(12) UK Patent Application (19) GB (11) 2570927 (13) A

(43) Date of A Publication 14.08.2019

(21) Application No: 1802254.1

(22) Date of Filing: 12.02.2018

(71) Applicant(s):
Electronica Products Limited
(Incorporated in the United Kingdom)
Suffolk House, Trade Street, CARDIFF, CF10 5DT, United Kingdom

(72) Inventor(s):
Nabeel Ahmed Shirazee

(74) Agent and/or Address for Service:
Murgitroyd & Company
Scotland House, 165-169 Scotland Street, GLASGOW, G5 8PL, United Kingdom

(51) INT CL:
H02K 3/26 (2006.01) ***H02K 1/12*** (2006.01)
H02K 15/02 (2006.01) ***H02K 15/04*** (2006.01)
H02K 15/06 (2006.01)

(56) Documents Cited:
CN 107170564 A **DE 102013214128 A1**
US 4707313 A **US 20170063183 A1**
JP H05283259

(58) Field of Search:
INT CL **H02K**
Other: **WPI, EPODOC, Patent Fulltext**

(54) Title of the Invention: **Electromagnetic devices**
Abstract Title: **A method of forming an electromagnetic device comprising depositing successive conductor layers**

(57) A method of forming an electromagnetic device, the method comprising depositing successive conductor layers 24, each deposited layer comprising a plurality of conductive regions of said conductive material which are electrically isolated from each other and which form portions of respective conductors 12 of the device, each conductive region of each successive layer at least partially overlying the conductive region of the respective conductor in an adjacent layer and being in electrical and mechanical contact therewith to form a plurality of elongate conductors which are electrically isolated from each other. The conductive regions of the layer maybe deposited to have equal cross-sectional areas to at least some of the other regions in that layer, and some conductor ends maybe interconnected to the ends of other conductors by interconnections to form turns of the device. The may also be formed depositing successive interconnection layers and maybe isolated from each other. Each conductor layer maybe deposited to provide at least one space in which no material is deposited, each space of each successive conductor layer overlying the respective space in the adjacent layer to form an elongate void which co-extends with the conductors. Former materials such as magnetic and insulating materials maybe used to form a laminated structure. Layers maybe deposited by 3D printing methods or vapour deposition.

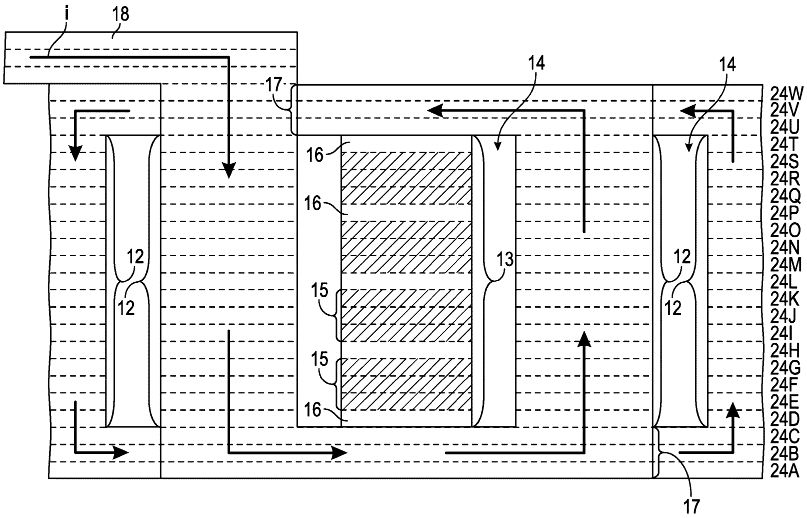

FIG. 2

GB 2570927 A

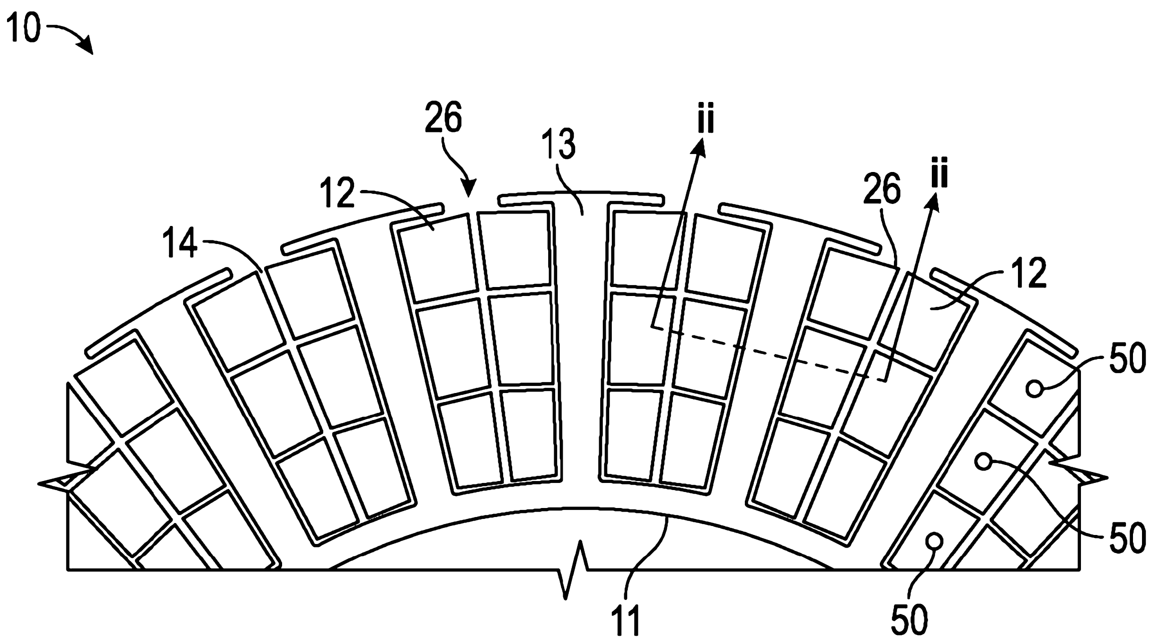

FIG. 1

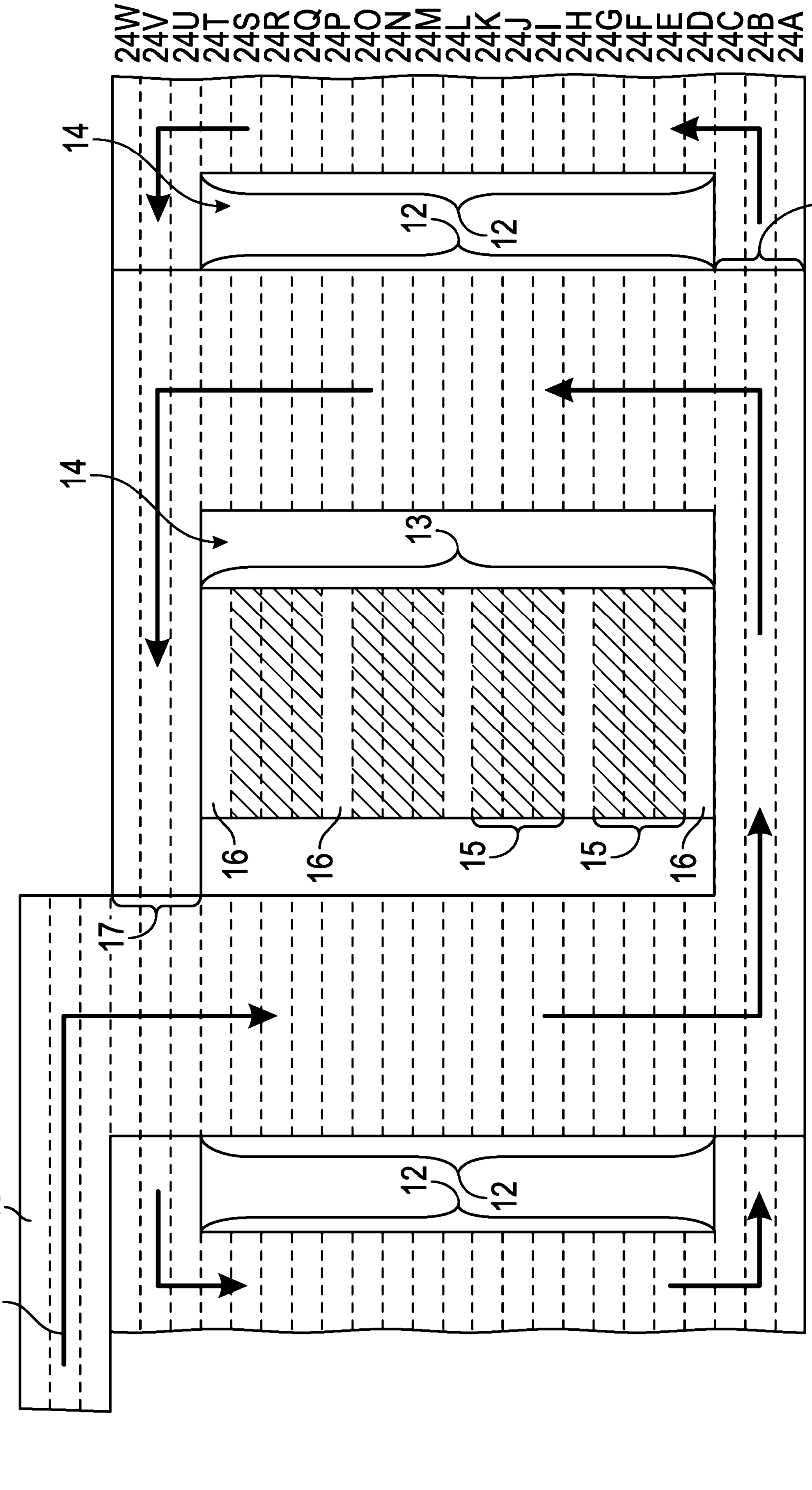
24W
24V
24U
24T
24S
24R
24Q
24P
24O
24N
24M
24L
24K
24J
24I
24H
24G
24F
24E
24D
24C
24B
24A
14
12
12
17
14
13
16
16
15
15
16
17
12
12
18
i

FIG. 2

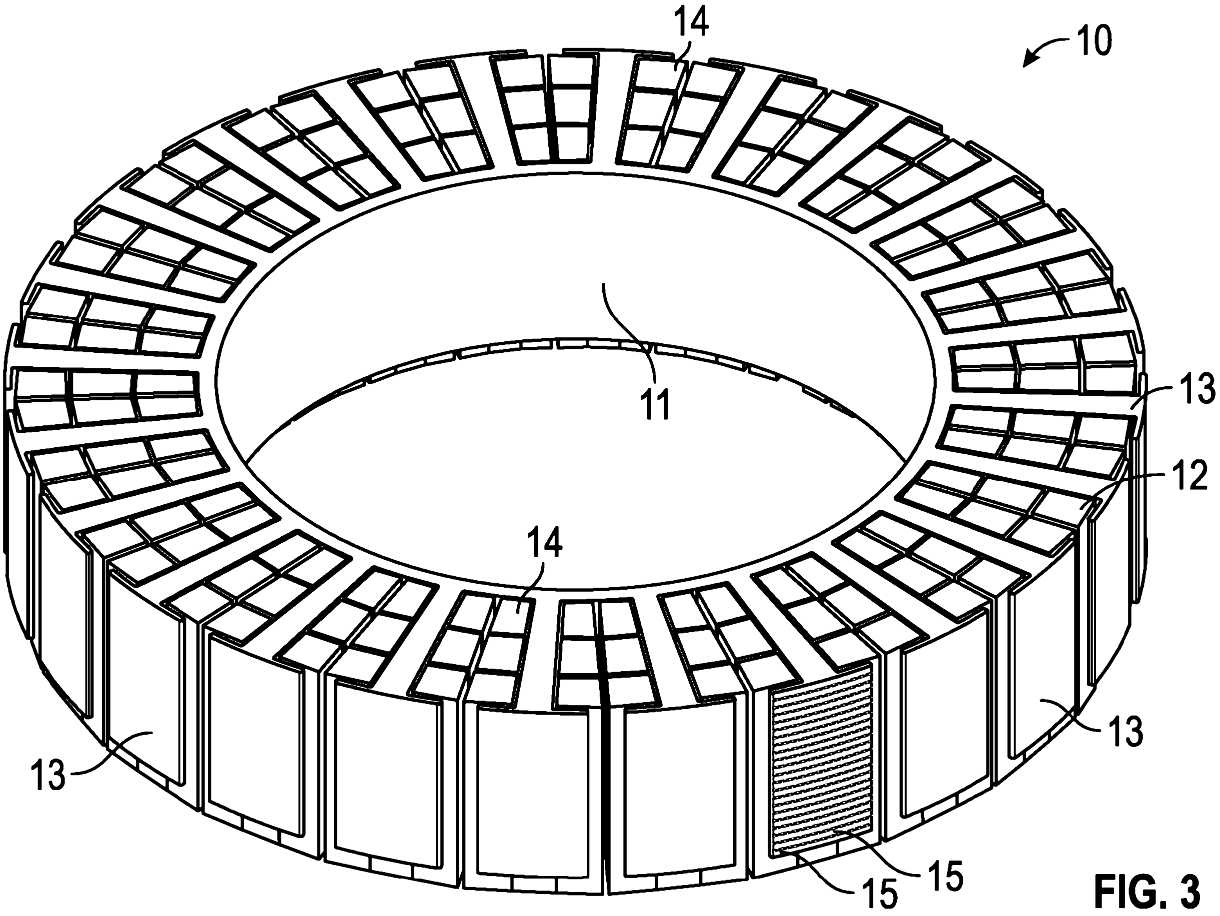

FIG. 3

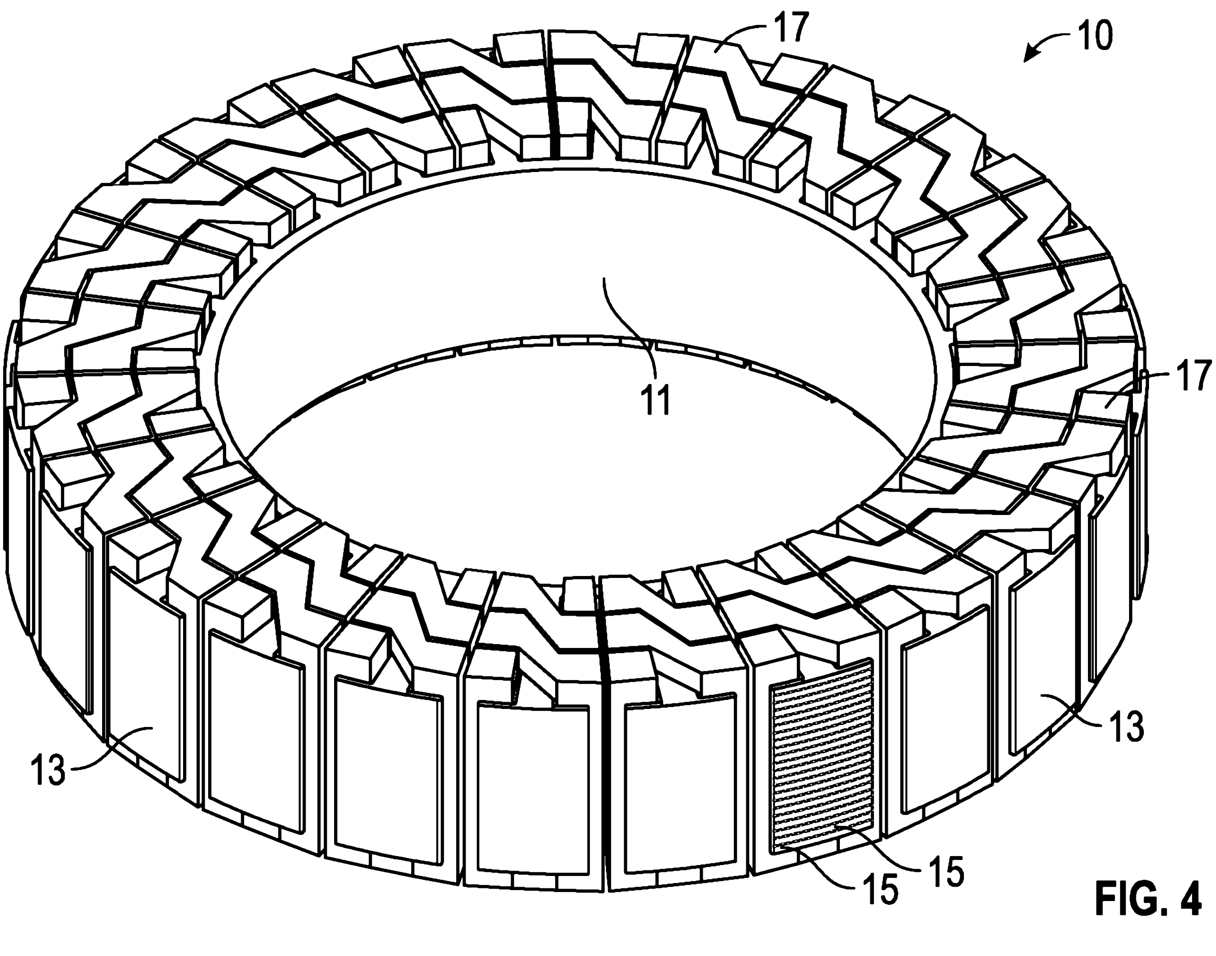

FIG. 4

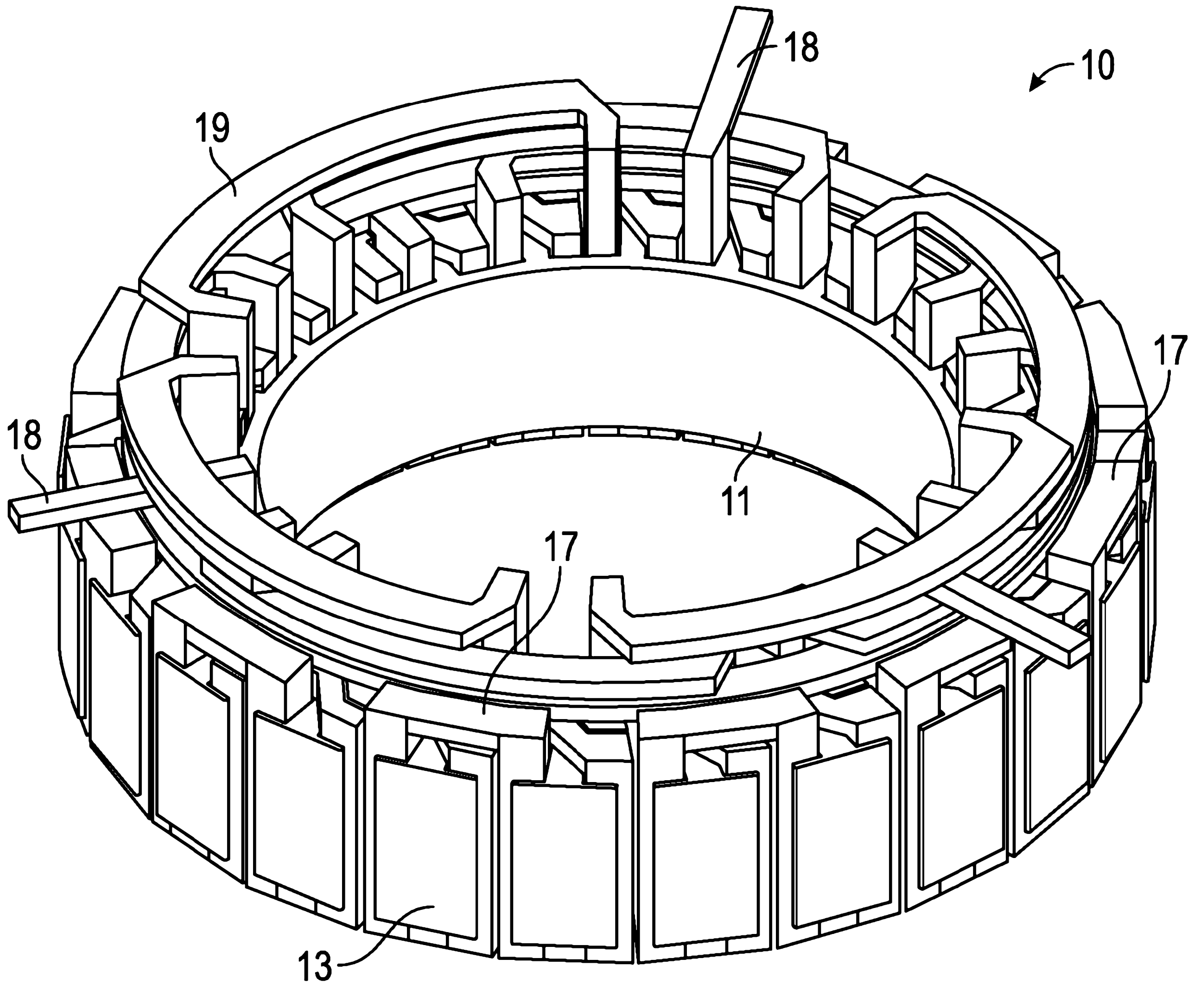

FIG. 5

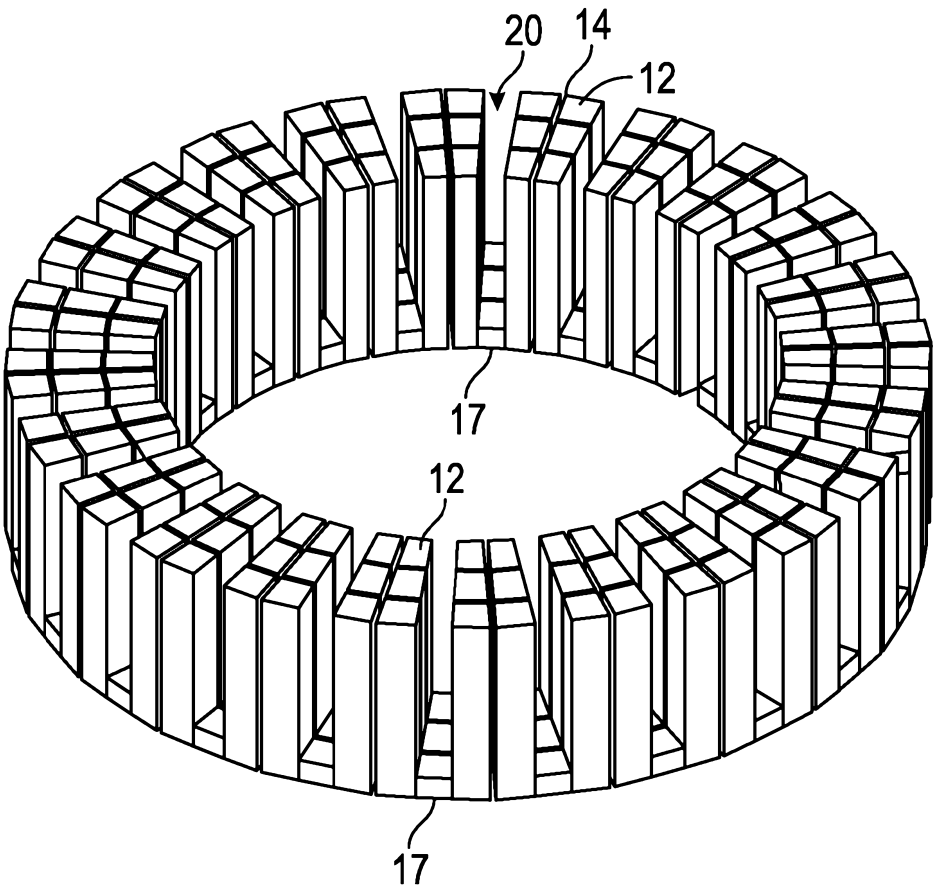

FIG. 6

The following terms are registered trade marks and should be read as such wherever they occur in this document:

Kevlar

Electromagnetic Devices

This invention relates to electromagnetic devices and more particularly, but not solely, to electrical machines such as motors and generators.

Billions of electromagnetic devices, such as solenoids, transformers, coils, inductors, chokes, motors and generators are manufactured each year. The majority of such devices have electrical windings in the form of insulated conductors, which are wound around rotor laminations, stator laminations, cores, yokes or other formers. In many such devices, the conductors are wound in voids or so-called slots. The fill factor of an electromagnetic device is defined as the ratio of the combined cross-sectional area of all conductors (excluding any insulation) in a void to the cross-sectional area of the void.

Ideally, the insulated conductors should completely fill the available void area, but a high fill factor is never achieved due to mismatches between the cross-sectional shape of the insulated conductor and/or the cross-sectional shape of the void. Accordingly, most electromagnetic devices have a poor fill factor and comprise airgaps that extend between the insulated conductors and adjacent insulated conductors and/or the side walls of the slot. In some electromagnetic devices, windings are used without formers, yokeless, but such devices still suffer the same or similar issues when wound.

Electromagnetic devices with a high fill factor are difficult and costly to produce because the windings have to be densely packed, which is time consuming. Machines are known for inserting windings into voids. However, this process produces longer end windings with increased winding resistance and requires additional space. Typically, the void fill factor is around 40 to 50% and, in some high fill factor cases, it is around 60% to 70%. Once such high fill factor winding is the so-called Hairpin winding used in motors and generators, in which the windings resemble individual hairpins and are typically made from rectangular wires, which are pushed into the lamination slots from one end. The hairpin ends are soldered to complete the winding. This method is complex and has many joints. If the joints are subjected to continuous high vibration it could lead to reliability issues.

With the foregoing problem in mind, we have now devised a method of forming an electromagnetic device.

In accordance with the present invention, as seen from a first aspect, there is provided a method of forming an electromagnetic device, the method comprising depositing successive layers, each deposited layer comprising a plurality of conductive regions of said conductive material which are electrically isolated from each other and which form portions of respective conductors of the device, each conductive region of each successive layer at least partially overlying the conductive region of the respective conductor in the adjacent layer and being in electrical and mechanical contact therewith to form a plurality of elongate conductors which are electrically isolated from each other.

The method of the present invention enables the shape of each conductive region to be configured, so that it lies as close as possible to adjacent conductive regions. The method of the present invention also enables the shape of conductive regions to be configured, so as to fit as closely as possible within slots or other voids in a former the device. In this manner airgaps are minimised and the density of conductors in the available space is maximised.

The regions of a layer may be deposited to have equal cross-sectional areas to at least some of the other regions in that layer.

The ends of some conductors may be interconnected to the ends of other conductors by interconnections to form turns of the electromagnetic device which are analogous to the windings of a traditional wound electromagnetic device. The interconnections may be formed by depositing successive layers, each layer comprising a plurality of regions of said conductive material which are electrically isolated from each other and which form portions of respective interconnections of the device, each region of each successive layer overlying the region of the respective interconnection in the adjacent layer and being in electrical and mechanical contact therewith to form a plurality of interconnections which are electrically isolated from each other and electrically connected to an end of at least one elongate conductor.

The ends of some conductors may be connected to wires, terminals or other connections which convey current to and/or from the conductors. The connections may be formed by depositing successive layers, each layer comprising a plurality of regions of said conductive material which are electrically isolated from each other and which form portions of respective connections of the device, each region of each successive layer overlying the region of the respective connection in the adjacent layer and being in electrical and mechanical contact therewith to form a plurality of connections which are electrically isolated from each other and electrically connected to an end of at least one elongate conductor.

Each layer may be deposited to provide at least one space within which no material is deposited, each space of each successive layer overlying the respective space in the adjacent layer to form an elongate void which co-extends with the conductors. The void may act as a cooling channel or may serve to insulate adjacent conductors.

A former may be inserted into the or each void. The former may comprise a plurality of portions which extend into respective voids. The connections and/or interconnections may be formed after the former has been inserted.

The method may comprise depositing said successive layers, each layer comprising said plurality of conductive regions and at least one region of a former material which is electrically isolated from the conductive regions, each region of former material of each successive layer overlying the respective region of former material in the adjacent layer and being in mechanical contact therewith to form an elongate former which is electrically isolated from the conductors and which co-extends with the conductors. In this manner the conductors and the former are simultaneously formed by deposition.

The former may be laminated and formed by successively depositing layers of a first former material and layers of a second former material to form a laminated structure. The first former material may be a ferromagnetic material and the second material may be an insulative material.

The former material may be treated, for example by a magnetic field and/or by laser scribing, to align or refine the magnetic domains and or the grains in a preferred magnetic circuit direction. This process reduces core losses and greatly increases the efficiency of the device.

The method may comprise depositing a plurality of soft magnetic materials with varying magnetic properties in respective regions of the former. For example, in an electrical machine, the tips of teeth of the former can be formed using an expensive material having a high saturation flux density, a body of the teeth can be formed with another mixed material and the rest of the former with inexpensive material, thereby forming a hybrid former.

The method may comprise depositing said successive layers, each layer comprising said plurality of conductive regions, each conductive region being surrounded by an insulative region of insulative material which electrically isolates each conductive region from adjacent regions in the layer, each insulative region of each successive layer overlying the respective insulative region in the adjacent layer to form an insulative surround around each conductor.

The layers may be deposited by 3-dimensional printing and/or by vapour deposition. Effectively, a multi head machine can "print" the complete electromagnetic device machine including all of the plastic, metallic and magnetic components. Some parts can me formed using carbon fibre or Kevlar filaments for added strength.

Different conductive materials may be deposited. The current density may be varied by selectively depositing stanene, silver, copper or gold, and the weight may be varied by selectively depositing copper and/or aluminium.

The method may comprise depositing said successive layers, each layer comprising said plurality of conductive regions and at least one wall region of a material which surrounds a space, each walled region of each successive layer overlying the respective walled region in the adjacent layer to form a duct. In use, a coolant fluid can be passed along the duct. The walled region may act as former.

The method may be a method of forming an electrical machine having and axis of rotation, the layers being successively deposited in the direction of the axis of rotation of the machine.

The above method allows the windings of the kind disclosed in WO2005043740 to be deposited to provide a plurality of winding configurations for electrical motors and generators.

An advantage of the invention is that the phase winding resistance will be the same in each phase. This is not always the case in a traditionally-wound electric machines leading to phase imbalances and unwanted circulating currents.

In accordance with the present invention, as seen from a second aspect, there is provided a method of forming an electromagnetic device, the method comprising depositing successive layers, each deposited layer comprising at least one region of a former material, each region of former material of each successive layer overlying the respective region of former material in the adjacent layer and being in mechanical contact therewith to form a former of the device, a coil then being disposed around the former.

The former may be formed by depositing layers of a first former material and layers of a second former material to form a laminated structure. The first former material may be a ferromagnetic material and the second material may be an insulative material.

The former material may be treated, for example by a magnetic field and/or by laser scribing, to align or refine the magnetic domains and or the grains in a preferred magnetic circuit direction. This process reduces core losses and greatly increases the efficiency of the device.

The method may comprise depositing a plurality of soft magnetic materials with varying magnetic properties in respective regions of the former. For example, in an electrical machine, the tips of teeth of the former can be formed using an expensive material having a high saturation flux density, a body of the teeth can be formed with another mixed material and the rest of the former with inexpensive material, thereby forming a hybrid former.

Embodiments of the present invention will now be described by way of examples only and with reference to the accompanying drawings, in which:

Figure 1 is a cross-sectional view through a stator of a motor formed in accordance with the present invention;

Figure 2 is a sectional view along the line ii - ii of Figure 1;

Figure 3 is a perspective view of the stator of Figure 1, when partly formed;

Figure 4 is a perspective view from above of the stator of Figure 1;

Figure 5 is a perspective view from above of the stator of Figure 1, showing interconnections; and

Figure 6 is a perspective view from above of a yoke used in an alternative embodiment of the method of the present invention.

Referring to Figures 1-5 of the drawings, there is shown a stator 10 of an electrical motor formed in accordance with the present invention. The stator 10 is annular and is formed by successfully printing layers e.g. 24A – 24W (see Figure 2) in the direction of the axis of the stator 10, from one axial end thereof to the other. Initially, bottom end layers e.g. 24A – 24C are deposited, the layers comprising regions of copper or other conductive material that form connections 17 between conductors 12 of the stator 10.

A plurality of conductors 12 are then formed by printing successive layers e.g. 24D – 24T, each layer comprising a plurality of conductive regions of the conductive material, which are electrically isolated from each other and which form portions of respective conductors 12 of the stator 10, each conductive region of each successive layer e.g. 24K partially overlying the conductive region of the respective conductor in the previous layer e.g. 24J and being in an electrical and mechanical contact therewith, so as to form a plurality of elongate conductors 12 which are electrically isolated from each other. Adjacent conductors 12 are electrically isolated from adjacent conductors by gaps 14 which may comprise air. In an alternative embodiment, the gaps 14 may comprise an insulative material which is printed in layers at the same time as the conductors 12. The insulative material may surround each conductor 12 and it may partly or completely fill the gaps 14. The gaps may be filled with insulative material after the layers have been deposited.

The stator 10 comprises a laminated annular yolk or former 11 having radially-extending teeth 13. The yolk 11 is formed by printing a region of yolk material in each successive layer e.g. 24D – 24T, the region of former material being electrically isolated from the conductive regions in each layer by air and/or the insulative material around the conductors 12. The yoke 11 is formed by successively depositing layers 15 of a first soft-magnetic former material and layers 16 of an insulative former material to form a laminated structure. Each region of former material of each successive layer overlies the respective region of former material in the previous layer and is in mechanical contact therewith to form a unitary former 11 having the desired cross-sectional shape.

So-called slots 26 are formed between the teeth 13 of the yolk 11 and the properties of the soft-magnetic material may be varied, for example to form the teeth 13 of the yoke 11 from a more expensive soft-magnetic material having a high saturation flux density than the rest of the yoke 11. The conductors 12 in each slot 26 are printed to have equal cross-sectional areas and their shape is selected, so that the conductors 12 fit closely within the area of the slots 26 without any unnecessary air gaps, thereby maximising the fill-factor of the slots 26. Once the final layer e.g. 26s having the conductors 12 is deposited, the top end layers e.g. 24t, 24u are deposited which comprise regions of copper or other conductive material that form connections 17 between conductors 12 of the stator 10. Layers forming interconnections 18 between the conductors 12 and supply terminals (not shown) may be deposited by printing. Layers forming interconnections 19 to other phases of the stator 10 may also be deposited.

The layers may be printed to provide cooling ducts 50, which can extend along the conductors 12, adjacent the conductors 12 and/or through the former 11.

In use, current i flows into the motor from a supply terminal (not shown) and along an interconnection 18 to one of the conductors 12. The current i then flows down the conductor 12 inside one slot 26 and then along a connection 17 which extends under a tooth 13 of the laminated former 11. The current i then flows up the conductor 12 inside the slot 26 on the opposite side of the tooth 13 and then along a connection 17 which extends over the tooth 13 to another conductor 12. This process then and it will be appreciated that the motor of Figure 1 effectively has nine winding turns formed by printing.

Referring to Figure 6 of the drawings, in an alternative embodiment the bottom end connections 17 and the conductors 12 of the stator are printed without a core. The printed conductors 12 can then be engaged with a pre-formed core (not shown), whereupon the assembly can be over-printed to form the necessary connections and interconnections as hereinbefore described.

The present invention allows the stator, rotor (not shown) and other components of the motor to be printed in a similar manner and it will be appreciated that motors and other electromagnetic devices having can be printed quickly and on demand.

The present invention thus provides a method of forming an electrical motor, generator or other electromagnetic device by 3-D printing, wherein layers e.g. 24c – 24s are successively deposited which comprise conductive regions and regions of a laminated, core, yoke or other former 11, so as to build up a plurality of conductors 12 extending inside spaces 26 in the former 11. The conductors 12 are interconnected at their ends to form a winding-like structure in or around the former 11 or a part thereof. The method enables each space 26 available in the former 11 to be filled with conductors 12, thereby maximising the efficiency of the device.

CLAIMS

1. A method of forming an electromagnetic device, the method comprising depositing successive conductor layers, each deposited layer comprising a plurality of conductive regions of said conductive material which are electrically isolated from each other and which form portions of respective conductors of the device, each conductive region of each successive layer at least partially overlying the conductive region of the respective conductor in an adjacent layer and being in electrical and mechanical contact therewith to form a plurality of elongate conductors which are electrically isolated from each other.

2. A method as claimed in claim 1, in which conductive regions of the layer are deposited to have equal cross-sectional areas to at least some of the other regions in that layer.

3. A method as claimed in claim 1 or 2, in which ends of some conductors are interconnected to the ends of other conductors by interconnections to form turns of the electromagnetic device.

4. A method as claimed in claim 3, in which the interconnections are formed by depositing successive interconnection layers, each layer comprising a plurality of regions of conductive material which are electrically isolated from each other and which form portions of respective interconnections of the device, each region of each successive layer overlying the region of the respective interconnection in an adjacent layer and being in electrical and mechanical contact therewith to form a plurality of interconnections which are electrically isolated from each other and electrically connected to an end of at least one elongate conductor.

5. A method as claimed in any preceding claim, in which the ends of some conductors are connected to connections which, in use, convey current to and/or from the conductors.

6. A method as claimed in claim 5, in which the connections are formed by depositing successive connection layers, each layer comprising a plurality of

regions of conductive material which are electrically isolated from each other and which form portions of respective connections of the device, each region of each successive layer overlying the region of the respective connection in the adjacent layer and being in electrical and mechanical contact therewith to form a plurality of connections which are electrically isolated from each other and electrically connected to an end of at least one elongate conductor.

7. A method as claimed in any preceding claim, in which each conductor layer is deposited to provide at least one space in which no material is deposited, each space of each successive conductor layer overlying the respective space in the adjacent layer to form an elongate void which co-extends with the conductors.

8. A method as claimed in claim 7, in which a former is inserted into the or each space.

9. A method as claimed in claim 8, in which a former comprising a plurality of portions has respective portions inserted into respective spaces.

10. A method as claimed in any preceding claim, comprising depositing said successive conductor layers, each layer comprising said plurality of conductive regions and at least one region of a former material which is electrically isolated from the conductive regions, each region of former material of each successive layer overlying the respective region of former material in an adjacent layer and being in mechanical contact therewith to form an elongate former which is electrically isolated from the conductors and which co-extends with the conductors.

11. A method as claimed in claim 8, in which the former is formed by sequentially depositing layers of a first former material and layers of a second former material to form a laminated structure.

12. A method as claimed in claim 11, in which the former is formed by successively depositing layers of a ferromagnetic material former material and layers of an insulative former material to form the laminated structure.

13. A method as claimed in claim 12, in which the ferromagnetic material is treated to align or refine the magnetic domains and or grains in a preferred magnetic circuit direction.

14. A method as claimed in claim 12 or claim 13, comprising depositing a plurality of ferromagnetic materials with varying magnetic properties in respective regions of the former.

15. A method as claimed in any preceding claim, comprising depositing said successive conductor layers, each conductive region being surrounded by an insulative region of insulative material which electrically isolates each conductive region from adjacent regions in the layer, each insulative region of each successive layer overlying the respective insulative region in the adjacent layer to form an insulative surround around each conductor.

16. A method as claimed in any preceding claim, comprising depositing said successive conductor layers, each layer comprising at least one wall region of a material which surrounds a space, each walled region of each successive layer overlying the respective walled region in the adjacent layer to form a duct.

17. A method as claimed in any preceding claim, in which the layers are deposited by 3-dimensional printing techniques.

18. A method as claimed in any preceding claim, in which the layers are deposited by vapour deposition.

19. A method as claimed in any preceding claim of forming an electrical machine having an axis of rotation, the layers being successively deposited in the direction of the axis of rotation of the machine.

20. A method of forming an electromagnetic device, the method comprising depositing successive layers, each deposited layer comprising at least one region of a former material, each region of former material of each successive layer overlying the respective region of former material in the adjacent layer

and being in mechanical contact therewith to form a former of the device, a coil then being disposed around the former.

21. A method as claimed in claim 20, in which the former is formed by sequentially depositing layers of a first former material and layers of a second former material to form a laminated structure.

22. A method as claimed in claim 21, in which the former is formed by successively depositing layers of a ferromagnetic material former material and layers of an insulative former material to form the laminated structure.

23. A method as claimed in claim 22, in which the ferromagnetic material is treated to align or refine the magnetic domains and or grains in a preferred magnetic circuit direction.

24. A method as claimed in claim 22 or claim 23, comprising depositing a plurality of ferromagnetic materials with varying magnetic properties in respective regions of the former.

Intellectual Property Office

Application No:	GB1802254.1	**Examiner:**	Andrew Isgrove
Claims searched:	1-19	**Date of search:**	12 July 2018

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
X	1-19	CN107170564 A (WANG) WPI Abstract Accession No. 2017-65639Y, figures
X	1-17 & 19	DE102013214128 A1 (ZAHNRADFABRIK FRIEDRICHSHAFEN) WPI Abstract Accession No. 2015-08549G, figs 1-10, 13
X	1-8	JP H05283259 A (MITSUBISHI ELECTRIC) WPI Abstract Accession No. 1993-380765, figures
A	-	US2017/063183 A1 (SHRESTHA)
A	-	US4707313 A (HOULE)

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

H02K

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

WPI, EPODOC, Patent Fulltext

International Classification:

Subclass	Subgroup	Valid From
H02K	0003/26	01/01/2006
H02K	0001/12	01/01/2006
H02K	0015/02	01/01/2006
H02K	0015/04	01/01/2006
H02K	0015/06	01/01/2006