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[54] **TRANSPOSED AIR CORE HOMOPOLAR GENERATOR CONDUCTORS**

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[73] Assignee: **The United States of America as represented by the Secretary of the Army**, Washington, D.C.

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[51] **Int. Cl.**[5] **H02K 31/00**

[52] **U.S. Cl.** **310/178**; 310/254; 310/261

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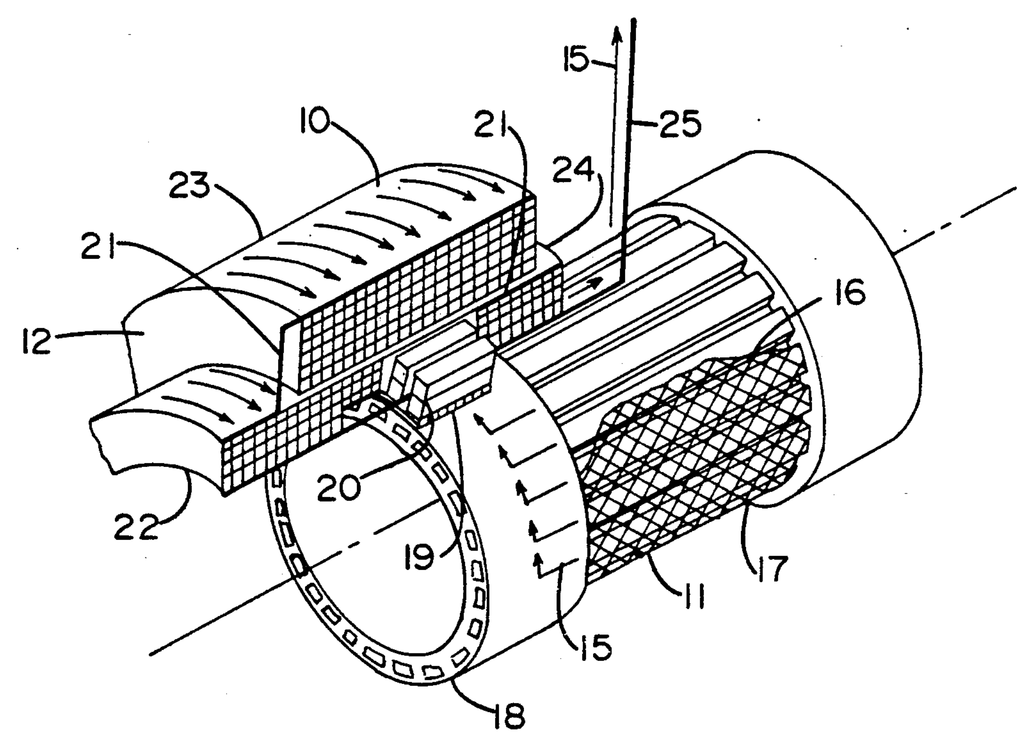
Attorney, Agent, or Firm—Anthony T. Lane; Edward Goldberg; Michael C. Sachs

[57] **ABSTRACT**

Current state of the art air core homopolar generators employ large time varying magnetic fields (4 Tesla Range). These high fields are required for proper voltage, but also induce significant eddy currents. Use of novel transposed rotor conductors and a novel transposed coil winding reduces these currents to acceptable levels. Furthermore use of a segmented stator current collection system further reduces the flow of eddy currents.

7 Claims, 5 Drawing Sheets



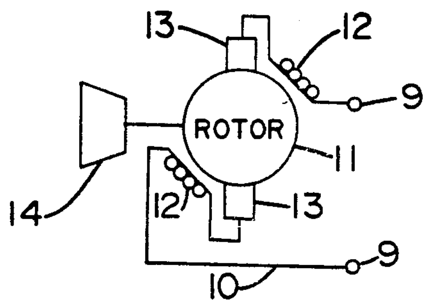
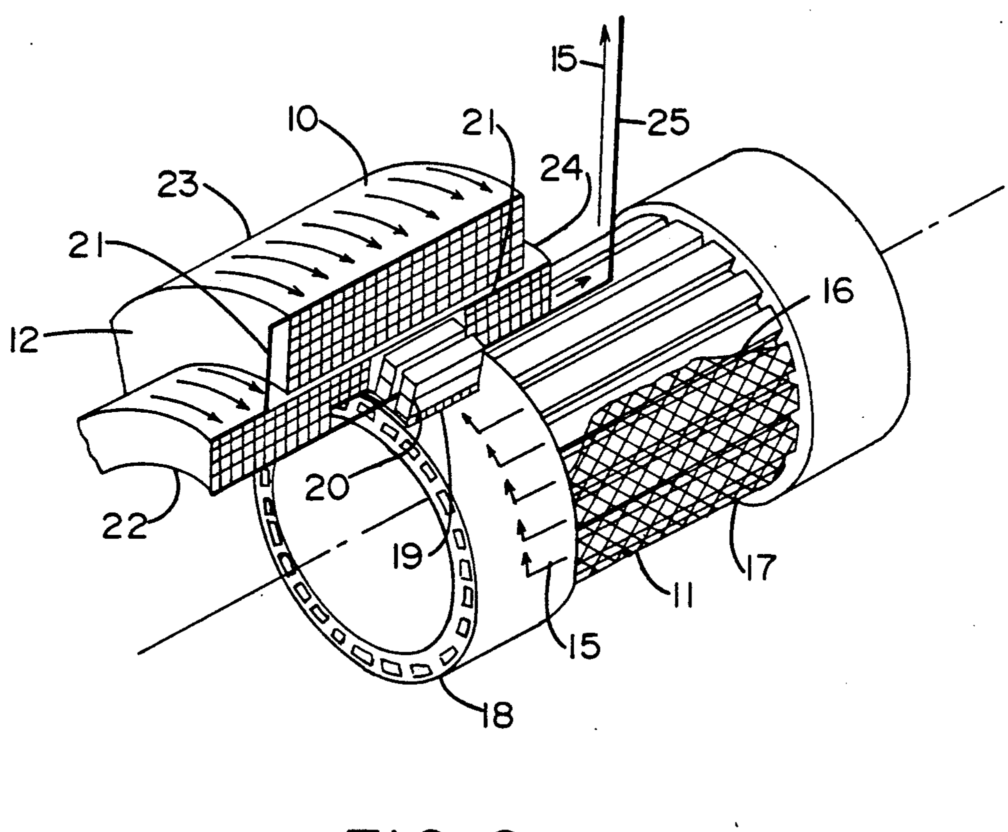

13
12
9
ROTOR
11
14
12
13
9
10

FIG. 1


15
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10
21
24
23
21
16
12
20
22
19
17
11
15
18

FIG. 2

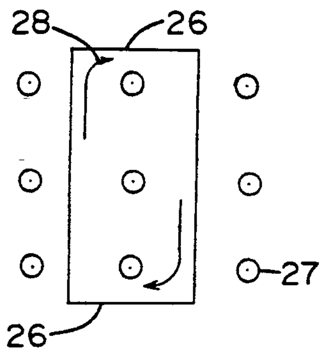

FIG. 3A

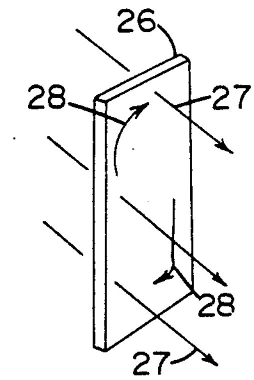

FIG. 3B

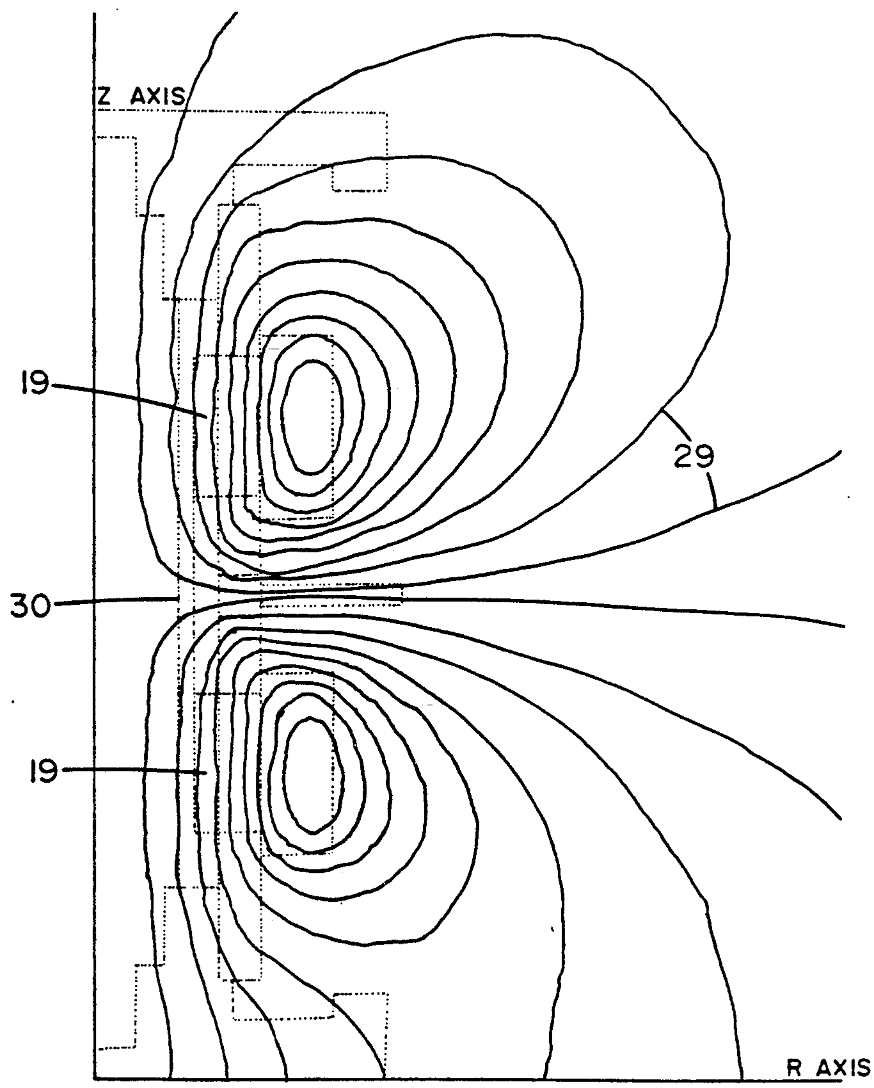

FIG. 4

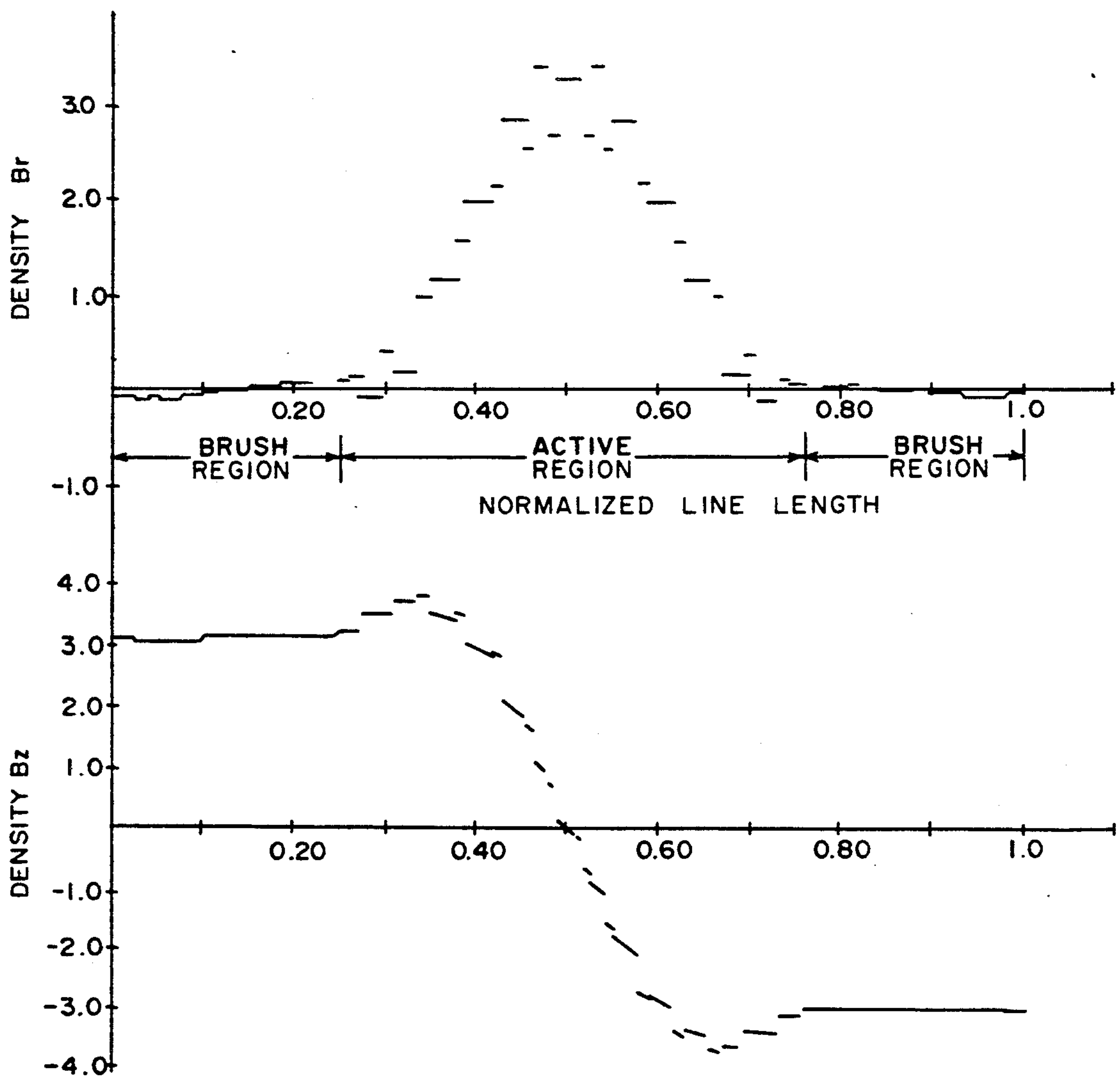
DENSITY Br
3.0
2.0
1.0
-1.0
0.20
0.40
0.60
0.80
1.0
BRUSH REGION
ACTIVE REGION
BRUSH REGION
NORMALIZED LINE LENGTH
DENSITY Bz
4.0
3.0
2.0
1.0
-1.0
-2.0
-3.0
-4.0
0.20
0.40
0.60
0.80
1.0

FIG. 5

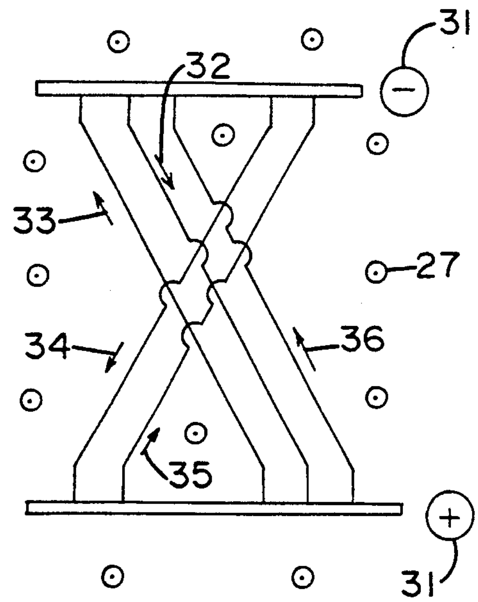

FIG. 6

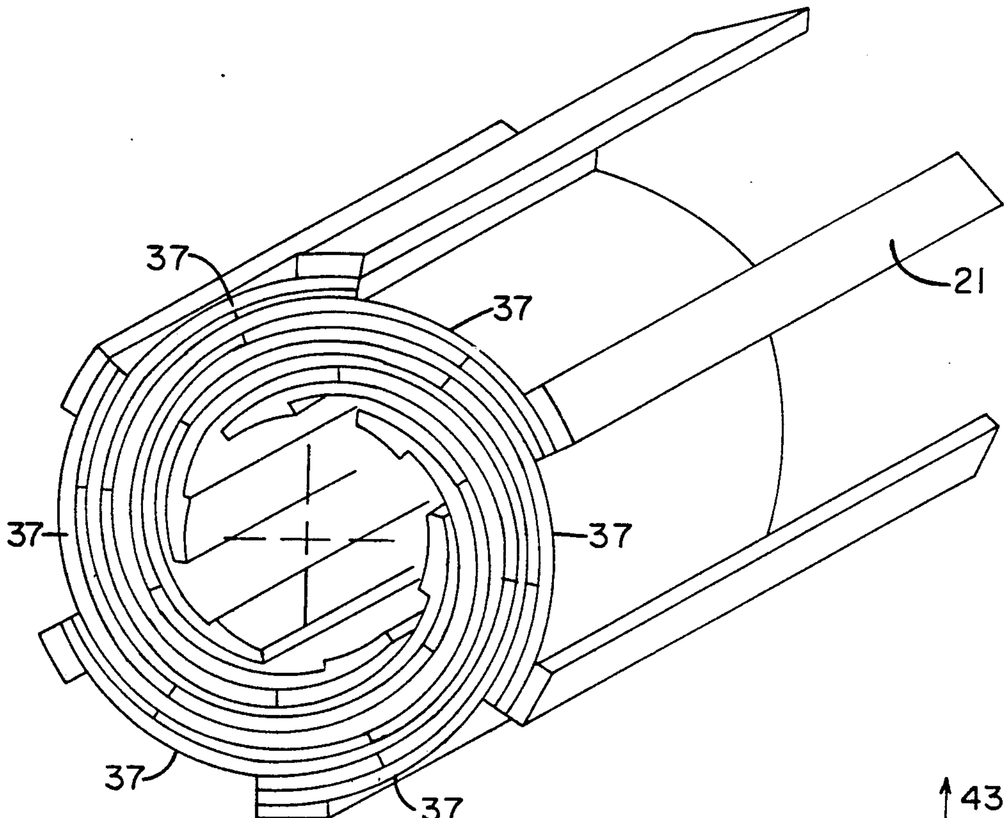

FIG. 7

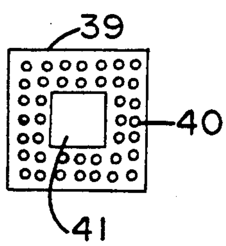

FIG. 9

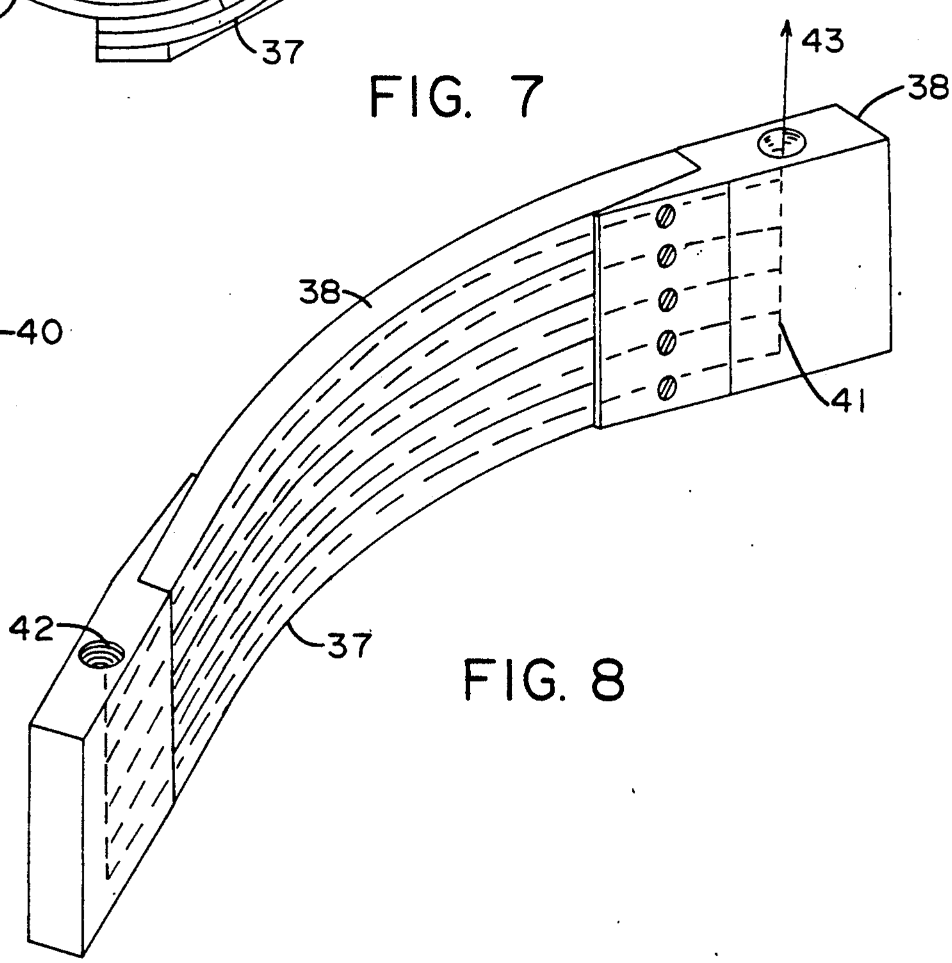

FIG. 8

TRANSPOSED AIR CORE HOMOPOLAR GENERATOR CONDUCTORS

GOVERNMENT INTEREST

The Government has rights in this invention pursuant to Contract No. DAAK-21-85-C-0214.

FIELD OF THE INVENTION

The present invention relates to an air core homopolar generator design (as opposed to "iron core") based on a series wound configuration which can provide viable sources of the electric power required for Electromagnetic (EM) launchers in the mobile tactical environment. The series wound air core configuration has proven favorable due to the tunable nature of the series wound air core firing circuit.

With such a generator, the load current is in series with the field windings, reference FIG. 1. That is the load current, which is the excitation current, varies as an exponential function of time and induces the generator magnetic flux. Due to the pulsed nature of the machine, this current varies with time. Consequently the generator magnetic field (4 Tesla range) varies with time. These high fields are required for proper voltage; but unfortunately eddy currents will also be induced by this changing field. The present invention provides a means of partial control of these eddy currents. A spiral coil geometry is used to develop the proper field magnitudes and profiles as well as provide for eddy current control.

DESCRIPTION OF THE PRESENT ART

Previous disclosures have discussed peripheral eddy current control; in other words eddy currents flowing circumferentially in the stator and rotor conductors. This disclosure, however, addresses global eddy currents. The present invention as hereinafter described completely addresses the global eddy currents in series wound air core homopolar generators.

The invention attempts to reduce the penalty imposed by the very nature of the series wound, self-excitation which creates a time varying magnetic field of large proportions. This time varying magnetic field causes eddy currents to flow in all conducting materials which are subject to it. Without the means, described herein, the magnetic field would be uncontrolled and would make the concept unworkable.

Anytime an electrically conducting material is subject to a time varying magnetic field, eddy currents will flow in that conductor in a direction to reduce the changing applied field, reference FIGS. 3A and 3B. These currents fall into two classes. The first class is called local eddy currents and the second class global eddy currents. Local eddy currents are those which flow in small loops. Examples of these are heating bolts and extra losses in conductors, etc., Their control is understood.

The second class, global eddy currents, are more of a problem. These are systems of eddy currents that have a high coupling with the excitation system and significant self-inductance. Thus, the excitation field is modeled as a closed resistive/inductive loop coupled to the main current system by mutual inductance. This is exactly as a shorted secondary on a transformer.

SUMMARY OF THE INVENTION

The purpose of this invention is to disclose means which can reduce the substantial eddy currents which are induced by the series wound air core homopolar generator. These currents are reduced with a segmented current collection system. The system is comprised of spiral coils with transposed conductors and a segmented rotor conductor with composite fiber reinforcement. The segmenting of the system prevents peripheral eddy currents from flowing. The use of transposed spiral conductors also reduces these eddy currents, reference FIG. 6. The invention allows independent current paths to be maintained. Closed conducting loops which trap substantial amounts of flux are avoided.

Small diameter coil conductors geometrically transposed produce opposing eddy voltages, eliminating or reducing eddy currents, FIG. 8. In this case an internally cooled design geometry is used. In as much as the structural strength of each coil spiral with transposed conductors is low, the spirals are nested in groups of eighteen and potted inplace; then the entire coil is wrapped with glass and kevlar composite, FIG. 7. Structural integrity is thus maintained by a high spiral packing and the outer composite layers.

It is therefore an object of the present invention to provide for the use of transposed rotor conductors, STET to reduce eddy currents to acceptable levels.

It is also an object of the present invention to provide transposed spiral coil windings to reduce eddy currents to manageable levels.

These and other objects of the invention will become apparent upon consideration of the detailed description of the preferred embodiment.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a simplified circuit diagram for a series wound, air core generator.

FIG. 2 shows a schematic of current flow path for one segment out of eighteen through the stator and rotor system of a series wound air core homopolar machine.

FIGS. 3A and 3B show a front view and a view at an angle respectively of radial eddy currents induced by a time dependent magnetic field current in a coil spiral cross section or rotor conductor bar section.

FIG. 4 shows the typical flux contours for a series wound air core homopolar generator.

FIG. 5 shows the axial and radial components of magnetic flux density along a line extending from the top to bottom brush box current collectors at the rotor surface.

FIG. 6 is a schematic of transposed conductors and their related eddy current flow induced by a time dependent magnetic field.

FIG. 7 shows a series wound air core spiral coil configuration with multiple transposed spiral conductors.

FIG. 8 is a schematic showing coil spiral.

FIG. 9 shows a cross section of the spiral conductor.

DETAILED DÈSCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 depicts the series wound air core generator 10 with its rotor 11, stator coils 12, and load brushes 13, shown being driven by a turbine 14. The voltage output is between the terminals 9.

FIG. 2 depicts the rotor **11** with rotor conductors **17** of the series wound machine **10**. FIG. 2 further depicts the stator **12** current system with its eighteen independent paths, one **15** of which is illustrated by the pointed arrows. This arrangement provides for the uniform distribution of current throughout the machine **10**, a highly conductive path for the load current, a smooth transition between the rotor **11** and the stator **12**, and only partial flux traps in the excitation winding.

FIG. 3 depicts two views of a solid conductor analogy wherein a field coil spiral section **38** or rotor conductor bar **17** cross section **26** is shown in which the time dependent magnetic field radial components **27** coming out of the paper are shown to induce local eddy currents **28**.

FIG. 4 shows the flux contours **29** for the machine geometry of FIG. 2 with initial optimization of the coil excitation levels. In the flux plots shown, only one machine **10** is illustrated, but two machines **10** and their interaction have been considered by the inclusion of an appropriate boundary condition. In interpreting the flux plot of FIG. 4, the machine rotational axis of FIG. 2 is represented by the Z-axis and the line of symmetry between the two machines **10** by the R-axis. In FIG. 4 the term lower brush **19** is used to identify the brush set **19** closest to the R-axis. For this reason adjustments were made to the excitation levels in the coils of the stator **22, 23, 24** to create a symmetrical magnetic field in the active region **30** of the machine, between the bottom brush **19** and the top brush **19**. In other words, each machine **10**, with its rotor **11** although symmetrical with respect to its centerline, requires different current levels in the field coils of the top and bottom brushes **19** to achieve similar radial field profiles in the brush **19** area and machine active region **30**.

By FIG. 4, it is clear that substantial radial flux exists in the windings of the rotor **11**. Current in the coil spirals is essentially perpendicular to their radial flux. This geometry combined with a time varying current will produce eddy currents within each coil spiral and in the rotor conductors **17**.

FIG. 5 shows the radial (Br) and axial(Bz) components of magnetic flux density along a line extending from the top to bottom brush box **20** at the rotor surface **11**. The magnitudes correspond to the initial coil excitations used for the machine flux map at FIG. 4. The excitation levels were subsequently increased to yield a peak machine field of 4.5 Tesla in the active region **30**. This higher field was required because of voltage needs of 320 volts per rotor **11**. One can observe this large field in the active region **30** and in the brush box **20** at the surface of the rotor **11**.

FIG. 6. depicts the path of flow of eddy currents under a varying magnetic field which is possible by a transposed conductor design. Between the two terminals **31** a number of eddy currents **32, 33, 34, 35, 36** flow. Eddy current **33** cancels eddy current **36** for no net eddy current. This process is repeated between eddy currents **33** and **34**. For this process to work, the number of transposed conducting strands must be kept odd.

Once again referring to the drawings, FIG. 2 depicts primarily the rotor **11** of a series wound air core machine **10** with the stator **12** with one of the **18** independent current paths which comprise the stator current system. Current **15** flows axially through the rotor bars **17** and into the slip ring **18**. At the slip ring **18**, the, current **15** flows axially and radially into a set of brushes **19**. Once in the brush box **20**, the current **15** flows axially through a jumper **21** to the inner radius of the outermost coil **22**. The current **15** then spirals outward to another jumper **21** where it is taken to the outer radius of the center coil **23**. The current **15** spirals radially inward to the outer radius of the most inboard coil, through a jumper **21**, and into the last coil in the subgroup **24**. From the inner radius of this coil **24**, the current **15** flows to a jumper **21** and then to one of the main lead segments where the current **15** flows out of the machine **10**. Only half the current flow has been illustrated. Current enters the machine in a symmetric pattern to that just described. The stator coil arrangement is made by indexing this flow pattern eighteen times about the periphery of the machine. These eighteen independent paths are joined electrically outside the machine prior to feeding the load.

FIG. 7 shows the stator coil arrangement when nested together, except that there are eighteen independent paths **37** rather than the six illustrated. The spiral arrangement ensures that each parallel path **37** is identical to each other and provides for uniform distribution of current throughout the electrical system.

Each coil of the individual conductors **37** lies on an Archimedian spiral and traverses an arc equal to the fraction of turn required to generate machine magnetic flux. For the eighteen spiral segments **37** proposed for the machine **10**, the field varies from plus to minus four percent about a mean value with the mean value being within 0.3 percent of that calculated for a circular current sheet. The spiral winding **37** is equivalent to a circular current sheet from the standpoint of excitation requirements.

In this design both the magnetomotive force and the current are dictated by generator design constraints; consequently the number of turns is specified completely for each coil **37**. This means less than one turn per coil **37**. The usual multi-turn design approach would lead to a seriously distorted solenoidal field if only a fraction of a turn were used to make the coil **37**. Ampere-turn per coil ranges were between 405,000 and 1,500,000 while the revised design maximum is 2,250,000 ampere turns. To overcome this difficulty, each of the eighteen brush boxes **20** was connected separately to each spiral coil partial turn. Each spiral **37** was then azimuthally indexed by one-eighteenth of a circle. This approach permits a reasonable averaging of the fields produced by individual overlapping partial turns and results in an acceptable field uniformity, and achieves the fractional turn required to meet the electromagnetic design constraints.

FIG. 8 depicts the details for one spiral section **37**. The wrapping of the eighteen such spiral sections **37** with their transposed conductors **40** with glass and kevlar composite **16** is shown at FIG. 2 in order to provide the requisite strength. In FIG. 8 the construction option selected comprises plates **38** made up of many parallel square transposed aluminum conductors **40**. FIG. 9 depicts a cross section **39** of the transposed aluminum conductors **40**. These conductors **40** are cooled where necessary by circulating water through an internal coolant passage **41** in each conductor as shown in FIGS. 8,9. The coolant entry **42** and exit **43** are shown at FIG. 8. While the present invention has been shown in but one major variation and a number of various means, it is obvious to those skilled in that it is not so limited, but is susceptible to various changes and modifications to be embodied in other specific forms without departing from the scope and spirit or essential attributes thereof.

Accordingly, it is intended that the present invention embrace all alternatives, modifications variations as fall within the spirit and broad scope of the appended claims.

What is claimed is:

1. A rotor/stator apparatus for a series wound air core homopolar generator with high magnetic fields which controls and reduces eddy currents comprising:

means for segmented stator current collection to prevent eddy currents from flowing;

means for segmented rotor conductors to prevent eddy currents from flowing.

2. A rotor/stator apparatus as set forth in claim 1 wherein said means for segmented stator current collection includes:

multiple independent current paths;

means for joining the multiple independent paths outside the apparatus to feed the desired load.

3. A rotor/stator apparatus as set forth in claim 1 wherein said means for segmented stator conductors includes:

an Archimedian coil arrangement of multiple spirals to reduce eddy currents which traverse an arc equal to a fraction of a required turn, which arrangement insures that each spiral comprises a respective parallel path each identical to one another and provides for uniform distribution of current to the stator;

means for wrapping of said stator conductors to provide added physical strength for the coil arrangement.

4. A rotor/stator apparatus as set forth in claim 3 wherein said coil arrangement further comprises:

plates which contain parallel transposed conductors to reduce eddy current; and

means for providing internal passages for water cooling.

5. A rotor/stator apparatus as set forth in claim 4 wherein the said transposed conductors in the plates are aluminum with square cross sections.

6. A rotor/stator apparatus as set forth in claim 3 wherein the said means for wrapping the said stator conductors to provide added physical strength comprises a composite material of glass and Kevlar®.

7. A series wound air core homopolar generator system comprising a segmented stator current collection system which is fed by current from multiple parallel rotor conductors to prevent eddy currents from flowing and comprised of spiral transposed aluminum conductors to reduce eddy currents.

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