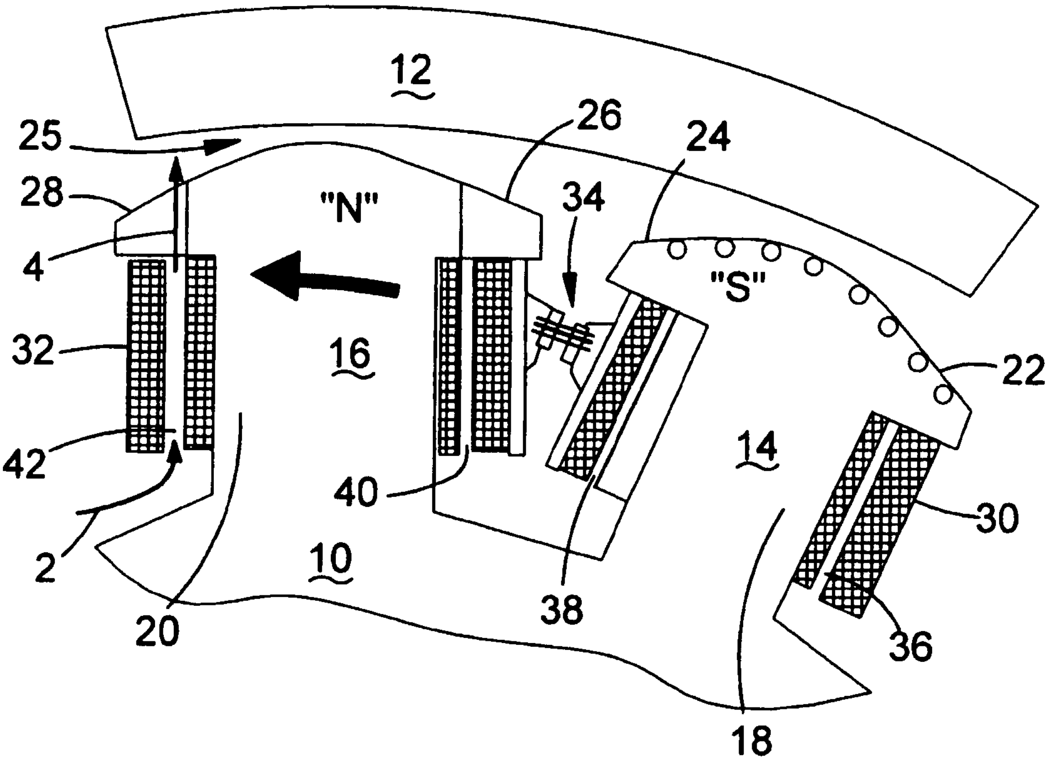
12
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26
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28
34
"N"
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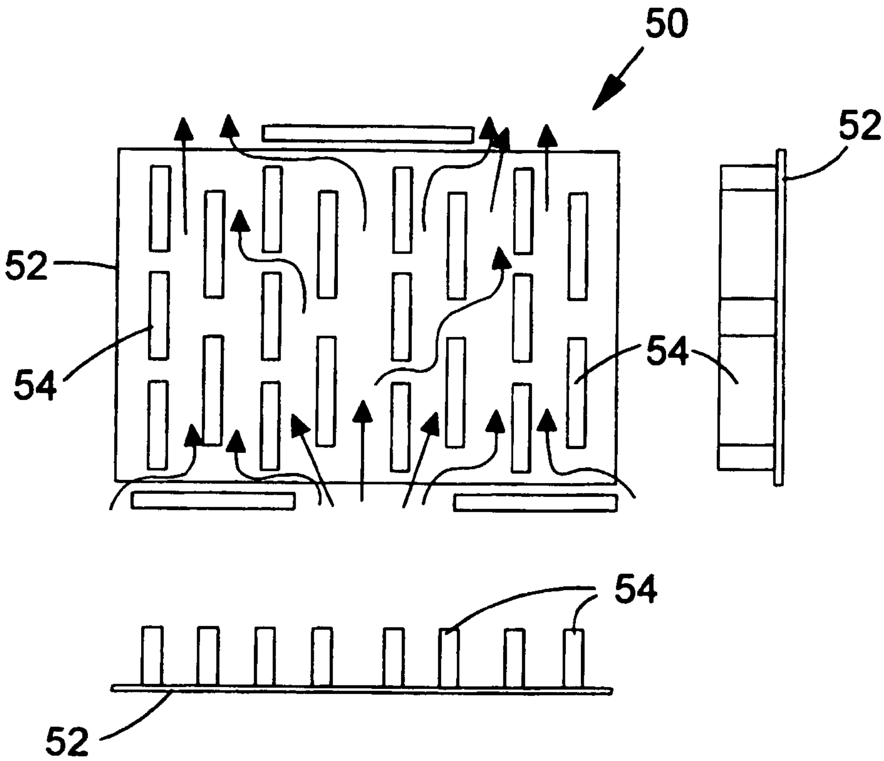
18

FIG.1


50
52
52
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52

FIG.2

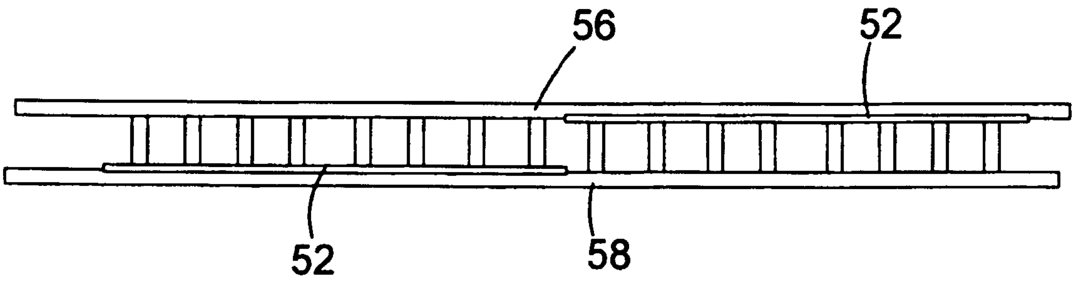

FIG.3

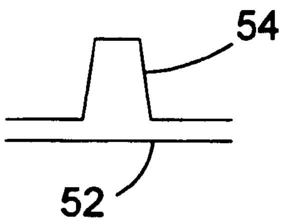

FIG.4

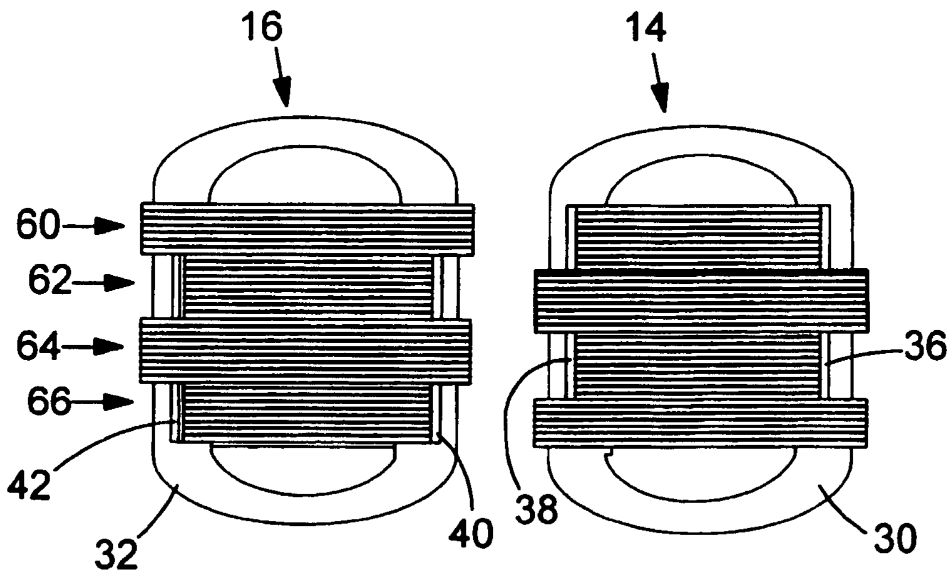

FIG.5

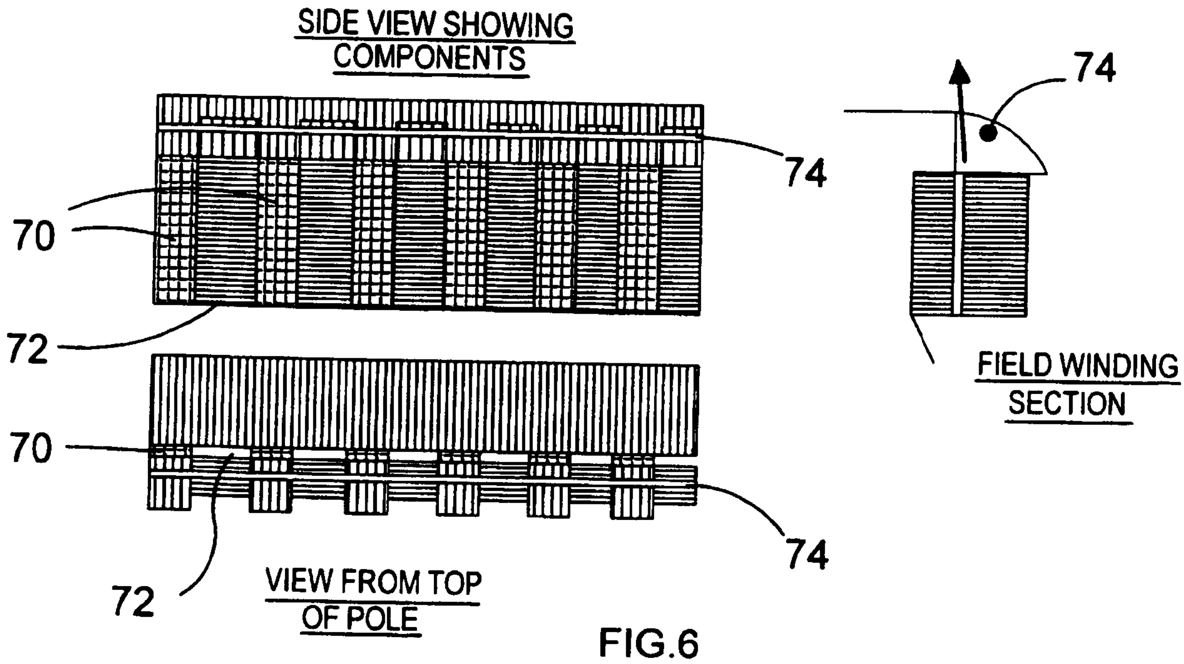
SIDE VIEW SHOWING COMPONENTS
74
74
70
72
FIELD WINDING SECTION
70
74
72
VIEW FROM TOP OF POLE

FIG.6

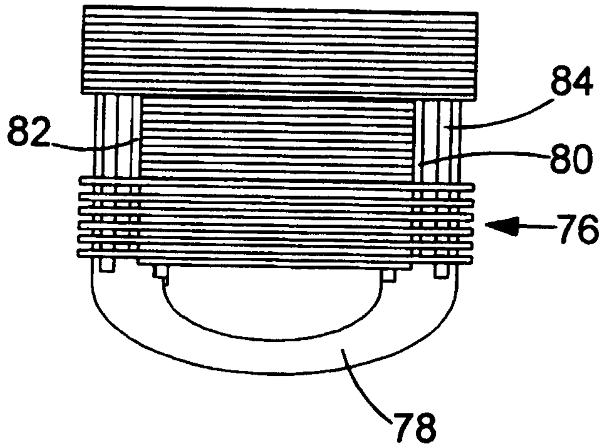
84
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FIG.7

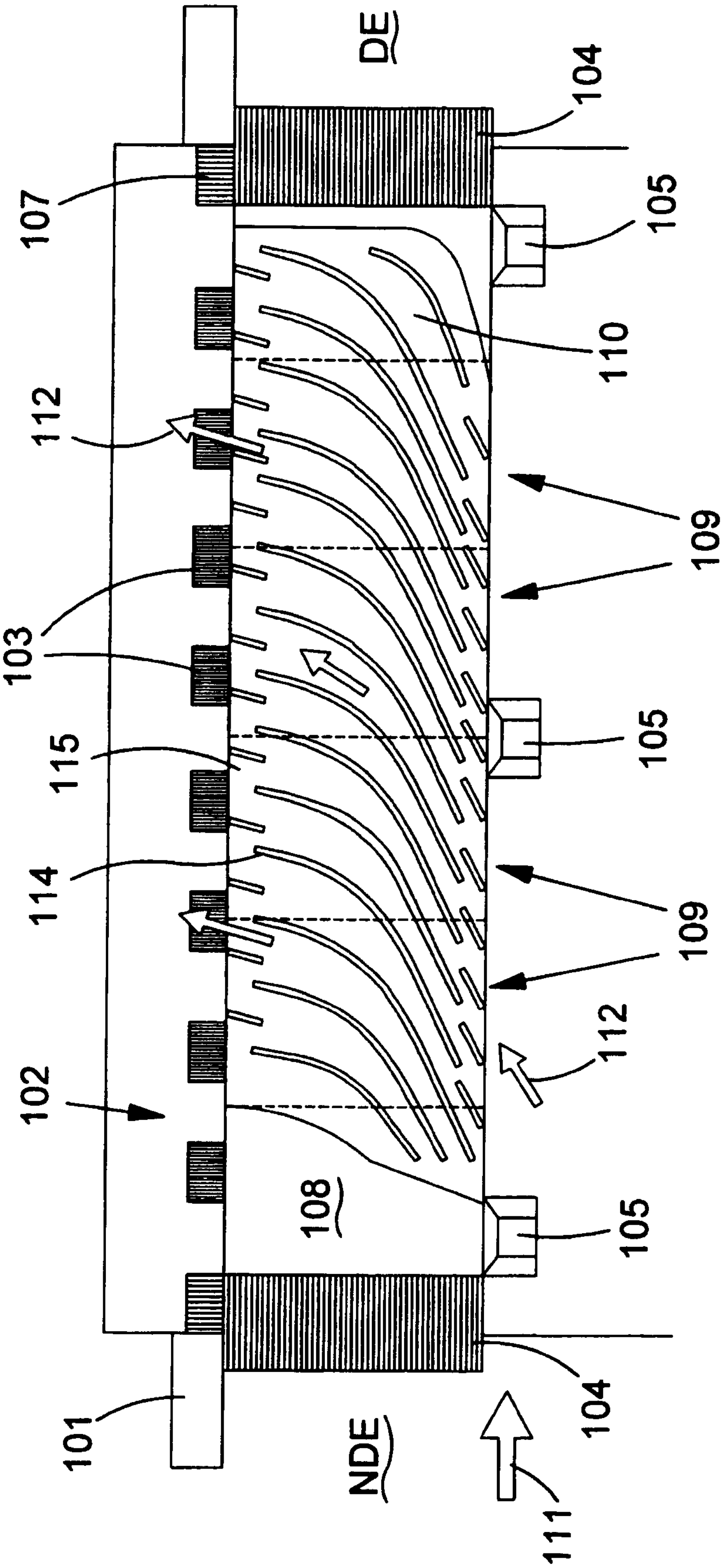
DE
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FIG.8

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ROTOR COOLING

The present invention relates to rotating electrical machines of a salient pole design, and in particular to techniques for improving the cooling of such machines.

Rotating electrical machines, such as motors and generators, generally comprise a rotor and a stator, which are arranged such that a magnetic flux is developed between the two. In a rotating machine of a salient pole design, the rotor has a plurality of poles which extend radially outwards, on which a conductor is wound. An electrical current flowing in these windings causes a magnetic flux to flow across the air gap between the rotor and the stator. In the case of a generator, when the rotor is rotated by a prime mover, the rotating magnetic field causes an electrical current to flow in the stator windings, thereby generating the output power. In the case of a motor, an electrical current is supplied to the stator windings and the thus generated magnetic field causes the rotor to rotate.

In a salient pole machine, as the rotor rotates centrifugal forces develop on the windings, which tends to force the windings outwards in a radial direction. For this reason many salient pole machines have pole shoes at the pole tip, and these shoes overlap the rotor windings. The pole shoes thus assist in retaining the windings against the centrifugal forces developed as the rotor rotates.

In electrical machines losses may occur due to, for example, resistance in the windings and in losses in the pole body. These losses result in heat being created within the machine. The machine rating is determined by the actual temperature rise of the rotor and stator, and thus the cooling efficiency of the construction may help to determine the rating of the machine.

Known techniques for cooling the rotor include creating air gaps in the rotor windings outhangs, and providing the rotor with finned wedging devices. However there remains a need to provide more efficient cooling of the rotor.

United Kingdom patent publication number GB 2425662, the contents of which are incorporated herein by reference, discloses a rotating machine of a salient pole design, in which cooling ducts are provided between two layers of windings in an area which is overlapped by a pole shoe. Exit paths for the cooling ducts are formed by circumferential grooves on the undersides of the pole shoes. This arrangement can allow the rotor to be cooled in an area which is potentially the hottest. However it has been discovered that air flow through the cooling ducts and grooves may not be optimum in all circumstances.

According to a first aspect of the present invention there is provided a rotor for a rotating electrical machine, the rotor comprising a plurality of salient poles, at least one of the poles comprising a main pole body and a pole shoe, wherein at least two layers of windings are wound on the main pole body, a cooling duct is provided between two layers of windings in an area which is overlapped by the pole shoe, and an exit path for the cooling duct is formed in a radial direction through the pole shoe by recessing a part of the pole shoe in a circumferential direction.

By recessing a part of the pole shoe in a circumferential direction, an exit path for the cooling duct can be formed through the pole shoe in a radial direction. This can provide a straight path for cooling fluid through the cooling duct and the exit path. This can allow cooling fluid to pass through the cooling duct and the exit path under centrifugal force due to rotation of the rotor, which may facilitate cooling of the rotor. Furthermore, by recessing a part of the pole shoe, the exit path can be formed during manufacture of the rotor without the need for drilling the rotor.

Preferably, for optimum cooling, the cooling duct is positioned towards the middle of the windings, for example, at a location between 25% and 75% across the windings in a circumferential direction. However, since the inside of the windings (i.e. the part closest to the pole) may become hotter than the outside, the position of the duct may be offset towards the inside of the windings. Thus the cooling duct may be located at a location between 50% and 75% across the windings in a circumferential direction. For example, the cooling duct may be located about two-thirds of the way through the windings. Generally, the position of the duct will be at or close to the point where the temperature would otherwise be the highest. Preferably the recessed part of the pole shoe is sufficiently recessed to expose at least partially an end of the cooling duct, thereby to provide an exit path for the cooling duct.

A single duct may be provided, or, in order to increase the cooling, a plurality of ducts may be provided between the layers of windings. In this case, a plurality of radial exit paths may also be formed in the pole shoe. For example, each cooling duct may have a corresponding exit path through the pole shoe. Alternatively, each cooling duct may have several exit paths, or a single exit path may serve two or more cooling ducts.

In order to ensure that the windings are retained by the pole shoe, the pole shoe may comprise at least two parts which are not recessed. For example, the pole shoe may be recessed above a cooling duct, and non-recessed elsewhere. Different parts of the pole shoe may be recessed by different amounts.

The most vulnerable part of a pole shoe may be the two ends, in an axial direction, of the pole shoe. These parts of the pole shoe are adjacent the winding out hangs, and thus may suffer additional centrifugal forces due to the winding out hangs. Thus the ends of the pole shoes in an axial direction may be non-recessed, in order to ensure the pole shoe has sufficient strength at these points. This may be the case for either or both ends of the pole shoe, and for some or all of the poles shoes in the rotor. In addition, intermediate parts of the pole shoe may also be non-recessed.

A plurality of ducts may be provided between the same two layers of windings, and/or a plurality of ducts may be provided between different layers of windings. Where two ducts are provided between different layers of windings, a part of the pole shoe may be recessed sufficiently to provide an exit path for both ducts.

When the machine is in use, it may be possible for dust, debris or other contaminants to enter the machine and to block, or partially block, a cooling duct. The cooling ducts preferably have a cross section of sufficient size to ensure that this is unlikely to happen. For example, the machine may have a filter for the cooling fluid, and the cooling duct or ducts may have a cross section which is larger than the largest particle size which can be passed by the filter. Preferably the size of the cooling duct or ducts is at least 5mm.

In a preferred embodiment of the invention, a plurality of cooling ducts is provided between two layers of windings, and at least two cooling ducts are interconnected. This can allow the cooling fluid to find another entry or exit path if part of one cooling duct is blocked for whatever reason. For example, the machine may be manufactured such that not all of the cooling ducts have corresponding exit paths, in which case it may be possible for the cooling fluid to find an alternative exit via another cooling duct. Such an arrangement may also help prevent the machine from overheating when a cooling duct is blocked by debris.

The cooling duct may be formed by providing a spacer between the two layers of windings. The spacer may be, for example, a strip of material. For example, a strip of substantially rectangular cross section may be used, in which case ducts may be created on either side of the strip. However strips of other cross section may be used, and the cross section may be tailored to conform to the shape of duct it is required to create. For example, to create a duct of substantially rectangular cross section, two strips of substantially triangular in profile section may be used, which are spaced apart to create the duct. Preferably the strip extends in a substantially radial direction, that is to say, one end of the strip is closer to the centre of rotation than the other. A strip may be an individual piece, or it may be part of a matrix of strips.

The strip may be made from an electrical insulator, such as glass epoxy or other material, in order to reduce the risk of a short circuit in the windings. The strip may be a heat insulator, and preferably can withstand high temperatures. Alternatively the strip may be made from a thermally conductive material, and part of the strip may extend out of the windings, for example in a radially inward direction. In this way cooling of the windings can also take place through thermal conduction through the strip.

In an embodiment of the invention, the cooling duct is formed by a spacing sheet comprising a backing layer and a plurality of spacers located on the backing layer. This may simplify the manufacturing process, since it may be easier to retain such a spacing sheet in position while winding the rotor. Furthermore, such an arrangement may allow a plurality of cooling ducts to be provided in predetermined locations, by locating the appropriate number of spacers at the appropriate positions on the backing layer.

The spacing sheet may be produced by casting, injection moulding, dough moulding, or may be machined from a solid piece, or manufactured in any other way. The backing layer and/or the spacers may be formed from an insulating material, or from a metal, such as aluminium. In the latter case the contact faces of the metallic surfaces may be protected by an insulating material. In general, the spacing sheet may be formed from two or more different materials, and the spacers may be formed from a different material from the backing layer. The backing layer may have adhesive on the reverse side to assist in retaining the spacing sheet in place while the rotor is being wound.

In order to ensure heat transfer from both layers of windings into the cooling duct, it may be desirable to provide two spacing sheets, and to arrange one spacing sheet to have a backing layer adjacent one layer of windings and the other spacing sheet to have a backing layer adjacent the other layer of windings. Alternatively a spacing sheet may be provided with spacers located on both sides of the backing layer. In either case, the backing layer may have holes in order to assist in the transfer of heat from the windings.

In a preferred embodiment of the invention the spacers are intermittent, that is, not continuous in a radial direction. This can allow cooling ducts to be interconnected, which can allow the cooling fluid to find another entry or exit path if part of one cooling duct is blocked.

Preferably the spacing sheet comprises a plurality of spacers defining a plurality of cooling ducts, and the plurality of cooling ducts are interconnected. This arrangement can allow cooling fluid to migrate axially as well as radially through the rotor windings. With such an arrangement it may not be necessary to align the cooling ducts precisely with the exit paths, since the cooling fluid may be able to find alternative paths through the rotor windings. This arrangement may therefore simplify the manufacturing process.

The spacers may be tapered, with a larger cross-section at the base than at the tip. This may help to ensure that the spacers are strong in compression and that they do not detach from the backing layer. At the same time, reducing the profile of the spacers towards the tips may reduce the overall cross-sectional area of the spacers, which may increase the amount of cooling fluid which can flow through the rotor windings.

Preferably the rotor also comprises an entry path for the cooling duct. The entry path may be located on a bottom surface, in a radial direction, of the windings. For example, the rotor may have an axial channel under the bottom surface of the windings, which channel is in communication with the duct. This channel can then supply the cooling fluid to the duct.

The most natural direction for the cooling duct to take would be radially through the windings, in order to allow cooling fluid to enter the cooling duct from under the windings and to exit through the pole shoe. However with such an arrangement, if the cooling fluid were supplied to the cooling duct from a channel passing axially through the rotor under the windings, then it would be necessary for the cooling fluid to undergo a 90° change in direction on entry into the cooling duct. This could result in a drop in the pressure of the cooling fluid, potentially reducing its effectiveness. Furthermore a machine which is cooled in this way may suffer from a temperature gradient axially through the windings, since the part of the windings which is closest to the inlet of the channel under the windings may be cooled more effectively than the part of the windings closest to the outlet of the channel.

In a preferred embodiment of the invention, the cooling duct is arranged to run at least partially in a direction which is at an angle to a radial direction through the windings. This can allow the cooling fluid to flow axially as well as radially through the windings. This arrangement may reduce the entry angle of the cooling fluid into the cooling duct, allowing the cooling fluid to flow more easily through the cooling duct. Furthermore, the cooling fluid may be directed at least partially in an axial direction towards a part of the windings which would normally be the hottest. Thus this arrangement may result in more effective cooling of the windings.

For example, where the cooling duct is formed by a spacing sheet comprising a backing layer and a plurality of spacers located on the backing layer, at least some of the spacers may run at least partially in an axial direction through the windings.

It has been discovered pursuant to the present invention that it may be advantageous for the cooling duct to be curved. In particular, the cooling duct may be curved such that the angle of the entry path to the cooling duct with respect to the radial direction is greater than the angle of the exit path to the radial direction. For example, the entry path to the cooling duct may run in an at least partially axial direction, while the exit path for the cooling duct may run in a substantially radial direction. This may allow more effective intake of the cooling fluid into the cooling duct, and may also allow the cooling fluid to be directed to the hottest part of the windings.

For example, where the cooling duct is formed by a spacing sheet comprising a backing layer and a plurality of spacers located on the backing layer, at least some of the spacers may be curved.

In some embodiments, two or more spacing sheets may be used to form the cooling ducts. In such embodiments some of the spacers in one spacing sheet may be arranged to align with some of the spacers in another spacing sheet, when the two spacing sheets are adjacent. This can allow a cooling duct to cross two or more spacing sheets.

Rotors in electrical machines are usually formed from a plurality of laminations (e.g. laminated sheets of metal), in order to reduce eddy currents flowing in the rotor. Where the rotor is formed from a plurality of laminations, a part of one lamination forming a pole shoe may be recessed with respect to the corresponding part of another lamination forming the same pole shoe. This may allow one or more recesses to be provided as part of the manufacturing process.

The laminations may be arranged in groups of two or more successive laminations, and the pole shoe in one group of laminations may be different from the pole shoe in another group of laminations. For example, the laminations in one group may be recessed with respect to the corresponding laminations in other group. This can allow the non-recessed parts of the pole shoe to comprise two or more adjacent laminations, which may help to ensure that the pole shoe has sufficient strength to retain the windings. This can also allow the recessed parts of the pole shoe to comprise two or more adjacent laminations, which provide an exit path of the appropriate dimensions.

In a preferred embodiment of the invention, the rotor comprises a plurality of laminations each of the same shape, and at least one lamination is rotated with respect to at least one other lamination. In this case, in each lamination, at least one of the pole shoes may have a different profile from at least one of the other pole shoes. For example, in each lamination, one pole shoe may recessed with respect to another pole shoe in the same lamination. This can simplify the manufacturing process, by allowing all of the laminations to be the same, and the recess or recesses to be formed simply by rotating the laminations. The at least one lamination may be rotated by the angle between the poles, or a multiple thereof (e.g. an odd multiple), with respect to the other laminations.

Laminations for rotors are usually made from rolled sheet steel. During manufacture of the rolled steel there may be a slight crowning across the width of the roll due to deflections in the roller. This crowning effect may lead to a rotor having slight differences in the mass of steel in different poles. Rotating some laminations with respect to other laminations may also produce the advantage that the mass of steel in each pole can be made more uniform. This may help to reduce vibration, and may also have the effect of raising the maximum flux density before saturation on the complete rotating field, thereby raising the rating of the machine.

The windings may be of any suitable type, such as copper wires, and may be of any cross section, such as round or rectangular. The rotor poles may be formed from any suitable magnetic material such as iron or steel. The cooling fluid may be air or another gas, or a liquid coolant.

The invention extends to a rotating electrical machine, such as a generator or motor, comprising a stator, and a rotor in any of the forms described above.

The spacing sheet arrangement described above may also be supplied separately from the rotor. Thus, according to a second aspect of the invention, there is provided a spacing sheet for forming cooling ducts between two layers of windings in an electrical machine, the spacing sheet comprising a backing layer, and a plurality of spacers located on the backing layer, wherein the spacers are discontinuous so as to define a plurality of interconnected cooling ducts.

The use of such a spacing sheet may simplify the manufacturing process, and may allow a more sophisticated arrangement of the cooling ducts. By arranging the spacers to be discontinuous, axial as well as radial paths may be formed through the windings, which may help to ensure effective cooling.

At least some of the spacers may run at an angle to a radial direction through the windings. Furthermore, at least some of the spacers may be curved. This may allow more effective intake of the cooling fluid into the cooling duct, and may also allow the cooling fluid to be directed to the hottest part of the windings.

As discussed above, in some embodiments, two or more spacing sheets may be used to form the cooling ducts. In this case it may be desirable for a cooling duct to cross from one spacing sheet to another. Thus some of the spacers may be arranged to align with some of the spacers in an adjacent spacing sheet. For example the spacers may be arranged such that, if an identical spacing sheet were adjacent, some of the spacers would be aligned. This can allow a cooling duct to span the joint between two adjacent spacing sheets.

Any of the features of the spacing sheet described in relation to the first aspect of the invention may also be applied to the second aspect of the invention.

According to another aspect of the invention there is provided a method of manufacturing a rotor for a rotating electrical machine, the rotor comprising a plurality of salient poles, at least one of the poles comprising a main pole body and a pole shoe, the method comprising the steps of:

manufacturing the rotor so that at least one part of a pole shoe is recessed in a circumferential direction with respect to another part of the same pole shoe;

winding a first layer of windings on the pole body;

positioning a spacer on the first layer of windings;

winding a second layer of windings on top of the first layer and the spacer so as to form a cooling duct between the two layers of windings, wherein at least part of the cooling duct is aligned with a recessed part of the pole shoe.

The rotor may be formed from a plurality of laminations, and a part of one lamination forming a pole shoe may be recessed with respect to the corresponding part of another lamination forming the same pole shoe. Each lamination may have the same shape, and one lamination may be rotated with respect to at least one other lamination to form the rotor.

Features of one aspect of the invention may be provided with any other aspect. Any of the apparatus features may be provided as method features and *vice versa*.

Preferred features of the present invention will now be described, purely by way of example, with reference to the accompanying drawings, in which:

Figure 1 shows parts of a rotating electrical machine according to an embodiment of the invention;

Figure 2 shows parts of a spacing sheet according to an embodiment of the invention;

Figure 3 shows two spacing sheets in place between two layers of windings;

Figure 4 shows a profile of a spacer in an embodiment of the invention;

Figure 5 shows a plan view of two poles of a rotating electrical machine according to an embodiment of the invention;

Figure 6 shows an alternative embodiment, in which spacers are formed from solid sheets of insulating material;

Figure 7 shows a plan view of part of a pole in another embodiment; and

Figure 8 shows another embodiment of the invention with an alternative spacing sheet.

Figure 1 shows parts of a rotating electrical machine. Referring to Figure 1, the machine comprises a rotor 10 and a stator 12. The rotor is formed from a plurality of laminated sheets of metal stacked together into the plane of Figure 1 to form a rotor of the required thickness. The rotor 10 comprises a plurality of salient poles 14, 16. For simplicity only two poles are shown in Figure 1, but it will be appreciated that the rotor has a number of poles disposed symmetrically about a central axis. Similarly the stator 12 extends circumferentially around the rotor 10.

In Figure 1, each pole comprises a pole main body 18, 20 and pole shoes 22, 24, 26, 28. Each pole main body is wound with a respective winding 30, 32. In operation an electrical current is supplied to the windings 30, 32. The windings of adjacent poles usually carry a current of the opposite sense, so that adjacent poles are of opposite polarity, as indicated by the symbols "N" and "S" in Figure 1. The current in the windings causes a magnetic flux to develop between the rotor and the stator.

In operation the rotor rotates about the central axis. The pole shoes 22, 24, 26, 28 are arranged to assist in retaining the windings 30, 32 against centrifugal forces as the rotor rotates. The pole shoes also help to distribute the magnetic flux across the air gap 25 between the rotor 10 and the stator 12. A wedging arrangement 34 is provided to wedge the windings 30, 32 in place.

As can be seen from Figure 1, the windings 30, 32 are provided with cooling ducts 36, 38, 40, 42. These cooling ducts extend through the windings in a radial direction. The ducts are located at that part of the windings 30, 32 which would otherwise experience the highest temperature rise, in order to provide the most effective cooling of the windings.

In Figure 1, each of the ducts 36, 38, 40, 42 is provided with an exit path which extends in a radial direction through the pole shoe. The exit paths are formed by recessing the parts of the pole shoes which are above the cooling ducts. Elsewhere the pole shoe is non-recessed, in order to ensure that the windings are retained against centrifugal forces, and that as much magnetic flux as possible is developed across the air gap 25 between the rotor and the stator.

In operation, as the rotor rotates, air is propelled through the ducts 36, 38, 40, 42 by centrifugal force as indicated by arrow 2, and through the exit paths as indicated by arrow 4. In this way air is pumped from the axial air space under the rotor windings, radially outwards into the air gap 25, and hence to the hot air exit of the machine.

The net effect of this air flow is that the temperature of the rotor winding will be reduced, leading to longer life. Potentially, if the machine design is rotor temperature rise limited, then the machine output or power density can be increased. The hot spot which is situated in the region of the ducting location will be reduced, and the maximum and minimum temperature spread within the average temperature measured by resistance, will be lowered, which may also lead to longer life. Furthermore, by removing some of the layers of conductors to facilitate the ducting construction, the cost of these conductors can be reduced. The internal stresses in the field winding, due to temperature gradient, may also be reduced.

Figure 2 shows a top, side and end view of a spacing sheet which may be used to produce the cooling ducts in a preferred embodiment of the invention. Referring to Figure 2, the spacing sheet 50 comprises a backing layer 52 on which are located a plurality of spacers, such as spacer 54. The spacing sheet 50 is located between two layers of windings on a rotor pole. The spacers on the spacing sheet separate the two layers of windings, so that an air gap exists between them. In this way cooling ducts are formed through the rotor windings.

As can be seen from Figure 2, the spacers are intermittent, that is, discontinuous in a radial direction through the windings. This can allow air to migrate axially as well as radially through the windings, in particular if the entry or exit to the spacing sheet is partially blocked. In Figure 2, typical air paths through the rotor windings are shown by the arrows.

Figure 3 shows two spacing sheets in place between two layers of windings 56, 58. The two spacing sheets are reversed with one backing layer adjacent one layer of windings, and the other backing layer adjacent the other layer of windings. Since the backing layers 52 may reduce the transfer of heat from the windings into the cooling ducts, this can allow both sides of the ducts to be cooled alternately. A number of such spacing sheets may be provided in a radial direction and/or in an axial direction or a combined axial/radial direction through the windings, in order to ensure effective cooling of both layers of windings.

Figure 4 shows a profile of one the spacers 54. The spacers have a tapered profile, and are thicker at the base than at the tops. This can help to ensure that the spacers are strong and do not detach from the backing layer. At the same time, the tapered profile allows the spacers to have a lower profile than would otherwise be the case, in order to allow as much air flow as possible to flow through the rotor windings.

The spacing sheet may be made from an insulating material, and may be produced by casting, injection moulding, dough moulding or machined from a solid piece. It can also be manufactured in metal, such as aluminium, by forming the metal to a similar profile. In the latter case the contact faces of the metallic surfaces are electrically protected by insulation on both sides of the material.

It has been found in practice that, for a typical machine, the width of the cooling ducts should be 5mm or greater, in order to prevent any dust or other debris blocking the passages over time. The cross section of the ducts also determines the number of layers of copper which are displaced, and hence the reduction in the number of turns of the windings. In order to maintain the required magnetic field strength, it may be necessary to increase the current flowing in the windings.

The location of the ducts in relationship to the outer peripheral face of the windings is also important. The machine power rating is often determined by its temperature rise, and thermal studies have indicated that the optimum location is approximately 2/3 of way through the winds circumferentially.

Figure 5 shows a plan view of the poles 14, 16 of Figure 1. Each pole is formed from a plurality of laminations which run from left to right in Figure 5. Each pole main body is wound with respective windings 30, 32. In Figure 5, the laminations are arranged in four groups 60, 62, 64, 66. The pole tips of the laminations in one group are cut away or otherwise recessed with respect to the pole tips of the laminations in an adjacent group, to create a castellation effect. For each group of laminations, the pole tips in one of the poles 14, 16 are cut away, while the pole tips in the other pole are not cut away. This causes the castellation of one pole shoe to be offset with respect to the castellation of the opposing pole shoe, so that cut-away parts of one pole shoe are aligned with non cut-away parts of the opposing pole shoe.

Cutting away the pole tips in the way shown in Figure 5 allows cooling ducts 36, 38, 40, 42, to be exposed, thereby providing exit paths for the cooling ducts. By using a spacing sheet with intermittent spacers, such as that shown in Figure 2, air flow through the cooling ducts can be ensured, even if some of the potential exit paths are blocked by non-recessed parts of the pole shoes. This can allow the machine to be manufactured without the need for careful alignment of the cooling ducts and exit paths.

In operation, as the rotor rotates, the cooling ducts function effectively as an air pump. Air is pulled radially from the axial passage under the windings, and discharged via the castellated sections of the pole tip into the axial air flowing in the air gap between the rotor the stator. The cooling air escapes more readily in the leeward side due to the direction of rotation. This can help to balance the temperature differential that might otherwise exist between the windward and leeward side of the windings.

In order to minimise the number of rotor lamination designs, each lamination may be of the same design with the pole tips removed from every other pole. The castellated effect may then be created by rotating some groups of laminations by an amount equivalent to the angle between adjacent poles, or an odd multiple thereof. To provide addition cantilever support at the end of the windings, single laminations, or smaller groups of laminations, may be rotated by the appropriate amount in the outer laminations.

The arrangement described above can allow each lamination to be the same, and the rotor to be formed simply by rotating some groups of laminations through the appropriate angle. This can reduce the manufacturing costs compared to the case where laminations with different profiles are used. Furthermore, rotating groups of laminations with respect to other laminations may also compensate for crowning effects in the steel, and thus may help to ensure that the mass of steel in each pole is uniform. If required, different laminations or groups of laminations may be indexed by different amounts. For example, in a four pole machine, different groups of laminations may be rotated by 90°, 180°, and 270° respectively.

Figure 6 shows an alternative embodiment, in which spacers are formed from solid sheets of insulating material. Referring to Figure 6, spacers 70 are strategically placed to create cooling ducts 72 through the rotor windings. Also shown in Figure 6 is amortessieur bar 74, which is a standard design feature and forms part of the amortessieur winding on the poles.

The spacers may be, for example, as disclosed in GB 2425662 referred to above.

Figure 7 shows a plan view of part of a pole in another embodiment. In Figure 7, the end group of laminations 76 is arranged such that individual laminations are alternately cut-away and not cut-away. This arrangement provides additional cantilever support for the windings at the ends of the poles where additional centrifugal loads due to winding out hang 78 are maximum. The arrangement of Figure 7 may thus be more robust than that of Figure 5, while still providing exit paths for cooling ducts 80, 82 between the windings. Also shown in Figure 7 is an amortessieur bar 84.

Figure 8 shows another embodiment of the invention in which a number of spacing sheets are used to provide the cooling ducts. In Figure 8, the spacing sheets are shown in place on a rotor on which a first layer of windings has been wound, but before a second layer of windings has been added.

Referring to Figure 8, the rotor comprises rotor pole assembly 102 on which is wound a layer of windings 104. A rotor support bar 101 supports the windings on the winding outhangs. A number of supports 105 are provided under the windings in order to hold the windings in place. These supports may be made from plastic or some other material, and may be tapered at the front and/or at the back for best air flow. The rotor also comprises a number of castellated pole tips 103. The end group of laminations 107 has laminations which are rotated individually in the way described above with reference to Figure 7.

In Figure 8 a total of six spacing sheets 108, 109, 110 are shown. Each spacing sheet is formed from a backing layer 115, on which are located a plurality of spacers, such as spacer 114. The spacers on the spacing sheet separate the windings 104 from another layer of windings which is wound on top of the spacing sheet (not shown in Figure 8). In this way cooling ducts are formed through the rotor windings.

In the embodiment of Figure 8 the four central spacing sheets 109 are identical, and the spacers in these sheets are arranged such that, when the sheets are placed next to each other, the spacers in one sheet are aligned with the spacers in the adjacent sheet. By aligning the spacers in this way, it is possible to form cooling ducts which cross two or more spacing sheets. This can facilitate the formation of the cooling ducts through the windings, and in particular can help with the formation of cooling ducts which run in a partially axial direction.

The two end sheets 108, 110 in Figure 8 have spacers with a different arrangement. The spacers in these sheets are designed to align with the spacers in an adjacent sheet on one side but not on the other, so as to ensure that exit paths for the cooling ducts are on the outward side, radially, of the windings.

In Figure 8, the driven end (DE) of the rotor is on the right, and the non-driven end (NDE) is on the left. In this embodiment, when the machine is in operation, air passes axially through a channel under the windings, as indicated by arrow 111. Typical air flow through the windings is indicated by arrows 112.

It can be seen that some of the spacers in Figure 8 are curved, so that cooling ducts are formed in which the entry paths are in a partially axial direction while the exit paths are in a more radial direction. This arrangement allows air to enter the cooling ducts at an angle of substantially less than 90°. This can help to ensure that there is minimal pressure drop on entry of the air into the ducts.

The arrangement of the spacers in Figure 8 also ensures that air is guided in an axial direction as well as a radial direction through the windings. Since air flow under the windings in Figure 8 is from right to left, the non driven end of the rotor on the left hand side would normally be the coolest, while the driven end of the rotor on the right hand side would normally be the hottest. By directing the air in a partially axial direction through the windings, the hotter driven end of the rotor can be cooled more than would be the case with purely radial cooling ducts. Thus the arrangement of Figure 8 may provide more effective cooling of the windings.

In the arrangement of Figure 8, as in that of Figure 2, the spacers are not continuous all of the way through the windings. This can help to ensure that there is always an alternative route available for the air, should one of the cooling ducts be blocked for any reason.

The spacing sheets 108, 109, 110 may be formed in any of the ways discussed above. A mirror image of the sheets 108, 109, 110 is provided on the other side of the pole.

While six separate spacing sheets are shown in Figure 8, it will be appreciated that the arrangement of spacers could be formed from any number of spacing sheets. For example, a single spacing sheet could be used where appropriate.

In any of the above arrangements, the castellations in the laminations may be formed with a specially adapted blanking tool when manufacturing a rotor with laminated steel, or by flame or laser cutting or otherwise profiling sheet steel laminations, or by having suitable shapes machined in the pole tips of solid rotors, or by any other method.

The present invention may be used in conjunction with techniques for reducing stray losses, such as those disclosed in co-pending United Kingdom patent application number 0713469.5, the contents of which are incorporated herein by reference.

The present invention may be used with a wedging arrangement, such as that disclosed in GB 2425663, the contents of which are incorporated herein by reference, or that disclosed in GB 2381389, the contents of which are incorporated herein by reference.

CLAIMS

1. A rotor for a rotating electrical machine, the rotor comprising a plurality of salient poles, at least one of the poles comprising a main pole body and a pole shoe, wherein at least two layers of windings are wound on the main pole body, a cooling duct is provided between two layers of windings in an area which is overlapped by the pole shoe, and an exit path for the cooling duct is formed in a radial direction through the pole shoe by recessing a part of the pole shoe in a circumferential direction.

2. A rotor according to claim 1, wherein the cooling duct is at a location between 25% and 75% across the windings in a circumferential direction.

3. A rotor according to claim 1 or 2, wherein the recessed part of the pole shoe is sufficiently recessed to expose at least partially an end of the cooling duct.

4. A rotor according to any of the preceding claims, wherein a plurality of cooling ducts are provided between the layers of windings.

5. A rotor according to any of the preceding claims, wherein a plurality of exit paths are formed in the pole shoe.

6. A rotor according to any of the preceding claims, wherein the pole shoe comprises at least two parts which are not recessed.

7. A rotor according to claim 6, wherein the ends of the pole shoes in an axial direction are not recessed.

8. A rotor according to any of the preceding claims, wherein the pole shoe is recessed above a cooling duct, and non-recessed elsewhere.

9. A rotor according to any of the preceding claims, wherein two cooling ducts are provided between different layers of windings, and a part of the pole shoe is recessed sufficiently to provide an exit path for both ducts.

10. A rotor according to any of the preceding claims, wherein the machine has a filter for cooling fluid, and the cooling duct has a cross section which is larger than the largest particle size which can be passed by the filter.

11. A rotor according to any of the preceding claims, wherein a plurality of cooling ducts is provided between two layers of windings, and at least two cooling ducts are interconnected.

12. A rotor according to any of the preceding claims, wherein the cooling duct is formed by providing a spacer between the two layers of windings.

13. A rotor according to claim 12, wherein the spacer is a strip of material.

14. A rotor according to any of the preceding claims, wherein the cooling duct is formed by a spacing sheet comprising a backing layer and a plurality of spacers located on the backing layer.

15. A rotor according to claim 14, wherein two spacing sheets are provided between two layers of windings, and one spacing sheet has a backing layer adjacent one layer of windings and the other spacing sheet has a backing layer adjacent the other layer of windings.

16. A rotor according to claim 14, wherein spacers are located on both sides of the backing layer.

17. A rotor according to any of claims 14 to 16, wherein the spacers are discontinuous.

18. A rotor according to any of claims 14 to 17, wherein the spacing sheet comprises a plurality of spacers defining a plurality of cooling ducts, and the plurality of cooling ducts are interconnected.

19. A rotor according to any of claims 14 to 18, wherein the spacers are tapered.

20. A rotor according to any of the preceding claims, further comprising an entry path for the cooling duct.

21. A rotor according to any of the preceding claims, wherein the cooling duct is arranged to run at least partially in a direction which is at an angle to a radial direction through the windings.

22. A rotor according to any of the preceding claims, wherein the cooling duct is curved.

23. A rotor according to any of the preceding claims, wherein the rotor is formed from a plurality of laminations, and a part of one lamination forming a pole shoe is recessed with respect to the corresponding part of another lamination forming the same pole shoe.

24. A rotor according to claim 23, wherein the laminations are arranged in groups of two or more successive laminations, and the pole shoe in one group of laminations is different from the pole shoe in another group of laminations.

25. A rotor according to claim 23 or 24, wherein the rotor comprises a plurality of laminations each of the same shape, and at least one lamination is rotated with respect to at least one other lamination.

26. A rotor according to claim 25 wherein, in each lamination, at least one of the pole shoes has a different profile from at least one of the other pole shoes.

28. A rotating electrical machine comprising a stator and a rotor according to any of the preceding claims.

29. A spacing sheet for forming cooling ducts between two layers of windings in an electrical machine, the spacing sheet comprising a backing layer, and a plurality of spacers located on the backing layer, wherein the spacers are discontinuous so as to define a plurality of interconnected cooling ducts.

30. A spacing sheet according to claim 29, wherein the spacers are tapered.

31. A spacing sheet according to claim 29 or 30, wherein at least some of the spacers run at an angle to a radial direction through the windings.

32. A spacing sheet according to any of claims 29 to 31, wherein at least some of the spacers are curved.

33. A spacing sheet according to any of claims 29 to 32, wherein some of the spacers are arranged to align with some of the spacers in an adjacent spacing sheet.

34. A method of manufacturing a rotor for a rotating electrical machine, the rotor comprising a plurality of salient poles, at least one of the poles comprising a main pole body and a pole shoe, the method comprising the steps of:

manufacturing the rotor so that at least one part of a pole shoe is recessed in a circumferential direction with respect to another part of the same pole shoe;

winding a first layer of windings on the pole body;

positioning a spacer on the first layer of windings;

winding a second layer of windings on top of the first layer and the spacer so as to form a cooling duct between the two layers of windings, wherein at least part of the cooling duct is aligned with a recessed part of the pole shoe.

35. A method according to claim 34, wherein the rotor is formed from a plurality of laminations, and a part of one lamination forming a pole shoe is recessed with respect to the corresponding part of another lamination forming the same pole shoe.

36. A method according to claim 35, wherein each lamination has the same shape, and one lamination is rotated with respect to at least one other lamination to form the rotor.

37. A spacing sheet substantially as described herein with reference to and as illustrated in Figures 2, 3, 4 and 8 of the accompanying drawings.

38. Apparatus substantially as described herein with reference to and as illustrated in the accompanying drawings.

39. A method substantially as described herein with reference to the accompanying drawings.

Amendments to the claims have been filed as follows

CLAIMS

1. A spacing sheet for forming cooling ducts between two layers of windings in an electrical machine, the spacing sheet comprising a backing layer, and a plurality of spacers located on the backing layer, wherein the spacers are discontinuous so as to define a plurality of interconnected cooling ducts.

2. A spacing sheet according to claim 1, wherein the spacers are tapered.

3. A spacing sheet according to claim 1 or 2, wherein at least some of the spacers run at an angle to a radial direction through the windings.

4. A spacing sheet according to any of claims 1 to 3, wherein at least some of the spacers are curved.

5. A spacing sheet according to any of the preceding claims, wherein some of the spacers are arranged to align with some of the spacers in an adjacent spacing sheet.

6. A spacing sheet according to any of the preceding claims, wherein the backing layer has an adhesive on its reverse side.

7. A spacing sheet according to any of the preceding claims, wherein the backing layer has holes.

8. A rotor for a rotating electrical machine, the rotor comprising two layers of windings and a spacing sheet according to any of the preceding claims between the two layers of windings.

9. A rotor according to claim 8, wherein two spacing sheets are provided between the two layers of windings, and one spacing sheet has a backing layer adjacent one layer of windings and the other spacing sheet has a backing layer adjacent the other layer of windings.

10. A rotor according to claim 8 or 9, wherein the cooling ducts are arranged to run at least partially in a direction which is at an angle to a radial direction through the windings.

11. A rotor according to any of claims 8 to 10, wherein the cooling ducts are curved such that the angle of an entry path to a cooling duct with respect to the radial direction through the rotor is greater than the angle of an exit path to the radial direction.

12. A rotor according to any of claims 8 to 11, wherein an entry path to a cooling duct runs in an at least partially axial direction through the rotor, while an exit path for a cooling duct runs in a substantially radial direction through the rotor.

13. A rotor according to any of claims 8 to 12, wherein cooling ducts are arranged to direct cooling fluid to hotter parts of the rotor.

14. A rotor according to any of the preceding claims wherein, in operation, cooling fluid is propelled through the cooling ducts by centrifugal force due to rotation of the rotor.

15. A method of manufacturing a rotor for a rotating electrical machine, the method comprising the steps of:

winding a first layer of windings on the rotor;

positioning a spacing sheet on the first layer of windings, the spacing sheet comprising a backing layer, and a plurality of spacers located on the backing layer, wherein the spacers are discontinuous so as to define a plurality of interconnected cooling ducts; and

winding a second layer of windings on top of the first layer and the spacer so as to form cooling ducts between the two layers of windings.

16. A spacing sheet substantially as described herein with reference to and as illustrated in Figures 2, 3, 4 and 8 of the accompanying drawings.

17. A method substantially as described herein with reference to the accompanying drawings.

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Application No:	GB0719887.2	**Examiner:**	John Cockitt
Claims searched:	1-28,34	**Date of search:**	11 February 2008

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
Y	1,34 at least	US3846651 A WESTINGHOUSE - see radial pole shoe ducts venting spaced stator winding parts
Y	1,34 at least	JP2001339883 A HITACHI - see circumferential slots formed by laminating which appears to allow coolant exit from inter core winding gaps- see figs 1-3
Y	1,34 at least	SU1101970 A1 PROIZV - see bore in pole shoe to exit coolant.

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

H2A

Worldwide search of patent documents classified in the following areas of the IPC

H02K

The following online and other databases have been used in the preparation of this search report

ONLINE: WPI, EPODOC

International Classification:

Subclass	Subgroup	Valid From
None		

2 ?

Application No: GB0719887.2 **Examiner:** Mr John Cockitt
Claims searched: 29-33 **Date of search:** 11 July 2008

Patents Act 1977
Further Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
Y	29 at least	US3781581 A ALSTHOM - see whole document
Y	29 at least	JP56107539 A MITSUBISHI - see fig 2,3
A		JP2001211607 A SHINKO - example of interlayer spacers

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art
Y	Document indicating lack of inventive step if combined with one or more other documents of same category	P	Document published on or after the declared priority date but before the filing date of this invention
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

Worldwide search of patent documents classified in the following areas of the IPC

The following online and other databases have been used in the preparation of this search report

International Classification:

Subclass	Subgroup	Valid From
None		