

1 TWO PULSE PERMANENT MAGNET BRUSHLESS D-C MOTOR

5 The present invention relates to a brushless permanent magnet d-c motor, and more particularly to such a motor whose stator structure includes armature pole shoes which have a circumference deviating from an exactly cylindrical shape so that the air gap is non-uniform.

10 A motor with a non-uniform air gap is described in DE-OS 28 35 210. Motors with non-uniform air gaps and which are pulse-energised are now known in the Art and have been described in both patent as well as technical literature, for example, German Patent 23 46 380, assigned
15 to the assignee of this application; and an article by the inventor hereof entitled "Two-Pulse Brushless d-c Motors - Construction and Operation", published in "asr-digesr für angewandte Antriebs-technik", issue
20 1-2/1977 (asr-digest for applied motive power technology) pages 27-31.

Two pulse brushless d-c motors have a stator winding which receives two current pulses for each rotation of the permanent magnet rotor over 360 electrical degrees ($^{\circ}$ -el). Typically, the pulses do not last for
25 180° -el but are shorter. Current flow through the windings or coils of the stator, typically, is controlled by solid-state switching elements, such as transistors, which are controlled to conduction or cut-off, respectively, by a galvano magnetic sensor, for example a Hall
30 generator.

1 Motors, for example as described in the aforementioned German Patent 23 46 380, are suitable for many applications. Some applications require an extreme of uniformity of torque throughout the entire range of
5 rotation of the rotor. The stator structure, using salient poles, will have gaps between the poles. These gaps are needed in order to permit winding of the armature windings on the stator poles. The presence of these stator pole gaps can become troublesome in selected
10 applications where an extreme of uniformity of torque is required. If the motor or its connected elements have sufficient inertia, then the torque variations due to the stator pole gaps may not be material. The momentary or instantaneous variations in speed as the torque changes
15 when a magnetically active portion of the permanent magnet rotor passes over the pole gaps are difficult to measure with the type of measuring equipment usually used to test motors. In applications in which the resolution of instantaneous speed is critical, however, for example in
20 video recording equipment, momentary variations in operating speed may produce distortions in the resulting picture. These distortions, apparently, are caused by the rotor pole gaps passing over the stator pole gaps and receiving, first, a driving reluctance torque - due to the increase in air
25 gap, and then a braking or retarding reluctance torque, due to the decrease in effective magnetic air gap.

 In accordance with the present invention there is provided a two-pulse brushless direct current (d-c) motor having a permanent magnet rotor element providing substantially trapezoidal magnetisation with narrow gaps between
30 the poles thereof, a stator element having a core, salient poles terminating in pole shoes extending from the core, the tips of adjacent pole shoes being separated by pole gaps and winding means on the poles, an essentially cylindrical air gap separating said rotor element and said stator
35

1 element, and means for controlling current flow, in pulses,
through respective ones of said winding means on the stator
poles to produce, in operation, an alternating magnetic
field to generate a driving torque in the rotor element
5 and wherein, in the direction of rotation and starting from
a first stator pole shoe tip adjacent a stator pole gap,
the magnetically effective air gap first increases to a
maximum located inwardly of and close to said adjacent
first stator pole shoe tip and then decreases over the major
10 portion of the pole shoe to a minimum value located inwardly
of and close to the other stator pole shoe tip, with the air
gap then increasing again to an intermediate value in a zone
adjacent said other pole shoe tip, the intermediate value
having a dimension which is smaller than the value of the
15 maximum air gap.

The shape of the air gap in the region of the pole
gap, with respect to an outer cylindrical theoretical envel-
ope, may have approximately the cross-section of a biconvex
lens. The lensatic cross section extends, for example, for
20 a distance of about 7° to 20° -el from said other stator pole
shoe tip.

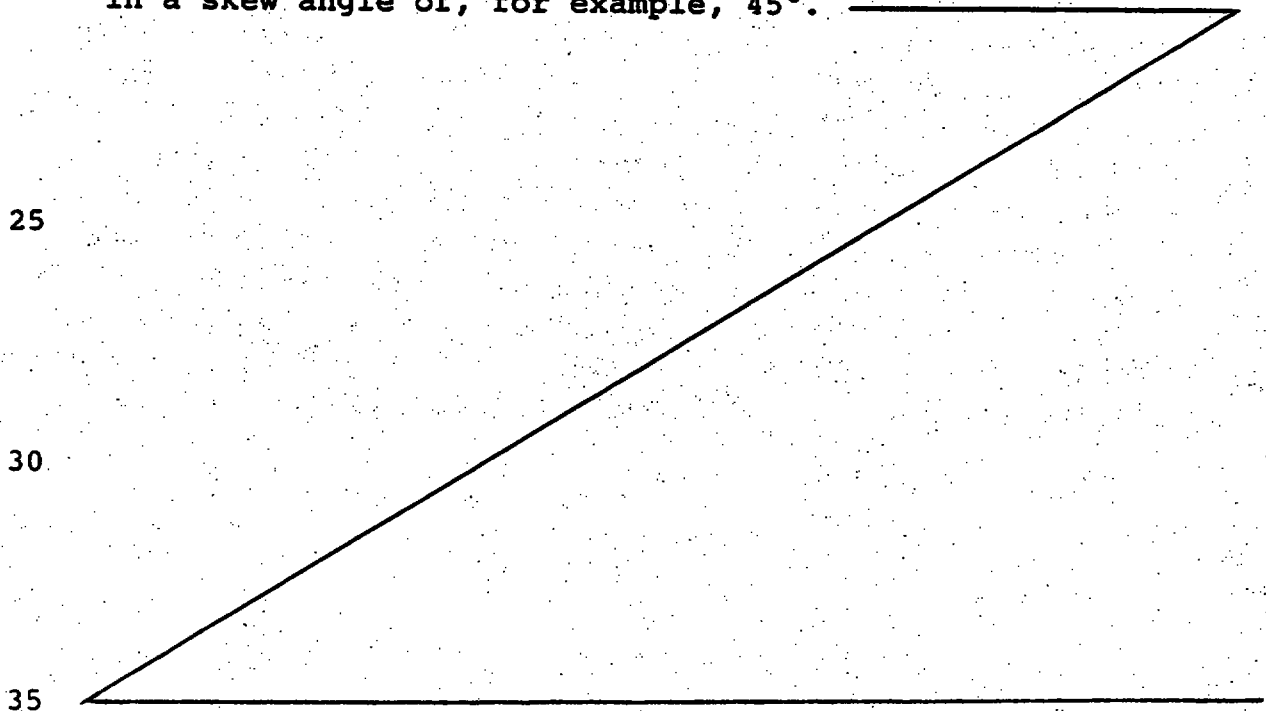
The particular structural shape of the stator pole
shoes thus provides a reluctance torque which increases
already before the stator pole gap is reached by any partic-
25 ular element of the rotor, for example, a pole gap thereof
during rotation of the rotor. Variations in torque, as the
rotor rotates, are thus effectively reduced.

Also, the width(N) of the stator pole gaps may be
more than 5% of one pole pitch (180° -el).

30 In accordance with a preferred feature of the
invention, the region of the stator pole shoe tips, which
has the maximum air gap, is offset approximately 10° to
 20° - el away from the adjacent pole shoe tip itself. The
maximum extent of this air gap is greater than the value
35 of the air gap at the other stator pole shoe tip.

1 In the preferred form, in which the maximum air
gap is offset about 10° to 20° - el from the pole shoe tip,
a preferred starting position for the rotor will be
defined since, then, a rotor pole gap will be approximately
5 opposite the region of maximum air gap. This defined
stopping position of the rotor, upon de-energisation of the
windings, defines a predetermined stop position which,
upon re-energisation, insures starting under optimum
electrical conditions and in one direction only.

10 Preferably, the rotor pole gaps are skewed, that is,
inclined with respect to the axis of rotation - in the
cylindrical air gap motor - and, preferably, include an
acute angle with respect to stator pole gaps. Of course,
15 the relationship can be reversed, that is, the stator pole
gaps can be skewed with respect to the axis of rotation;
for ease of winding, however, skewing the rotor pole gaps
is preferred. The extent of inclination or skew should be
such that the rotor pole gap extends from one pole tip of
20 the stator to the other. In some motors, this may result
in a skew angle of, for example, 45° .



The invention will now be further described by way of example only with reference to the accompanying drawings, in which:

Fig. 1 is a highly schematic view, partly in section, of a motor incorporating the invention and illustrated as an external rotor motor, the section being taken along line I-I of Fig. 2;

Fig. 2 is a top view of the motor of Fig. 1;

Fig. 3 is a top view of a stator lamina, used in the motor of Figs. 1 and 2, and to an enlarged scale of about 2 : 1 with respect to Fig. 1 or 2;

Fig. 4 is a fragmentary view of a stator lamina of Fig. 3, to a scale of about 5 : 1 with respect to Fig. 3; and

Fig. 5 is an enlarged developed view of the air gap of the motor of Figs. 1 to 4 over a portion of the circumference thereof.

Fig. 1 illustrates an external rotor motor 10 drawn, for one model, approximately to a scale of 1 : 1. It has a rotor bell 11 made of deep-drawn steel, and having a center bushing 12 fitted thereon, coupled to a shaft 13. Shaft 13 is journaled in suitable bearings 14 externally of the motor, and secured in a suitable frame or support, not shown. A magnetic ring 16 is adhesively secured to the inside 15 of the rotor bell 11. Typically, ring 16 is a rubber magnet, that is, a mixture of hard ferrite material and elastomeric material. The ring 16 is radially magnetized and has four poles, see Fig. 5, in which two poles are shown. The pole gaps 17 of the rotor 16 are highly skewed or inclined and, in a four-pole motor as shown, are inclined approximately by 45° (Fig. 1). The inclination or skew is so selected that uniform torque or uniformity of running and speed throughout the entire rotation is obtained; in other words, the torque output per incremental angular rotation is uniform. The extent of inclination or skew of course depends on the height or thickness of the stator laminar stack 18 and of the width N (Fig. 5) of the stator pole gaps 44. The stator

1 stack 18 is coated with a plastic - except at the air
gap 19 - which simultaneously is shaped to provide coil
forms 22 (Fig.1). Four stator windings or coils are wound
on form 22; only windings 23, 24, 25 are visible in Figs. 1
5 and 2. The windings can be arranged in various ways and,
for purposes of a motor with extremely uniform torque and
two-pulse operation, for example as known and as described
in the literature, and specifically as described in German
Patent 23 46 380, Fig.1, or as described in connection with
10 Figs.2 and 3 of the aforementioned literature reference "Two-
Pulse Brushless d-c Motors" by the inventor hereof. Two
current pulses are supplied to the winding for each rotor
rotation of 360° -el. Typically, the duration of a pulse is
less than 180°-el so that gaps in the electromagnetic drive
15 torque will result. These gaps in torque are supplemented
by a reluctance torque, for example, as disclosed in the
referenced DE-OS 28 35 210. In this respect also, see Fig.
5 of the aforementioned German Patent 23 46 380 and Fig.9
of the referenced literature. Since the basic structure, as
20 well as the operation and the operating theory, is known and
described in the literature, and this forms part of the
State of the Art, a further detailed explanation is not
necessary. A brief review will be given below where the
difference between the present invention and prior art
25 structures is explained.

The direction of rotation of the motor is indicated
in Figs. 2, 4 and 5 by arrow 26.

The stator package or stack 18 is formed with a
central opening 27 through which the bushing 12 extends;
30 further, three attachment holes 28 (Fig.2) are provided in
order to attach the motor to the support structure which,
also, can retain the bearing. The external rotor 11 can be
used to directly drive a utilization element.

A printed circuit (PC) board 29 is secured to the lower side of the motor 10 (Fig. 1), attached to the stator winding form 22 at three attachment points 32, 33, 34. Connecting pins 35 and electrical and electronic elements 36 are retained on the PC board. The PC board further carries a Hall generator 37 which, as shown, is positioned approximately over the pole gap between a pair of stator poles - compare also the referenced application by the inventor^{hereof}. Hall generator 37 is offset slightly in the direction of rotation of the rotor - for example by about 1 mm - in order to obtain magnetic feedback with respect thereto, as described and claimed in US Patent No. 4,099,104.

Hall generator 37 is used to control flow of current through the motor winding. It is controlled by the magnetic field from the rotor magnet 16. A rubber bushing 38 is secured to the PC board 29 to attach a connecting cable thereto. The respective terminals of the windings 23, 24, 25 are soldered to suitable connecting pins or eyes of the PC board 29.

The stator stack 18 has four salient poles 40, 41, 42, 43. The poles are identical and separated from each other by pole gaps 44 which lead inwardly to grooves or slots 45 in which - as best seen in Figs. 1 and 2 - the windings 23... are placed. The winding slots 45 are covered with insulating material 46 which, as described, extends to form the winding forms 22. The extent of the insulating material 46 is shown in chain-dotted lines in Fig. 4, and forms an integral part of the winding forms.

In accordance with the present invention, the shape of ^{especially} air gap -/ in combination with the magnetization of the rotor magnet - is of critical importance in order to obtain the desired course of the reluctance torque. In theory, it would be desirable to obtain a completely monotonic air gap, that is, an air gap free of any

magnetic discontinuities. In actual practice, however, this cannot be achieved since the pole gaps 44 are required in order to permit introduction of the wire for the windings into the grooves 45.

Thus, the gaps 44 must have a certain minimum width. In the motor illustrated, the stator stack 18 has a diameter of 56 mm; the pole gaps have a width N of 3 mm. This is about the minimum which permits introduction of a wire for winding under commercially reasonable^{conditions}/. The pole gaps 44 introduce momentary or instantaneous variations in torque. In most all applications, these minute variations in torque can be neglected. In some extremely sensitive applications, however, for example in video recording equipment these minute instantaneous variations may cause disturbances. The present invention is directed to reducing these instantaneous variations in drive torque and is particularly applicable for small motors in which the width of the pole gaps is relatively great with respect to the overall length of the pole shoe.

For a motor of 56 mm diameter, corresponding to a pole pitch of about 44 mm in a four-pole motor, the relationship of pole gap to pole pitch is about 7%; this percentage of course decreases with increasing motor diameter and then has decreasing influence on the course of the instantaneous torque-rotation relationship.

Fig. 5 illustrates - in developed form - the air gap extending over 180° -el, that is, over one pole width. The air gap is the same for all four stator poles, and thus is shown in detail only with respect to pole 41.

Figs. 3 and 4 illustrate the circular cylindrical envelope 49 in chain-dotted outline of the stator stack 18. As best seen in Fig. 4, the point of minimum air gap⁵⁰ occurs at the upper pole tip 51, somewhat inwardly of the actual tip end. The point of maximum air gap⁵² occurs at the lower pole tip 51A, also somewhat inwardly of

1 the tip end 60° itself. The rotor magnet 16 is magnetized
in trapezoidal shape, as disclosed in the previously
referenced DE-OS 28 35 210, and has narrow magnetic pole
gaps 17, extending approximately from 10 to 20°-el between
5 the poles. As described in connection with Fig.1, the
gaps 17 are skewed. In quiescent state, that is, when the
motor 10 is de-energized, the gaps 17 will position
themselves opposite points 52, that is, at the position of
the widest air gap 19. This position is indicated in Fig.5.
10 The reluctance torque, at that point, is zero. The air
gap 19 increases monotonically between the minimum point
50 and the maximum point 52, approximately according to the
function of the formula $y = a \cdot x^b$, wherein y represents the
width of the air gap, x the angle of rotation, and the
15 abscissa can be taken approximately at the level of the
point 50, that is, at minimum air gap. Starting at the
point of maximum air gap 52, and extending towards the next
adjacent pole gap shown in Fig.4 at 44A, the air gap decreases
rapidly and almost to the minimum value corresponding to
20 point 50 - but not quite. In the example selected, the air
gap at point 50 - 25°-el from the center of the pole gap
44B (see Fig.5) is approximately 1mm - see the scale representation in Fig.5- increasing to about 3mm at point 52, that is,
at about 160°-el. Adjacent the air gap 44A, that is, at about
25 172°-el, the air gap is about 1.5mm. These measurements
are represented, to scale, in Fig.5. At the other side of
the pole gap 44A, that is, at about 188°-el, the air gap will
be approximately 1.25mm, increasing rapidly to about 1.6mm at
about 192°-el, to form an intermediate maximum 53, and then
30 decreases to point 50', corresponding to the next pole 42,
that is, at about 205°-el to the minimum of about 1mm.

In accordance with a feature of the invention, a
zone 54 is provided between the minimum 50 (or 50') and
the adjacent pole

gap 44B or 44A, respectively, in which the air gap 19 passes through an intermediate height or level 53. This region 54 is relatively short, and in the example has a length of only about 15° -el. It has been found that this simple arrangement - see specifically the developed view of Fig. 5 - and particularly when combined with the magnetization of the magnet 16, as specified, and the shape of the increasing air gap of the tip region 51A, instantaneous variations in torque caused by the relatively wide pole gaps 44 - 44A, 44B in Fig. 4 - can be effectively and almost entirely eliminated. Skewing the rotor pole gap 17 additionally effectively contributes to this result.

In the stator 18 for an external rotor motor, as shown at 10 in Fig. 1, the region or zone 54 together with the envelope 49 may have the shape of a biconvex lens - see Fig. 4. What is, however, important at all times is the course of the magnetically effective air gap 19. Various different shapes of stator laminae can be used to obtain the particular air gap relationship - see, for example, U.S. Patent 2,185,990, in which various shapes of laminae are described. The important feature is the generation of a driving reluctance torque when in the air gap 19, the rotor pole gaps 17 pass over a stator pole gap 44 so that the rotor is not excessively retarded or braked by the rapidly increasing air gap occurring at the edge of the stator pole gaps and, further, that the rotor has its quiescent or stop position at a predetermined position with respect to the stator and, specifically, at the point where the rotor pole gaps 17 will be opposite the position 52 defining the maximum air gap.

Looked at from another point of view, the invention can be considered as shifting the locus of generation of the rotary torque in the rotor pole gaps. When the rotor pole gaps pass through a

1 region of increasing air gap, a driving torque is generated;
when they pass through a region of decreasing air gap, a
braking or retarding torque is generated. If one considers
the rotor pole gaps 17 as optical elements which are extremely
5 near-sighted, that is, if they are in the position of Fig.5
opposite the additional iron tips 60,61 at both sides of the
stator pole gaps 44, then the rotor pole gaps 17 will "see"
instead of the gap 44 an average volume of stator iron
magnetic material which would correspond approximately to a
10 uniform or monotonic air gap between the extreme values 50
and 52. It is preferable that these additional iron volume
accretions 60, 61 at both sides of the gap opening 44 include
a narrow angular range, that is, are concentrated within an
angular range of only about 5 to 10°-el from the limit of
15 the stator pole gap. Consequently, the characteristic tips
60', 61', will be formed at the ends of the pole tips 51,
51A, extending in the direction towards the essentially
cylindrical air gap 19.

The developed view in accordance with Fig.5 clearly
20 shows these extending tips. The same principle, of course,
can be applied to an internal rotor motor. For ease of
visualization, one may consider Fig.5 being drawn on a
stretchable support, for example a rubber band. For an
external rotor motor, Fig.5 would have to be bent upwardly;
25 for an internal rotor motor, Fig.5 would have to be bent
downwardly.

In a preferred form, the rotor pole gaps 17 are
skewed; the rotor pole gaps 17, of course, may also be made
straight and, instead, the stator poles 40 to 43 can be
30 skewed so that the stator pole gaps 44 will extend under an
angle of about 20° to 45° with respect to the axis of
rotation of the motor. Of course, it is also possible to
both skew the rotor pole gaps and the stator pole gaps in
opposite directions to obtain the relative skew angles. For
35 ease of manufacture, skewing of the rotor pole gaps is

11^A

1 preferred.

Various changes and modifications may be made within the scope of the inventive concept.



1 CLAIMS

1. A two-pulse brushless direct current (d-c) motor having a permanent magnet rotor element providing substantially trapezoidal magnetisation with narrow gaps between the poles thereof, a stator element having a core, salient poles terminating in pole shoes extending from the core, the tips of adjacent pole shoes being separated by pole gaps and winding means on the poles, an essentially cylindrical air gap separating said rotor element and said stator element, and means for controlling current flow, in pulses, through respective ones of said winding means on the stator poles to produce, in operation, an alternating magnetic field to generate a driving torque in the rotor element and wherein, in the direction of rotation and starting from a first stator pole shoe tip adjacent a stator pole gap, the magnetically effective air gap first increases to a maximum located inwardly of and close to said adjacent first stator pole shoe tip and then decreases over the major portion of the pole shoe to a minimum value located inwardly of and close to the other stator pole shoe tip, with the air gap then increasing again to an intermediate value in a zone adjacent said other pole shoe tip, the intermediate value having a dimension which is smaller than the value of the maximum air gap.

2. A motor according to claim 1, wherein the air gap in said zone adjacent said other stator pole shoe tip has, with respect to a cylindrical envelope, the approximate form of a biconvex lens.

3. A motor according to claim 2, wherein said zone extends over a range of from between 7° to 20° -el from said other stator pole shoe tip.

4. A motor according to any preceding claim, wherein the terminal ends of the other stator pole shoe tips are formed with essentially radially directed extensions



-13-

- 1 projecting towards the air gap, to provide zones
adjacent said extensions of increasing air gap.
- 5 5. A motor according to any preceding claim,
wherein the position of the maximum air gap is approximately
10° to 20° - el away from the adjacent first stator pole
shoe tip.
- 10 6. A motor according to any preceding claim,
wherein the pole gaps of the rotor element are inclined
or skewed with respect to the pole gaps of the stator
element.
7. A motor according to claim 6, wherein said
angle of inclination or skew is in the order of between
20° to 45°.
- 15 8. A motor according to claim 1, wherein the stator
pole shoe tips are pointed projections directed towards
the rotor.
- 20 9. A motor according to any preceding claim,
wherein the terminal zones of the stator pole shoe tips
immediately adjacent the pole gaps comprise zones
of increased iron volume magnetically effective to
decrease the magnetic effect of said pole gaps, said
zones of increased iron volume being concentrated
within an angular range of between about 5° to 10° -el
from the limit of the stator pole gap.
- 25 10. A motor according to any preceding claim,
wherein the width (N) of the stator pole gaps is more
than 5% of one pole pitch (180° -el)
11. A motor according to claim 10, which is an
external rotor motor.
- 30 12. A brushless d-c motor substantially as
hereinbefore described with reference to the accompanying
drawings.

The text of the specification has been reproduced by photocopying the applicants original typescript. It may contain a few amendments which are difficult to read. The original typescript containing these amendments may be inspected on the premises of the Patent Office