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Description

The present invention relates to improvements in rotor windings for use in ventilated dynamoelectric machine rotors.

Conventional dynamoelectric machines, such as generators used with gas and steam turbine drives employ forged rotors of magnetic material into which slots are machined for receiving the conductive turns of field windings which are interconnected so as to produce a desired magnetic flux pattern. The rotor may be pedestal mounted so as to be rotated on an axis to cause the flux pattern to interact with stator windings such that electric power is generated in response to the rotation supplied by a turbine or other motive device or a rotational torque is generated responsive to input electrical energy.

FIGURE 1 is illustrative of a conventional generator rotor 1 constructed of a single-piece forging having coil slots 2, winding retainer rings 3, a fan for stator winding ventilation, as well as shaft bearing surfaces and couplings.

The rotor windings are conventionally directly cooled by way of a radial flow design of coolant gases through openings in the winding conductors and insulating layers. Such coolant gas is supplied via subslots in the rotor winding slots wherein the coolant gases move axially through the subslots and radially through the winding flow channels. The manner in which the rotor slots are shaped and insulated, as well as the efficiency of the flow channels for eliminating heat from the windings present formidable space utilization design problems, particularly where high maximum permissible current limits are contemplated. Additionally, design considerations involve obtaining sufficient clearance for ventilation passages along with relatively high winding slot fill factors as well as insulating the individual winding turns from each other and from the rotor forging.

In this regard, FIGURE 2 illustrates the present conventional practice of including one coil per slot wherein the conductors 20 are nearly the full width of the slot with only sufficient coil installation clearance between conductors and the forging to allow the inclusion of slot armor 21 to be used for insulating the turns from the rotor forging. Additionally, turn insulation 22 in the form of insulating strips are used between each turn conductor for insulating the individual winding turns from each other.

Such conventional slot configurations, as illustrated in U.S. Patent No. 4,659,381 issued to Jenkins et al on August 22, 1989, may include a U-shaped subslot liner for supporting the coil turns 20, which in combination with a single U-shaped slot armor or two L-shaped portions of slot armor serve to support and insulate the turns from the metal rotor forging. Additionally included in such conventional rotor slots are creepage blocks 26 at both the top and bottom ends of the slot (only one of which is illustrated in FIGURE 2), as well as dovetail wedges 24 for resisting the radially outward forces exerted on the windings when the rotor is operational. Further illustrated elements include radially directed passages 25 which are punched or machined slots in each of the winding turns, as well as the turn insulation, for providing radial ventilation passages. The U-shaped subslot liner 23 and the lower winding turn or creepage block provide an axial channel or subslot for furnishing a supply of coolant gas, such as air, to each of the ventilating passages or slots in the winding turns and turn insulation so as to provide high velocity gas, thus cooling the copper winding turns.

Still other slot configurations with relatively narrow machined subslots using subslot covers for supporting the winding turns are known, as may be seen from the disclosure in the aforementioned Jenkins et al patent. Still another approach may be seen from a review of U.S. Patent No. 5,065,646 issued to Kaminski on November 12, 1991, wherein the rotor slot insulation includes two insulating slot armors, each of which extends in an offset manner through the transition between the rotor slot and subslot, thus eliminating the need for a subslot cover.

In each of the above referenced configurations the slots, subslots, windings and insulation extend the full length of the rotor. Coolant gas enters through the full length subslots and is discharged into the air gap between rotor and stator along the length of the rotor body through radial slots that are machined or punched in the copper conductors, turn insulation, creepage blocks and wedges. As aforementioned, present design practice involves the use of one coil per rotor slot wherein the copper conductors are nearly the full width of the slot. As illustrated in FIGURE 3, such full width slot conductors 30 separated by turn insulation strips 31 are formed into coils by brazing straight rectangular copper sections to them at their ends. The thus formed coils are inserted into a slot 32 after brazing and cleaning. Aligned ventilating slots such as 33, for example, may be included in both the copper conductors and insulting turn separators to allow the radial flow of coolant gases. Additionally, lateral grooves 34 may be included in the end turns to allow the circumferential flow of coolant gases.

DE-B-1015528 discloses a dynamoelectric machine including a slotted rotor comprising a first and a second winding positioned adjacent first and second sidewall of the slot, and a plurality of insulating spacers in order to form radial ventilation passages.

According to the invention there is provided a rotor winding assembly for use in a dynamoelectric machine, having the features recited in claim 1.

In the present invention the innermost coil sides of the two coils are separated by insulating spacer driven between the coils after they are wound offers several advantages in the construction, operation and repair of such dynamoelectric machines. That is to say, the separation of the coils by a plurality of spacers distributed in a spaced relationship along the axial length of the ro-
tor slots not only serves to electrically insulate the coils from each other but additionally form ventilating passages between the coil sides and spacers for allowing the radial flow of coolant gases. Additionally, the spacing between the two coils allows the coils to be forced away from the slot armor, thus allowing the replacement of damaged slot armor insulation. Moreover, after the insulating spacers are driven in place, no clearance exists between the rotor slot sidewalls, the slot armor and the coil sides, thus heat transfer from the copper turns to the steel rotor forging will increase resulting in lower copper temperatures. A further advantage of the disclosed structure is that the reduction in slot side clearance allows increased ventilation passage size or results in a better slot fill factor.

Still further advantages may be realized by the present winding design. For example, since the coil turns are approximately half the normal width, they may be wound in place from a long length of conductor. Such winding would have the advantage of eliminating the brazing and cleaning of the aforementioned fabricated rotor windings even in the event that the increased stresses produced by winding the coils in place resulted in damaged slot armor. As aforementioned, the slot armor could be easily replaced without removing the coil from the slot. Moreover, although in some known indirectly cooled single full width coil rotor designs the coil end turns are formed by bending rather than the aforementioned brazing, relatively large upsets occur at the corners due to the bending of the rather wide full width conductors. Such upsets or dimensional irregularities in turn require pressing and/or grinding to eliminate the upsets. In contrast, where two coils are wound in the same slot bending of the relatively narrow coil conductors results in much less upset or dimensional irregularities in the half width conductors. Thus, only pressing may be required.

Additionally, it will be noted from the detailed description of the invention which follows, that the ability to install slot armor in the slot sides adjacent the rotor poles after the coils are in place allows the distance between the ends of the rotor forging and the nearest end turn winding to be reduced. Thus, a reduction in effective rotor length or a relative increase in active machine length may be obtained.

In the accompanying drawings:-

FIGURE 1 illustrates the general details of a conventional dynamoelectric rotor according to the prior art;

FIGURE 2 is a cross-sectional view of a dynamoelectric rotor slot along with windings, insulation and ventilation elements in accordance with the prior art.

FIGURE 3 is a partial view of a conventional rotor slot illustrating a conventional manner of forming rotor coil end turns;

FIGURE 4 is a cross-sectional view of a rotor slot incorporating two wound coils in accordance with an exemplary embodiment of my invention;

FIGURE 5 is a partial perspective of an end view of the rotor slots and coil end winding configurations; and

FIGURE 6 is a top cross-sectional view of a rotor slot at a location below the dovetail wedge illustrating the placement of insulating coil spacers along the axial length of the rotor slots.

As indicated in FIGURES 2 and 3, present conventional practice is to include only one coil per rotor slot with the conductors configured to occupy close to the full width of the slot. That is to say, sufficient clearance is allowed for the installation of the slot armor insulation, as well as that which is necessary for the installation of the turn conductors. For ventilation purposes, slots of approximately one and 1.27 to 5 cm (one-half to two inches) long and 0.32 cm (one-eighth inch) wide are punched or machined into the conductors, as well as the turn insulation between the conductors. Such slots are spaced on approximately 5 to 6.35 cm (two to two and one-half inch) centers and are aligned with similar openings in the crease blocks and coil wedges to form radial ventilation passages. Such slot conductors are conventionally formed into coils by brazing straight rectangular copper sections to the ends of the slot conductors. The coils are inserted into the slots after brazing and cleaning along with strips of turn insulation placed between each of the conductors.

Clearly, where the slot armor requires replacement due to damage during installation of the coils or other causes, replacement of the slot armor insulation would require removing the coil. Additionally, the use of full width coils dictates away from winding the coils in place with a long length of conductor since such construction would require additional steps of pressing and/or grinding to eliminate localized increases or upsets in the cross section areas of the bends.

As illustrated in FIGURE 4, for example, I have designed a "twin turn" or two coils per slot configuration. Each of the two coils 40A and 40B, as illustrated in the drawing, form two stacks of conductors in each of the rotor slots. The coils are supported by a plurality of nonmetallic subslot support members 41. Although only one such support member is illustrated, it is contemplated that in a conventional rotor having a length of 55.88 cm (22 inches), a single such support member, approximately 5 cm (two inches) in length, may be used at the rotor ends along with a third such coil support midway along the length of the rotor slot. Additional such supports may be added as needed depending upon the design and dimensions of the dynamoelectric machine.
The individual turns of each coil are insulated from each other through the use of turn insulation 42 which may comprise strips of resin filled glass weave or similar material which are 0.025 to 0.035 cm (10 to 14 mils) thick. The coil conductors are additionally insulated from the steel rotor forging through the use of two relatively straight insulating armor elements 43, which generally conform to the shape of the rotor slot sidewalls.

After the coils 40A and 40B are formed in the rotor slots, the twostacks of conductors are separated by approximately 0.31 cm (one eighth of an inch) by insulating spacers 44 that are driven between the separate coils and extend over the full radial height of the coils. Such separation serves to electrically insulate the coils 40A and 40B from each other. Additionally, in the axial direction a plurality of such spacers are used which are approximately 1.27 cm (one-half inch) wide and are placed on 10.16 to 15.24 cm (four to six inch) centers in the general manner illustrated in FIGURE 6. In this manner, radial ventilation passages are formed between the central coil sides of coils 40A and 40B and the spacers whereby coolant gas, such as air, enters the subslot through and around the hollow subslot support 41 in an axial direction and then through the above noted radial ventilation passages, as well as the corresponding radial openings in the creepage block 45 and rotor slot wedge 46 to discharge into the air gap between the rotor and stator.

An advantage of the above noted two coils per slot design is that in case the slot armor requires replacement, the central coil spacers may be removed and the coils forced away from the slot armor 43. Thus, the earlier disclosed design would allow slot armor insulation to be removed and replaced without removing the coils from the slot. Moreover, with the insulating spacers 44 in place, no side clearance exists between the rotor forging, the slot armor and the coil turn conductors whereby heat transfer from the copper to the rotor steel will increase resulting in lower copper temperatures.

As illustrated in FIGURE 5, since each coil conductor is approximately half the slot width, the coil turns of coils 50A and 50B can be wound in place from long lengths of conductors with the illustrated end turns bent so as to be closely received within the rotor retaining ring 51 and the centering ring 52 that are conventionally included in known rotor structures of the nature illustrated in FIGURE 1. Such winding in place offers the advantage of eliminating the brazing and cleaning of the coil conductors as is conventional. Moreover, as aforementioned, if an insulating slot armor is broken due to the stresses of winding the coil conductors in place, the armor can be replaced prior to the insertion of the insulating separators 53 and wedges 54.

The insulating blocks 55 of FIGURE 5 are used as spacers in the end turn regions of the windings. Such blocks are normally 5.08 to 7.62 cm (two to three inches) wide and spaced from each other to provide free convection heat transfer from the end turns. The thus formed ventilation passages in combination with the use of two coils per slot substantially doubles the heat transfer surface area available for free convection. As will be appreciated by the artisan, if forced convection is necessary for still further heat transfer, sinusoidal ventilation passages may be formed by spacer blocks between the coils.

As illustrated in FIGURE 6, which is a top view of a single slot in a rotor body with the dovetail wedge removed, the positioning and relative spacing of the insulated separators between coil conductors 62A and 62B may be seen. As illustrated, the separators are rectangular in cross section and may, for example, be approximately 0.31 cm (one-eighth inch) thick and 1.27 cm (one-half inch) wide. The length of the separators is sufficient to extend to the full depth of the coils. Moreover, the separators are spaced in the axial direction in such a manner as to be placed on 10.16 to 15.24 cm (four to six inch) centers, thus forming radial ventilation passages 63.

Additionally, slot armor elements 64A and 64B are partially illustrated in FIGURE 6. As will be noted, these elements extend out of the slot, usually 1.27 to 1.9 cm one-half to three-quarters of an inch, for electrical creepage. As previously noted, the ability to install the slot armor in the slot sides adjacent to the poles after the coil is in place allows the distance "D" between the ends of the forging 60 and the number one coil illustrated as 62A to be reduced. Conventionally, 7.62 cm (three inches) or more are required to insert the turns lowest in the stack into the slot in order to avoid breaking the slot armor adjacent the pole where it extends out of the slot. With the present design the distance "D" could be reduced about 5 cm (two inches) on each end. For a conventional generator of about 55.88 cm (22 inches) in length, such reductions in the distance "D" represent a substantial portion of the active machine length.

As will be appreciated by the artisan from a review of FIGURES 4 through 6, after the spacers are driven in place, no side clearance exists, and the eliminated clearance increases the size of the ventilation passages. Alternatively, the side clearance may be replaced with copper, thus resulting in a better slot fill factor. Still further, for the same number of turns in the slot, as in a prior art device, the volume of turn insulation for the two coils in the slot is reduced from that which is required for a single coil in each slot. Still further, where the coils are wound in place and formed by bending, as illustrated in FIGURE 5, for example, since the conductors are approximately half the width of the prior art conductors, much less upset occurs, thus eliminating the need for grinding at the corners of a bend. Additionally, where the coil turns are wound in place, the end turns are insulated from each other through the use of coil space blocks 55, as shown in FIGURE 5. For increased surface area exposed to coolant gases and thus higher heat transfer characteristics, the coil space blocks 55 may be re-
placed with winding separators similar to elements 53 as used in the slots. The use of such separators along with winding the half width conductors in place will advantageously lead to a reduction in the extension of the end turns beyond the rotor ends.

Claims

1. A rotor winding assembly for use in a dynamoelectric machine including a rotor having axially extending slots for receiving conductive windings (40A, 40B, 50A, 50B, 62A, 62B) said slots including insulating slot armor (43, 64A, 64B) along axially directed sidewalls of said slots, said rotor winding assembly comprising:
   a first winding (40A, 50A, 62A) in each of said rotor slots, said winding including a stack of conductors with insulation (42) between each adjacent conductor, said first winding being positioned adjacent said insulating armor on a first sidewall of said slots;
   a second winding (40B, 50B, 62B) in each of said rotor slots, said winding including a stack of conductors with insulation (42) between each adjacent conductor, said second winding being positioned adjacent said insulating armor on a second sidewall of said slots;
   a plurality of insulating spacers (44, 53, 61) between said first and second windings in each of said slots, said spacers being distributed axially along each said slot such that said spacers and said first and second windings form radial ventilation passages (63),

characterized in that said spacers extend the full radial height of said windings, said slot armor in each of said slots comprising two straight unitary pieces.

2. A rotor winding assembly as claimed in claim 1, characterized in that said rotor slots, said slot armor, said windings and said spacers are dimensioned such that no clearance space exists between said slot sidewalls and said armor and between the windings and said armor.

3. A rotor winding assembly as claimed in claim 1 or 2, characterized in that said rotor slots include subslots positioned below said windings for providing coolant gas flow to said radial ventilation passages.

4. A rotor winding assembly as claimed in claim 3, characterized in that means (41) are provided in each said subslot for supporting said winding in the slots.

5. A rotor winding assembly as claimed in any one of claims 1 to 4, characterized in that said insulation between each adjacent conductor comprises strips of resin filled glass weaves material.

6. A rotor winding assembly as claimed in any one of claims 1 to 5, characterized in that a plurality of separate spacer elements (61) are separated from each other in the axial direction of said slots.

7. A rotor winding assembly as claimed in claim 6, characterized in that said windings and said spacer elements form a plurality of radially directed ventilation passages (63) in each said slot.

8. A rotor winding assembly as claimed in any one of claims 1 to 7, characterized in that said windings are formed of continuous lengths of conductors which are bent to form end windings connecting the winding conductors of one of said slots with the winding conductors of another of said slots.

9. A dynamoelectric machine having a rotor assembly according to any one of claims 1 to 8.

Patentansprüche

1. Rotorwicklungsanordnung zur Verwendung in einer dynamoelektrischen Maschine mit einem Rotor, der zur Aufnahme von Leiterwicklungen (40A, 40B, 50A, 50B, 62A, 62B) axial verlaufende Nuten aufweist, die isolierende Nutauskleidungen (43, 64A, 64B) entlang ihren axial gerichteten Seitenwänden aufweisen, wobei die Rotorwicklungsanordnung enthält:

   eine erste Wicklung (40A, 50A, 62A) in jeder der Rotornuten, wobei die Wicklung einen Stapel von Leitern mit einer Isolierung (42) zwischen jedem benachbarten Leiter aufweist, wobei die erste Wicklung benachbart zu der isolierenden Auskleidung auf einer ersten Seitenwand der Nuten angeordnet ist,
   eine zweite Wicklung (40B, 50B, 62B) in jeder der Rotornuten, wobei die Wicklung einen Stapel von Leitern mit einer Isolierung (42) zwischen jedem benachbarten Leiter aufweist, wobei die zweite Wicklung benachbart zu der isolierenden Auskleidung auf einer zweiten Seitenwand der Nuten angeordnet ist,
   mehrere isolierende Abstandshalter (44, 53, 61) zwischen den ersten und zweiten Wicklungen in jeder der Nuten, wobei die Abstandshalter axial entlang jeder Nut derart verteilt sind, daß die Abstandshalter und die ersten und zweiten Wicklungen radiale ventilationskanäle (83) bilden,
dadurch gekennzeichnet, daß sich die Abstandshalter über die volle radiale Höhe der Wicklungen erstrecken, wobei die Nutauskleidung in jeder der Nuten zwei gerade einheitliche Stücke aufweist.

2. Rotorwicklungsanordnung nach Anspruch 1, dadurch gekennzeichnet, daß die Rotorlatten, die Nutauskleidung, die Wicklungen und die Abstands- halter derart dimensioniert sind, daß zwischen den Nuteilwänden und der Auskleidung und zwischen den Wicklungen und der Auskleidung kein Spielraum besteht.

3. Rotorwicklungsanordnung nach Anspruch 1 oder 2, dadurch gekennzeichnet, daß die Rotorlatten untereinander aufgezogen, die unter den Wicklungen angeordnet sind, um eine Kühlgasströmung zu den radialen Ventilationskanälen zu bilden.


5. Rotorwicklungsanordnung nach einem der Ansprüche 1 bis 4, dadurch gekennzeichnet, daß die Isolation zwischen jedem benachbarten Lüfterstreifen aus harzgefülltem Glasgewebematerial aufweist.

6. Rotorwicklungsanordnung nach einem der Ansprüche 1 bis 5, dadurch gekennzeichnet, daß mehrere getrennte Abstandshalterelemente (61) in der axialen Richtung der Nuten voneinander getrennt sind.

7. Rotorwicklungsanordnung nach Anspruch 6, dadurch gekennzeichnet, daß die Wicklungen und die Abstandshalterelemente mehrere radial gerichtete Ventilationskanäle (63) in jeder Nut bilden.

8. Rotorwicklungsanordnung nach einem der Ansprüche 1 bis 7, dadurch gekennzeichnet, daß die Wicklungen aus kontinuierlichen Leiterlängen gebildet sind, die gebogen sind zur Bildung von Wickelköpfen, die die Wicklungsleiter von einer der Nuten mit den Wicklungsleitern von einer anderen Nut verbinden.


**Reivendications**

1. Ensemble d'enroulement rotatoire à utiliser dans une machine dynamo-électrique qui comprend un rotor avec des encoches s'étendant axialement et destinées à recevoir des enroulements conduc-

teurs (40A, 40B, 50A, 50B, 62A, 62B), lesdites encoches contenant des caniveaux d'encoche isolants (43, 64A, 64B) le long des parois latérales dirigées axialement desdites encoches, ledit ensemble d'enroulement rotatoire comprenant :

- un premier enroulement (40A, 50A, 62A) dans chacune desdites encoches de rotor, ledit enroulement comprenant un empiètement de conducteurs avec une isolation (42) entre tous les conducteurs adjacents, ledit premier enroulement étant placé pour être adjacent audit caniveau isolant se trouvant sur une première paroi latérale desdites encoches,

- un deuxième enroulement (40B, 50B, 62B) dans chacune desdites encoches de rotor, ledit enroulement comprenant un empiètement de conducteurs avec une isolation (42) entre tous les conducteurs adjacents, ledit deuxième enroulement étant placé pour être adjacent audit caniveau isolant se trouvant sur une deuxième paroi latérale desdites encoches,

- une pluralité de séparateurs isolants (44, 53, 61) entre lesdits premier et deuxième enroulements se trouvant dans chacune desdites encoches, lesdits séparateurs étant répartis axialement le long de chaque encoche de telle sorte que lesdits séparateurs et lesdits premier et deuxième enroulements forment des passages radiaux de ventilation (63), caractérisé en ce que lesdits séparateurs s'étendent sur toute la hauteur radiale desdits enroulements, ledit caniveau d'encoche se trouvant dans chacune desdites encoches comprenant deux pièces rectilignes monoblocs.

2. Ensemble d'enroulement rotatoire selon la revendication 1, caractérisé en ce que lesdites encoches de rotor, ledit caniveau d'encoche, lesdits enroulements et lesdits séparateurs sont dimensionnés pour qu'il n'existe aucun espace libre entre lesdits parois latérales des encoches et ledit caniveau ni entre les enroulements et ledit caniveau.

3. Ensemble d'enroulement rotatoire selon la revendication 1 ou 2, caractérisé en ce que lesdites encoches de rotor comprennent des sous-encoches placées en-dessous desdits enroulements pour permettre l'écoulement d'un gaz de refroidissement vers lesdits passages radiaux de ventilation.

4. Ensemble d'enroulement rotatoire selon la revendication 3, caractérisé en ce que des moyens (41) sont prévus dans chaque sous-encoche pour soutenir lesdits enroulements dans les encoches.

5. Ensemble d'enroulement rotatoire selon l'une quel-
conque des revendications 1 à 4, caractérisé en ce
que ladite isolation située entre conducteurs adja-
cents comprend des bandes de matériau en verre
tissé imprégné de résine.

6. Ensemble d'enroulement rotorisque selon l'une quel-
conque des revendications 1 à 5, caractérisé en ce
que plusieurs éléments de séparation distincts (61)
sont séparés les uns des autres dans la direction
axiale desdites encoches.

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7. Ensemble d'enroulement rotorisque selon la reven-
dication 6, caractérisé en ce que lesdits enroule-
ments et lesdits éléments de séparation forment
une pluralité de passages de ventilation (63) dirigés
radialement dans chacune desdites encoches.

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8. Ensemble d'enroulement rotorisque selon l'une quel-
conque des revendications 1 à 7, caractérisé en ce
que lesdits enroulements sont formés de tronçons
continus de conducteurs qui sont pliés pour former
des enroulements d'extrémité reliant les conduc-
teurs des enroulements de l'une desdites encoches
aux conducteurs des enroulements d'une autre
desdites encoches.

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9. Machine dynamo-électrique comportant un ensem-
ble de rotor selon l'une quelconque des revendica-
tions 1 à 8.