

[54] WINDING FOR ELECTROMECHANICAL TRANSDUCERS WITH CORELESS ROTOR

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310/208, 310/268

[51] Int. Cl..... **H02k 23/30, H02k 23/32**

[58] Field of Search ... 310/154, 155, 266, 268, 203,
310/207, 208

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Primary Examiner—J. D. Miller

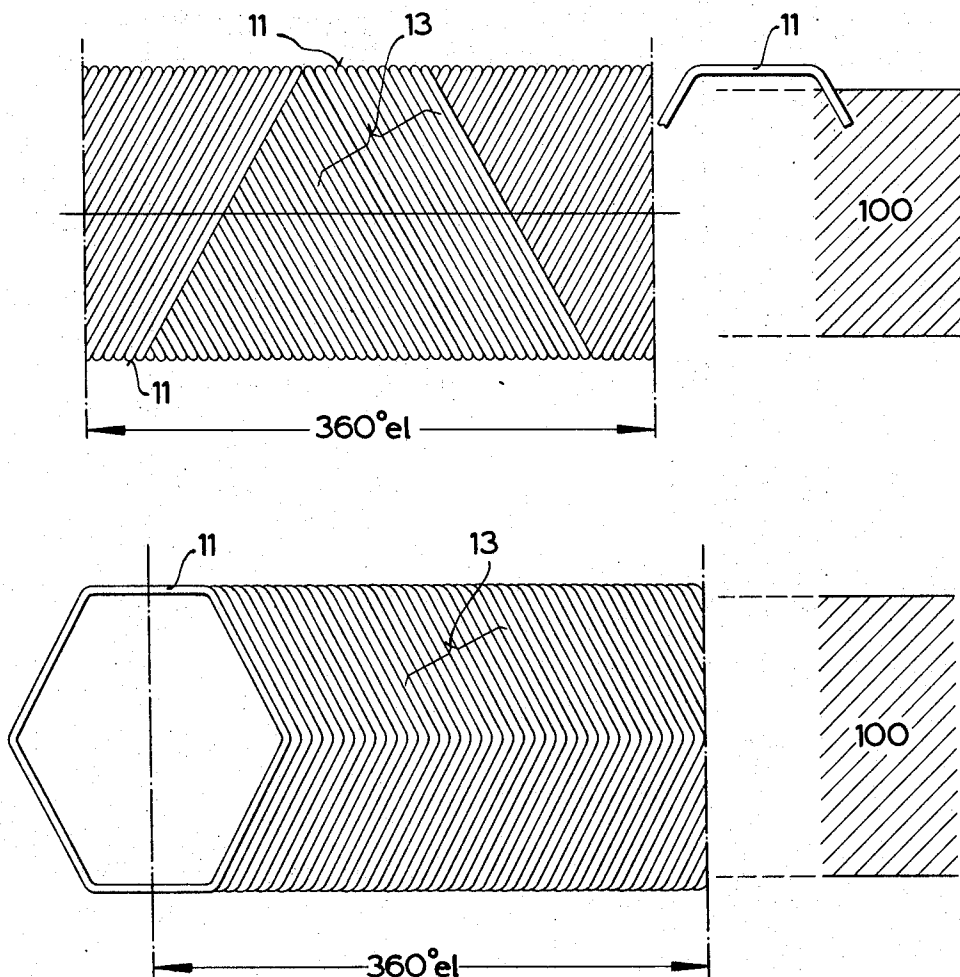
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[57] ABSTRACT

An electromechanical transducer has a coreless rotor winding formed of a series of loops, each of the loops having an active portion inclined to both the axial and tangential directions of the rotor and an inactive head portion oriented perpendicular to the axial direction. The relative length of the head portion of each loop affects the electrical characteristics of the transducer, such as starting torque, time constant and efficiency. By selecting the proper relative length for the head portion, the performance characteristics of the transducer may be optimized.

10 Claims, 14 Drawing Figures



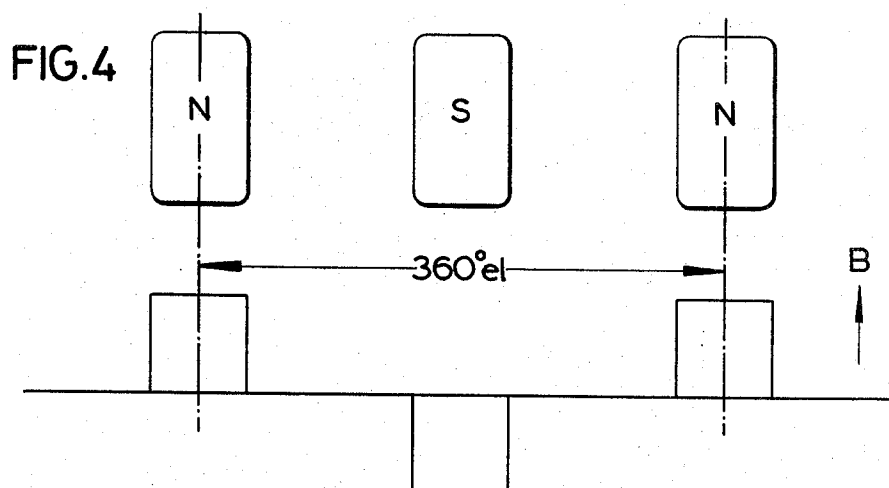
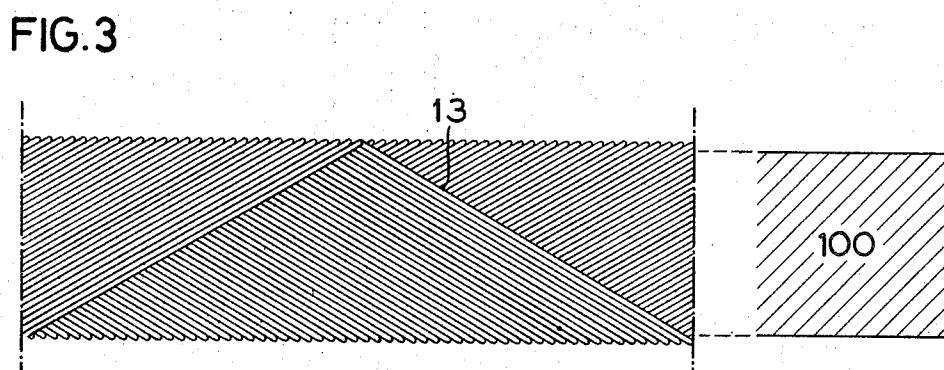
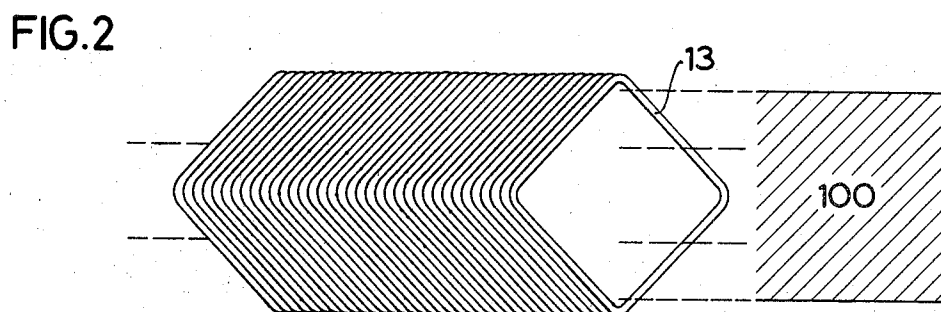
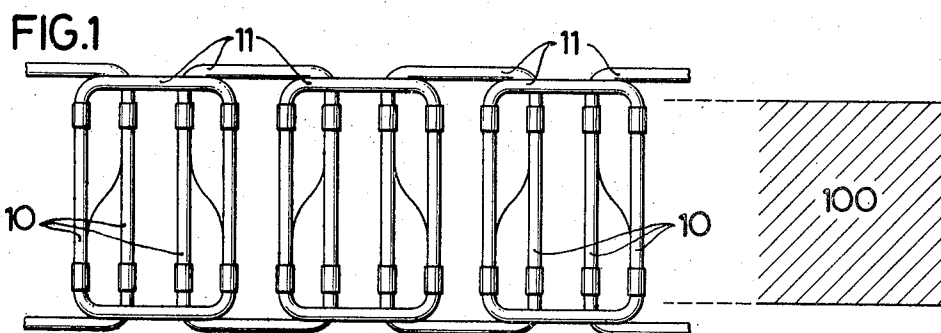


FIG. 5

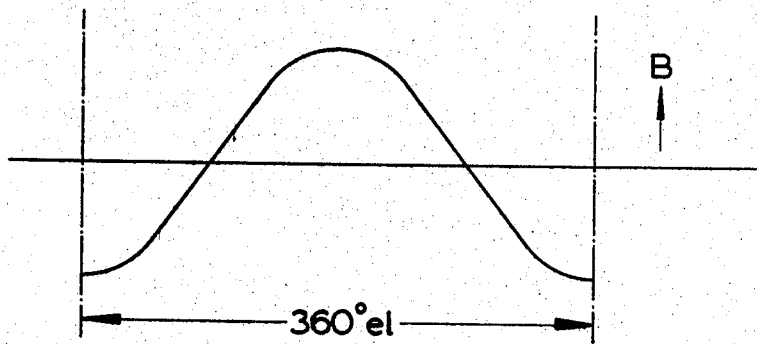


FIG. 6

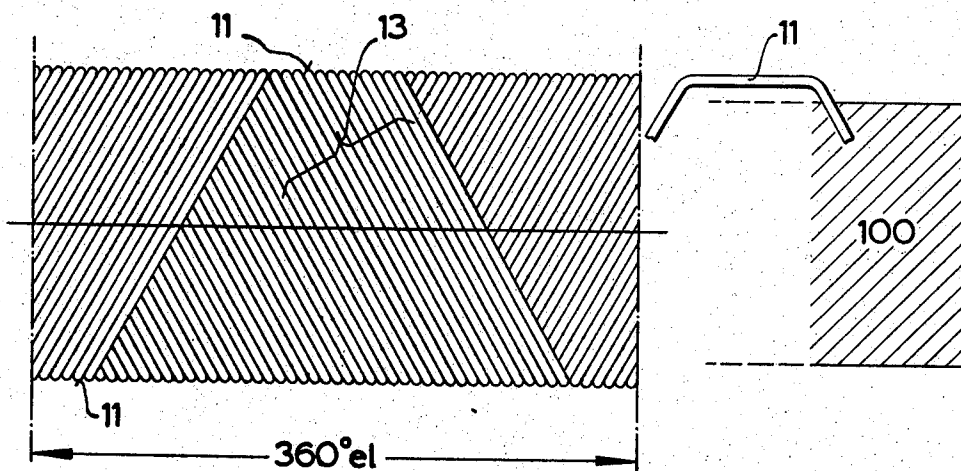


FIG. 7

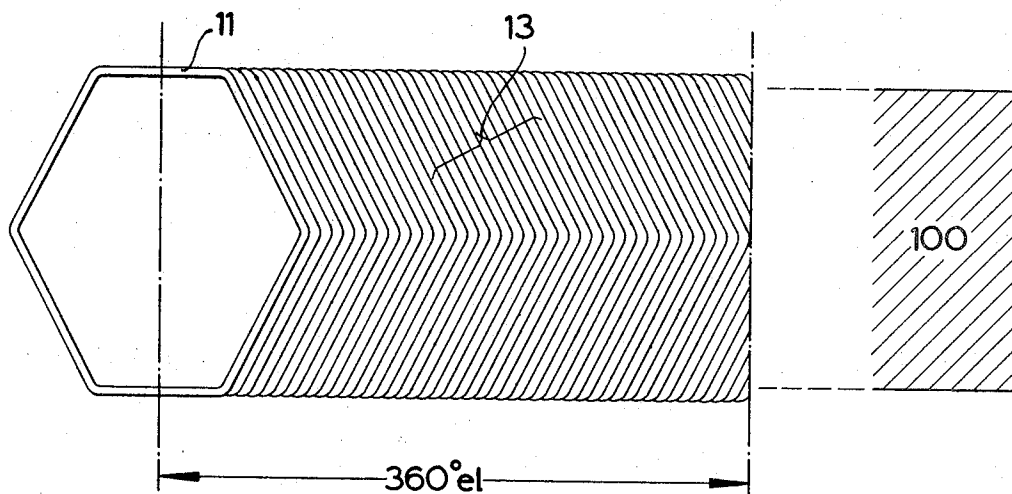


FIG. 8

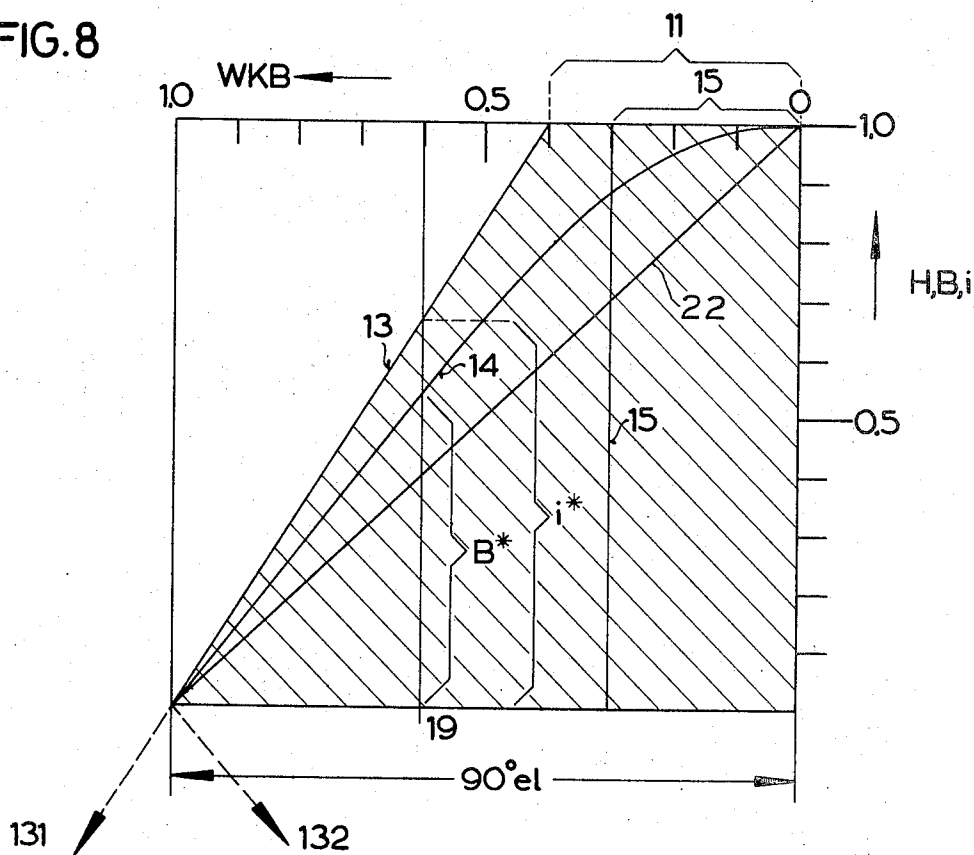


FIG. 11

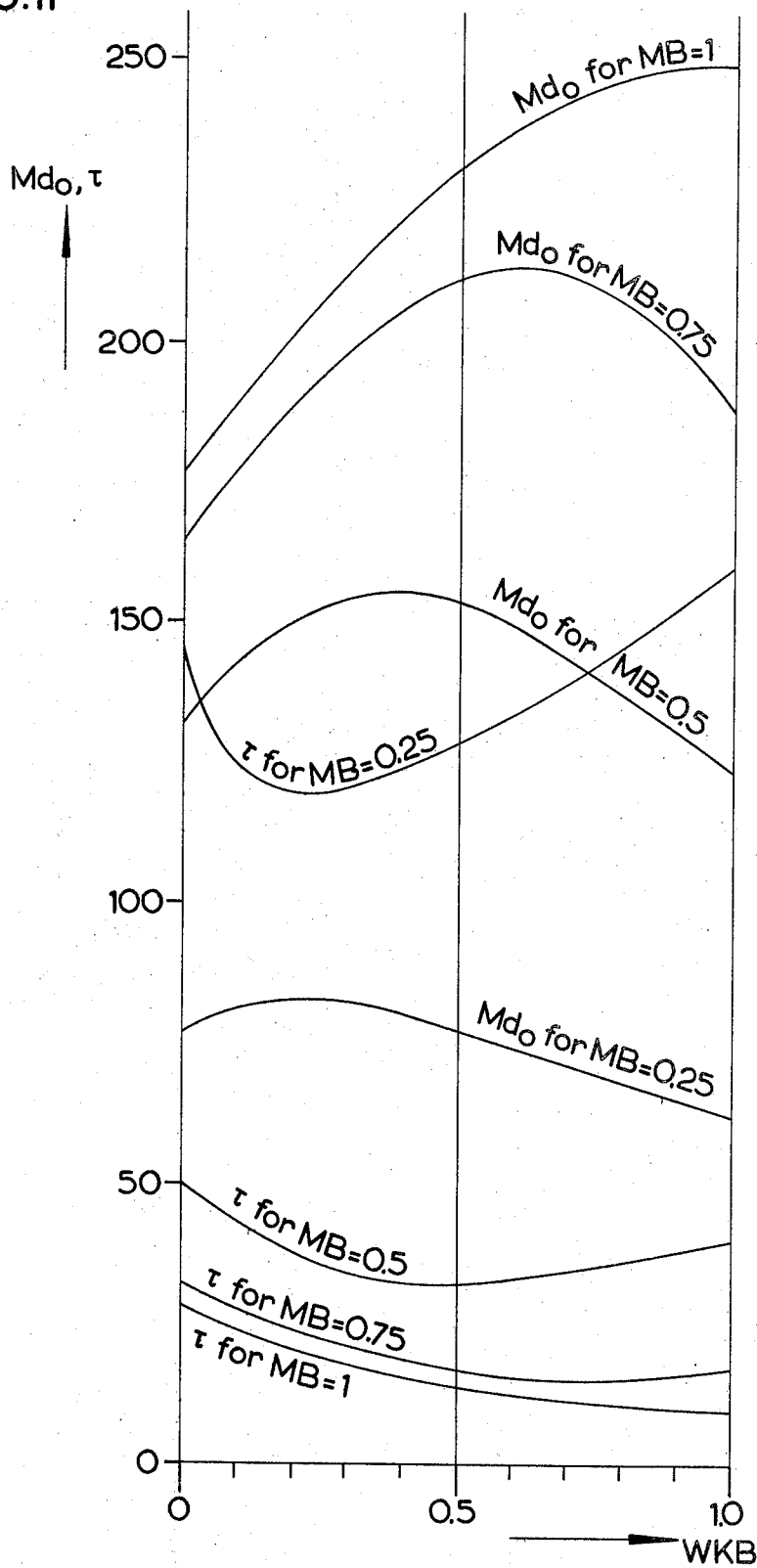


FIG.12

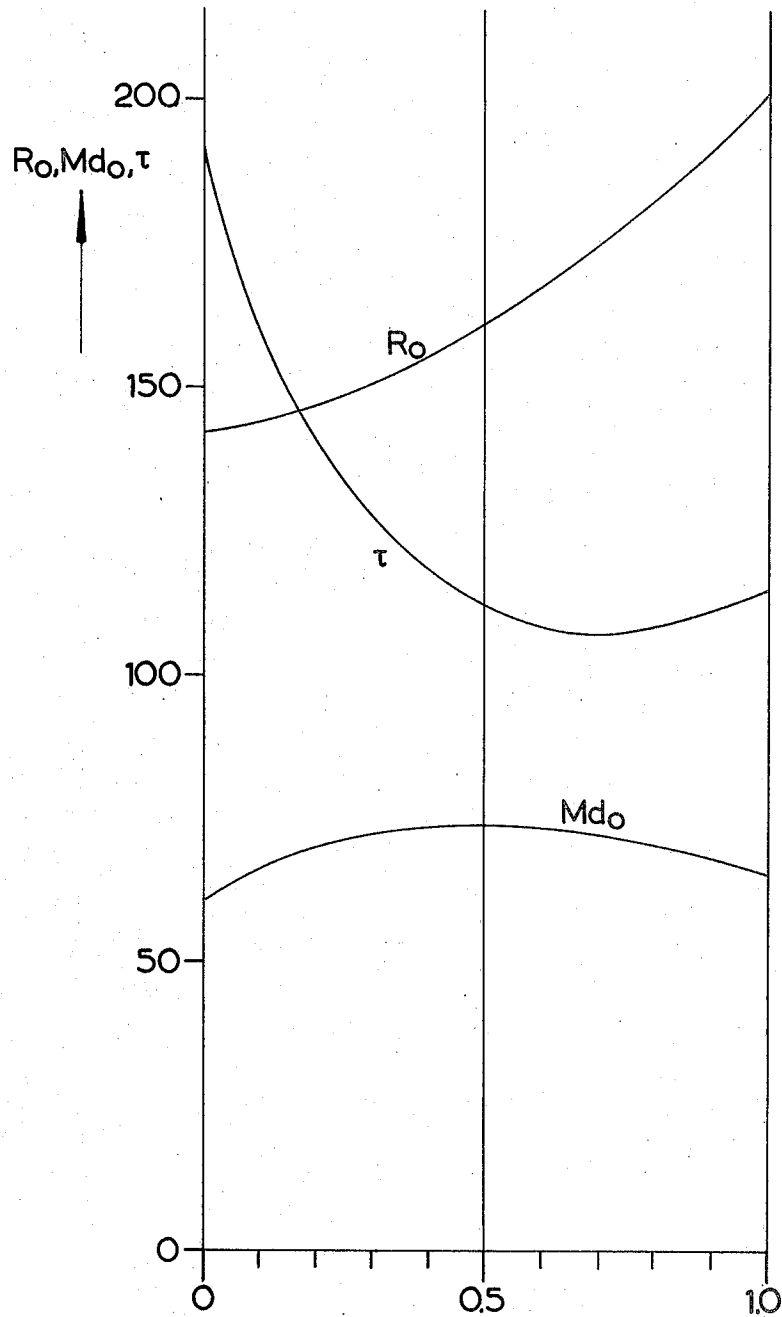
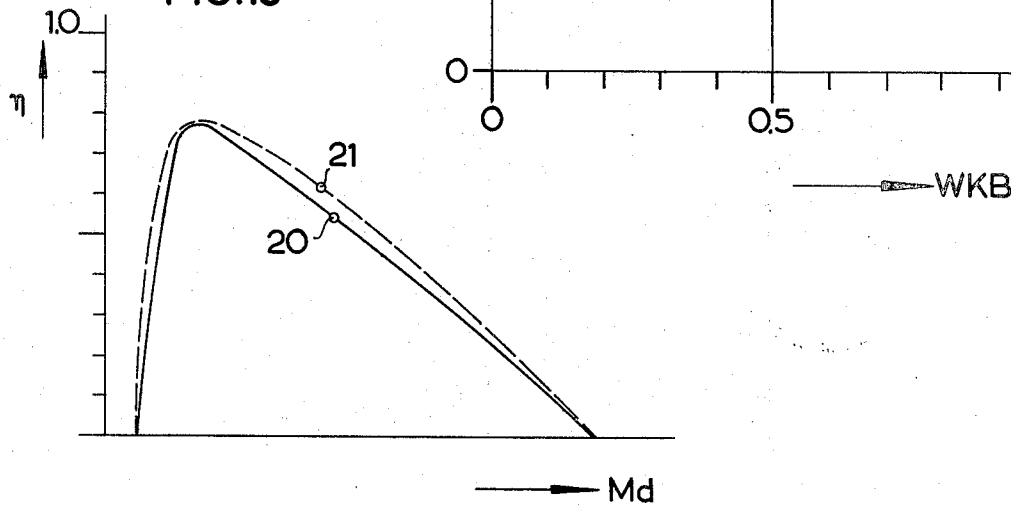


FIG.13



WINDING FOR ELECTROMECHANICAL TRANSUCERS WITH CORELESS ROTOR

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to mechanical transducers, and more particularly to an improved winding arrangement therefor.

2. The Prior Art

Two types of windings have been developed for coreless rotors of electromechanical transducers. One type, hereinafter referred to as a rectangular loop winding, is composed of closed loops formed of active portions oriented in parallel with the axial direction of the rotor, and head portion oriented in parallel with the tangential direction, which is perpendicular to both the axial and radial directions of the rotor. Such windings are illustrated and disclosed in German Patents No. 859,501 and No. 1,021,466. The second type of winding consists entirely of active portions which are inclined to both the axial and tangential directions. Such windings may be either lap windings, as described in Czechoslovakian Patent No. 486,150 or wave windings, as described in German Patent No. 1,188,709. Both wave windings and lap windings are customarily formed of one single length of wire, with taps for connection to a source of power provided where desired. Rectangular loop windings and lap windings are also described in my U.S. Pat. No. 3,467,847.

The rectangular loop windings are best adapted for use with units having stators with discrete rectangular poles in the magnetic circuit, whereas the distributed lap and wave windings are better suited to a sinusoidal stator field distribution. Distributed windings which are without inactive head portions have the lowest possible winding resistance, because less wire is needed.

Although the winding types known in the prior art perform generally satisfactorily, it is desirable to provide a winding arrangement which improves the electrical and mechanical characteristics of the transducer.

SUMMARY OF THE INVENTION

Accordingly, it is a principal object of the present invention to provide such an improved winding arrangement.

Another object of the present invention is to provide a winding arrangement by which higher starting torques may be obtained.

A further object of the present invention is to provide a winding arrangement by which a smaller time constant may be obtained.

Another object of the present invention is to provide a winding arrangement by which a smaller figure for the weight-to-power ratio is obtained.

These and other objects and advantages of the present invention will become manifest upon an examination of the following description and the accompanying drawings.

In one embodiment of the present invention there is provided a winding for an electromechanical transducer having loops with an active portion inclined to both the axial and tangential directions, and an inactive head portion aligned with the tangential direction.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference will now be made to the accompanying drawings in which:

FIG. 1 is a plan view of a developed winding formed in accordance with the so-called rectangular loop winding arrangement;

FIG. 2 is a plan view of a developed winding formed in accordance with the so-called lap winding arrangement;

FIG. 3 is a plan view of a developed winding formed in accordance with the so-called wave winding arrangement;

FIG. 4 is a plan view of three poles of a developed stator arrangement, including a graph illustrating the flux density in the space occupied by the rotor;

FIG. 5 is a graph illustrating the flux density in the space adjacent a different stator arrangement;

FIG. 6 is a plan view of a developed winding formed in accordance with one embodiment of the present invention;

FIG. 7 is a plan view of a developed winding formed in accordance with another embodiment of the present invention;

FIG. 8 is a graph illustrating the relationship of certain parameters of a winding formed in accordance with the present invention;

FIG. 9 is a schematic illustration of the current flowing through various portions of a winding constructed in accordance with the present invention;

FIG. 10a is a cross-section taken through a two pole transducer having a stator arrangement for producing a sinusoidal field;

FIG. 10b is a cross-section taken through a four pole transducer having a stator arrangement for producing a pulse type field;

FIG. 11 is a series of graphs illustrating the relationship of various parameters in a transducer incorporating the present invention and having a stator arrangement like that shown in FIG. 10a;

FIG. 12 is a series of graphs illustrating the relationship of various parameters in a transducer incorporating the present invention and having a stator arrangement like that shown in FIG. 10b; and

FIG. 13 is a graph showing the relationship of efficiency to torque in a transducer incorporating the present invention, compared with one employing a prior art winding.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 1 to 3 illustrate three different views of developed winding arrangements employed in the prior art. A developed winding is one which has been straightened from its normal circular-cylindrical configuration into a plane, for the purpose of illustrating the relationship of the various parts of the winding. In FIG. 1 the various loops of a rectangular loop winding have active portions 10 which are parallel to the axial direction of the rotor, and inactive portions 11, which are parallel to the tangential direction of the rotor. The inactive portions 11 are hereinafter referred to as winding heads. The winding heads are not active because they do not cross the magnetic flux produced by the stator field arrangement. The flux, in a plan view of a developed winding, is aligned generally in a direction perpendicular to the plane of the paper.

The area in which the stator flux is effective is illustrated in FIGS. 1-3 by a shaded area 100. The active portions of the windings pass through the area 100, and a rotational force is produced by the interaction of current flowing through the winding and the magnetic flux.

In FIGS. 2 and 3 no winding heads or inactive portions are included in the windings shown; in each case, the entire winding is made up of a series of loops having inclined portions 13, oriented at an angle to the axial direction and also at an angle to the tangential direction of the rotor. The winding illustrated in FIG. 2 is a lap winding, and the winding of FIG. 3 is a wave winding.

The rectangular loop winding of FIG. 1 is most suited to a stator pole arrangement which is shown in developed condition in FIG. 4. The poles N and S are discrete elements having rectangular cross-sections. A graph of the flux density B, along a line parallel to the faces of the poles N and S in the space occupied by the rotor, is illustrated in FIG. 4. The flux density B increases abruptly to a positive value in the space aligned with the north poles N and increases abruptly to a negative value in the space aligned with the south pole S. The distance extending between centers of two adjacent poles of the same polarity corresponds to 360 electrical degrees, as illustrated in FIG. 4.

FIG. 5 illustrates a graph of flux density produced by a different stator arrangement, in relation to points along a line in the space occupied by the rotor. The flux density B illustrated in FIG. 5 is sinusoidal in shape, and is most effective with windings of the type illustrated in FIGS. 2 and 3. However, coils constructed in accordance with the present invention are more effective than any of the prior art coils illustrated in FIGS. 1 to 3 in achieving an optimum combination of performance characteristics, as described more fully hereinafter.

A plan view of 360 electrical degrees of a developed winding incorporating the present invention is illustrated in FIG. 6. The winding of FIG. 6 is composed of loops, each of which has an active portion 13 inclined to both the axial and tangential directions of the rotor, and an inactive winding head portion 11, oriented in a direction generally aligned with the tangential direction. The shaded area 100 shows the area of the stator flux. A section of one loop of the winding is also illustrated in FIG. 6, illustrating that the inactive portion 11 is aligned generally in a tangential direction.

The winding of FIG. 6 is of the wave winding type in FIG. 7 a plan view of a developed winding of the lap winding type is illustrated, incorporating another embodiment of the present invention. The winding of FIG. 7 incorporates inactive winding head portions 11 which are aligned generally in a peripheral direction relative to the rotor, while the inclined portions 13 are inclined to both the radial direction of the rotor and also to its tangential direction.

A winding constructed in accordance with the present invention, having an inactive head portion 11 which is aligned with the tangential direction of the rotor, may be referred to as an inclined winding with a winding head or as a trapeze winding.

A feature of the present invention relates to the length of the winding head 11 in relation to the tip-to-tip length of the loop in the tangential direction. Varying the relative length of the winding head 11, in relation to the tip-to-tip length of the loop, changes the

characteristics of the transducer incorporating the winding, so that the optimum parameters for a variety of circumstances may be produced, by selecting the appropriate length of the winding head 11 in relation to the tip-to-tip length of each loop.

FIG. 8 shows 90 electrical degrees of a single loop of a winding incorporated in the present invention. The winding may be similar to that shown in FIG. 7, for example, in which case the upper left hand quarter of a loop is represented in FIG. 8 by the lines 11 and 13, corresponding, respectively, to the inactive and active portions of the loop. The vertical scale indicates, on a scale from 0 to 1, the height H of the winding, as well as the current i and the flux density B. The horizontal scale indicates on a scale from 0 to 1, the proportion of the inactive portion 11 to the loop length which, in the example of FIG. 8, extends over 90 electrical degrees, relative to the stator field. The quarter loop of FIG. 8 has its portion 11 equal to 40 percent of the loop length, as shown by the upper scale. Beyond the portion illustrated in FIG. 8 the inclined portion 13 of the winding extends in the direction of an arrow 131 when it is a wave winding type, and it extends in the direction of an arrow 132 when it is a lap winding type. The stator flux may be either a sinusoidal type, 90 electrical degrees of which are illustrated by the curve 14, or a pulse type, 90 electrical degrees of which are illustrated by the curve 15.

If the relative length WKB of the winding head 11 is 0, the quarter loop becomes a diagonal line 22, and the winding becomes a lap winding or a wave winding. Similarly, if the relative length WKB of the winding head 11 is unity, the winding becomes similar to the rectangular loop type winding of FIG. 1. The present invention has a construction in which the relative winding head length WKB lies intermediate 0 to 1.

FIG. 9 is a schematic illustration of the current in a developed winding constructed in accordance with the present invention, over 360 electrical degrees, resulting from connection to a current source at two points spaced 180 electrical degrees apart. The connections to the current source are via lines 23 and 24, and are made via slip rings, a commutator, or the like. In the zone 16 of FIG. 9, the resulting flow of current has a downward direction, as illustrated in FIG. 9, and in the zone 17 the current has an upward direction. In both of the zones 16 and 17 there is some current which flows in the winding heads in a tangential direction and contributes nothing to the production of torque. The nature of this current is explained in greater detail in German Patent No. 1,188,709.

The graph illustrated in FIG. 8 can be employed to calculate certain parameters of the transducer including the time constant and the starting torque. The starting torque is proportional to the product of the current i within the winding and the flux density B. In order to calculate the force tending to rotate the coil which acts at a specific point on the circumference thereof, for example at the location 19 in FIG. 8, the incremental force is calculated by the relation:

$$dMd_K = i \cdot B$$

The entire force, over the circumference of the rotor is determined by integration.

The time constant τ is:

$$\tau = \Theta \cdot \omega_o / Md_o$$

The factor Θ is proportional to the winding length l .

Thus, one may state:

$$\tau = f_1(l \cdot \omega_0 / Md_0)$$

wherein l represents the combined lengths of the inactive winding head 11 as well as the active portion 13, and f_1 is a function symbol.

The term ω_0 is calculated from the flux ϕ and the applied voltage V by the relation:

$$\omega_0 = V / f_2(\phi)$$

The flux ϕ is dependent upon the characteristics of the magnetic circuit of the stator of the transducer.

In FIGS. 10a and 10b embodiments of the present invention are illustrated, employing two different stator arrangements. The arrangement illustrated in FIG. 10a is primarily intended for a two pole machine, while the arrangement of FIG. 10b is primarily designed for a multi-pole machine. Both systems employ a surrounding ferromagnetic shield ER and magnets M spaced inwardly from the outer shield ER. Accordingly, flux is produced in a gap between the outer shield ER and the interior parts of the apparatus, as conventional in the art. The rotor winding rotates in this gap. The apparatus of FIG. 10a employs a single magnet M of circular configuration, while four magnets M are employed in the apparatus of FIG. 10b, together with an interior ferromagnetic member ER to complete the magnetic circuit.

In the apparatus of FIG. 10a, flux distribution in the air gap between the shield ER and the magnet M is generally sinusoidal. For example, the flux density reaches a maximum along a horizontal line bisecting the apparatus of FIG. 10a, and a minimum along a vertical line bisecting the apparatus. The rotor, in making one complete revolution, thus passes through a complete cycle of sinusoidal flux density. In the apparatus of FIG. 10b, the waveform of the flux density is rectangular in shape, reaching a maximum value at locations adjacent to the magnets M and a minimum between such locations.

When a winding constructed in accordance with the present invention is employed with the apparatus of FIG. 10b, it is unnecessary to make the winding head 11 any larger than the width of the magnet M. When the loops of the winding are approximately the same size as the area through which the effective flux passes, virtually all of the effective flux is linked by the loops. However, it has been found that employing a winding, with a winding head 11 equal to the width of the magnet M does not give optimal results. On the contrary, it has been found that by employing a winding head having a width which is smaller than the width of the magnet M, better characteristics are obtained, as more fully discussed hereinafter.

Curves illustrating the characteristics of transducers employing the present invention are illustrated in FIGS. 11 and 12. In FIG. 11 the horizontal axis is plotted on a scale of 0 to 1 in terms of WKB, which, as in FIG. 8, describes the relative length of the winding head, in proportion to the length of a winding loop. Accordingly, the curves illustrated in FIG. 11 for WKB=0 give values for a transducer having a coil formed of inclined windings such as shown in FIGS. 2 and 3. As the WKB dimension increases, the change in the parameters is illustrated in FIG. 11. The curves of FIG. 11 hold for the sinusoidal system illustrated in FIG. 10a and the curves of FIG. 12 hold for the pulse type stator arrangement illustrated in FIG. 10b.

The curves of FIG. 12 are plotted on the same scale, namely in terms of the relative winding head length

WKB on a scale from 0 to 1. The curve Ro in FIG. 12 illustrates that the resistance Ro of the winding rises from a minimum at WKB=0 to a maximum at WKB=1. Nevertheless, in spite of the rising resistance, the starting torque rises as the WKB dimension is increased from 0, as shown by the curves in FIG. 11. The starting torque curves are designated Md_0 , and four such curves are illustrated in FIG. 11, in accordance with the length of a loop of the winding in relation to the tangential distance between adjacent poles of the stator field. This is indicated in FIG. 11 by the parameter MB. When MB=1, the loop length is the same as the distance between adjacent poles of the stator field. When MB=0.25, the coil length is equal to one-fourth of the distance between poles of the stator field. For an MB of between 0.50 and 0.75, the starting torque Md_0 reaches a maximum when the winding head length is approximately one-half of the total length of the loop, giving a WKB equal to 0.5. This value is somewhat dependent on the length (and therefore the height H) of the winding. Nevertheless it remains in about the same relation to the time constants as is illustrated in FIG. 11.

The time constants τ for the four different values of MB are also illustrated in FIG. 11. The minimum values for the time constants when MB is approximately 0.50 to 0.75 occurs at about the same value of WKB as the maximum starting torques. For higher values of WKB, the condition becomes worse, with decreasing starting torques and higher time constants. In addition, transducers having higher values of WKB increase in size due to the increased length of the winding head, and the weight of the transducer increases accordingly. It is therefore desirable to choose a compromise value of WKB, where size and weight are tolerable, and the starting torque and time constant are improved.

The curves in FIG. 12, which hold for multi-polar machines having individual magnets, illustrate that although the resistance of the winding increases as the WKB parameter increases, the starting torque Md_0 has a maximum at approximately WKB=0.5, and the time constant reaches a minimum at a higher value of WKB. The curves of FIG. 12 are shown for one value of MB, but it is understood that the variation of MB results in different curves such as are illustrated in FIG. 11.

For machines constructed in accordance with FIG. 10b, it is necessary to take into consideration the magnet width, meaning the tangential dimension of the magnet M. In general a magnet width of an entire pole division (in which MB=1) is not practical, for then the leakage between adjacent magnets short circuits the greater part of the flux. Accordingly, the magnet widths must be less than 1 and are preferably about 0.8 the distance between poles.

The starting torque Md_0 has a distinct maximum and the time constant τ has a distinct minimum at another value of WKB in FIG. 12. Accordingly, if a transducer with maximum starting torque is desired, WKB is chosen at about 0.5, while, if a minimum time constant is desired, a WKB value of 0.7 is chosen.

If it is desired to design a transducer with an especially low weight, rather than attempting to minimize the time constant or maximize the starting torque, then smaller magnet widths W are selected. As the cross-section of the magnet is smaller, the cross-section of the ferromagnetic shield ER may also be smaller, which

appreciably reduces the size and weight of the transducer.

The selection of different magnet widths does not appreciably affect the heat-emitting surface of the transducer so that, for a given magnet width, if the parameters of the winding are optimized, an optimal transducer may be designed.

By employing the curves of FIGS. 11 and 12, and others like them for other values of MB, it is possible to design in each case an optimum transducer for the design required, by choosing an appropriate relative length of the winding head. The important factors to be taken into consideration in arriving at such a design are the armature resistance R_a , the starting torque Md_0 , the time constant τ , the weight per unit power, etc.

In the past only the number of turns in a winding, and the size of the wire employed therefor, have been varied in attempting to reach an optimum design for a particular application. By means of the present invention the relative length of the winding head may also be varied, thus permitting a substantially better solution for any given set of design parameters. The advantages of using the present invention in such a case, is that the time constant is improved and the starting torque is improved, as compared with prior art windings.

As the relative length of the winding head is increased, the total length of the winding is also increased, so that for a given current the i^2R losses increase with the length of the winding. However, the increase in resistance increases more slowly than the increase in the torque, so that when the present invention is employed to produce a given torque, there is a lower heat loss because less current is required to develop the required torque. This factor is illustrated in FIG. 13, in which the efficiency η is plotted against the torque Md developed by the transducer. The curve 20 is for a transducer employing one of the prior art windings whereas the dashed line curve 21 is for a transducer incorporating the present invention. The maximum efficiency, which is reached at relatively low torque, is equal for both systems. However, at other torques, the winding constructed in accordance with the present invention has a higher efficiency than achieved by the previous windings.

Although the taps, by which current is supplied to the windings, have not been shown in the drawings referred to above, it will be understood that the windings are tapped in the same way as is conventional in the art, and that such taps are brought to a location outside the transducer by means of slip rings, commutators, or the like.

A winding incorporated in the present invention is usable not only with motors and generators, but also with prime movers whose armatures do not rotate in complete revolutions, such as in measuring devices, for example. The present invention may also be employed when the rotor and the stator exchange their roles in the known manner, and the winding described herein is stationary while the magnetic field generating system rotates about the stationary winding.

Although the winding heads 14 have been shown as being oriented in a tangential direction, they may also be constructed to have a radial component, so as to

form chords at the axial ends of the windings. Windings constructed in accordance with the present inventions may be either distributed, by being wound from a single length of wire, or alternatively they may be formed as individual loops.

What is claimed is:

1. In an electromechanical transducer having means for generating a magnetic field and a coreless rotor adapted to rotate through said field, a winding for said rotor comprising a plurality of loops, each of said loops having an active portion inclined to the axial direction of said rotor and inclined to the tangential direction of said rotor and an inactive winding head portion oriented generally perpendicularly to said radial direction.

2. The winding according to claim 1, wherein said winding head portion is oriented generally in a tangential direction.

3. The winding according to claim 1, wherein said winding head portion has a tangential length greater than 0.4 of the tangential length of one of said loops.

4. The winding according to claim 3, wherein said winding head portion has a tangential length less than 0.7 of the tangential length of one of said loops.

5. The winding according to claim 1, wherein said loops are formed as individual loops.

6. The winding according to claim 1, wherein said loops are formed of a single length of wire.

7. In an electromechanical transducer having means for generating a magnetic field and a coreless rotor adapted to rotate through said field, a winding for said rotor comprising a plurality of loops, each of said loops having an active portion inclined to the axial direction of said rotor and inclined to the peripheral direction of said rotor and an inactive winding head portion connected with said active portion, said winding head portion having a tangential length of between 0.4 and 0.7 of the length of said loop.

8. In an electromechanical transducer having means for generating a magnetic field and a coreless rotor adapted to rotate through said field, a winding for said rotor comprising a plurality of loops, each of said loops having an active portion inclined to the axial direction of said rotor and inclined to the peripheral direction of said rotor and an inactive winding head portion connected with said active portion, said winding head portion having a tangential length of between 0.4 and 0.7 of the distance between two points separated by 180 electrical degrees of said field.

9. In an electromechanical transducer having means for generating a magnetic field, the combination comprising a winding located within said field, and means for rotating said magnetic field relative to said winding, said winding having a plurality of loops, each of said loops having an active portion inclined to the axial direction of said rotor and inclined to the tangential direction of said rotor and an inactive winding head portion, said winding head portion being oriented generally perpendicularly to said radial direction.

10. Apparatus according to claim 9, wherein said means for rotating comprises means for supporting said winding and means for rotating said field generating means.

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