COMMONWEALTH of AUSTRALIA

PATENTS ACT 1952 609707

APPLICATION FOR A STANDARD PATENT

We UNIQUE MOBILITY, INC., of
3700 S. Jason Street,
Englewood,
Colorado 80110,
United States of America

hereby apply for the grant of a Standard Patent for an invention entitled:

"LIGHTWEIGHT HIGH POWER ELECTROMAGNETIC TRANSDUCER AND ARMATURE THEREFOR"

which is described in the accompanying ~~provisional~~ complete specification.

Details of basic application(s):—

Number	Convention Country	Date
812,306	United States of America	23 December,1985

APPLICATION ACCEPTED AND AMENDMENTS
ALLOWED 19.2.91

The address for service is care of DAVIES & COLLISON, Patent Attorneys, of 1 Little Collins Street, Melbourne, in the State of Victoria, Commonwealth of Australia.

Dated this 23rd day of December, 19 86.

H. W. Rinington

To: THE COMMISSIONER OF PATENTS

(a member of the firm of DAVIES & COLLISON for and on behalf of the Applicant).

Davies & Collison, Melbourne and Canberra.

COMMONWEALTH OF AUSTRALIA

PATENTS ACT 1952

DECLARATION IN SUPPORT OF CONVENTION OR NON–CONVENTION APPLICATION FOR A PATENT

Insert title of invention.

In support of the Application made for a patent for an invention entitled: Lightweight High Power Electromagnetic Transducer

Insert full name(s) and address(es) of declarant(s) being the applicant(s) or person(s) authorized to sign on behalf of an applicant company.

I ~~We~~ John S. Gould of

3700 S. Jason Street
Englewood, Colorado 80110
United States of America

Cross out whichever of paragraphs 1(a) or 1(b) does not apply
1(a) relates to application made by individual(s)
1(b) relates to application made by company; insert name of applicant company.

do solemnly and sincerely declare as follows :–

~~1. (a) I am / We are the applicant............ for the patent~~

or (b) I am authorized by Unique Mobility ,Inc.

the applicant............. for the patent to make this declaration on ~~its~~ their behalf.

Cross out whichever of paragraphs 2(a) or 2(b) does not apply
2(a) relates to application made by inventor(s)
2(b) relates to application made by company(s) or person(s) who are not inventor(s); insert full name(s) and address(es) of inventors.

2. (a) ~~I am / We are the actual inventor............ of the invention~~

or (b)

Gene A. Fisher, a citizen of the U.S.A.,
residing at 9198 So. Bitterweed Ct.,
Highlands Ranch, Colorado USA
United States of America

State manner in which applicant(s) derive title from inventor(s)

is ~~are~~ the actual inventor........... of the invention and the facts upon which the applicant........... is ~~are~~ entitled to make the application are as follows :– by virtue of as assignment dated December 9, 1986, the inventor assigned the invention to the applicant.

Cross out paragraphs 3 and 4 for non-convention applications. For convention applications, insert basic country(s) followed by date(s) and basic applicant(s).

3. The basic application........... as defined by Section 141 of the Act was ~~were~~ made

in U.S.A. on the 23rd of December 1985
by Gene A. Fisher
in .... on the ....
by ....
in .... on the ....
by ....

4. The basic application.......... referred to in paragraph 3 of this Declaration was ~~were~~ the first application.......... made in a Convention country in respect of the invention the subject of the application.

Insert place and date of signature.

Declared at Englewood, CO USA this 9th day of Decembr 1986

Signature of declarant(s) (no attestation required)

Note: Initial all alterations.

Unique Mobility Inc.

By..............................
(Name) John S. Gould
(Title) President

(12) PATENT ABRIDGMENT **(11)** Document No. **AU-B-66908/86**
(19) AUSTRALIAN PATENT OFFICE **(10)** Acceptance No. **609707**

(54) Title
ELECTROMAGNETIC TRANSDUCER

International Patent Classification(s)
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812306	**23.12.85**	**US UNITED STATES OF AMERICA**

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(56) Prior Art Documents
FR 2243512
FR 2036866
FR 1272083

(57) Claim

1. A lightweight electromagnetic transducer having high power output capability, said transducer comprising:

> magnetic flux producing means including a plurality of spaced magnetic elements; armature means positioned to receive magnetic flux produced by said magnetic flux producing means, said armature means comprising spaced sections of dispersed conductors formed from insulated fine wires and a plurality of dispersed-phase flux carrying means positioned between said sections of dispersed conductors, said dispersed conductors and said flux carrying means being configured and dispersed so as to create low opposing induced currents and low eddy currents; and actuation enabling means for interconnecting said magnetic flux producing means and said armature means and enabling

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movement of one of said magnetic flux producing means and said armature means relative to the other of said magnetic flux producing means and said armature means such that said relative movement therebetween in at least one mode is at a rate of speed sufficiently high such that said high power output from said transducer is greater than one horsepower for each pound of weight of said transducer.

COMMONWEALTH OF AUSTRALIA

PATENT ACT 1952

COMPLETE SPECIFICATION

(Original)

609707

FOR OFFICE USE

Class Int. Class

Application Number: 66908/86
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Related Art:

Name of Applicant: UNIQUE MOBILITY, INC.

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1 Little Collins Street, Melbourne, 3000.

Complete Specification for the invention entitled:

"LIGHTWEIGHT HIGH POWER ELECTROMAGNETIC TRANSDUCER AND ARMATURE THEREFOR"

The following statement is a full description of this invention, including the best method of performing it known to us :-

LIGHTWEIGHT HIGH POWER ELECTROMAGNETIC TRANSDUCER AND ARMATURE THEREFOR

Field of the Invention

This invention relates to an electromagnetic transducer, and, more particularly relates to a lightweight high power electromagnetic transducer capable of use as a motor, alternator or generator. The invention also extends in particular aspects to an armature for an electromagnetic transducer, and to an electric motor.

Background of the Invention

Electromagnetic transducers are known for use both in transforming electrical power into mechanical power and transforming mechanical power into electrical power. In both cases, power producing capability results due to relative movement between magnetic elements and electrically conductive elements, as is well known, for example, in the application of this phenomenon to motors, alternators and generators.

While it is well known that motor, alternator and generator devices can be made that are quite light in weight, and while at least some known lightweight devices have been capable of operation at high speeds, such devices have not been capable of operation at high speeds to produce high power. For example, high power density devices of 0.6 horsepower per pound of weight are known for intermittent operation, but such devices are incapable of continuous operation at high power densities in excess of 1.0 horsepower per pound.

Known electromagnetic transducer devices have also not been capable of simultaneous high speed and high torque operation and/or have not provided adequate efficiency in operation. In addition, prior shell construction devices have not used both dispersed conductors and dispersed phase flux carrying means in the armature and have, therefore, also been limited to low speed, which, even at high torque, leads to low power density.

It is also well known that an electromagnetic transducer can include a stator and rotor arrangement, and that such an arrangement can include positioning magnetic elements on the rotor (see, for example, U.S. Patent Nos. 3,663,850, 3,858,071, and 4,451,749), as well as on the stator (see, for example, U.S. Patent Nos. 3,102,964, 3,312,846, 3,602,749, 3,729,642 and 4,114,057). It has also been heretofore suggested that a double set of polar pieces could be utilized (see, for example, U.S. Patent No. 4,517,484).

In addition, a shell type rotor has been heretofore suggested (see, for example, U.S. Patent Nos. 295,368, 3,845,338 and 4,398,167), and a double shell rotor arrangement has also been suggested (see, for example, U.S. Patent No. 3,134,037).

It has also been heretofore suggested that a bundle of wires can be utilized in place of a single conductor in the armature assembly of a motor (see, for example, U.S. Patent

Nos. 497,001, 1,227,185, 3,014,139, 3,128,402, 3,538,364 and 4,321,494, as well as British Patent No. 9,557) with such wires being stated to be for high voltage and high current usage and/or to reduce current flow loss, the so-called skin effect, and heating due to eddy currents, and with such wires being utilized in conjunction with solid and/or laminated cores (see, for example, U.S. Patent Nos. 3,014,139, 3,128,402, and British Patent No. 9,557).

It has also been heretofore suggested than an electromagnetic transducer could have a power to weight ratio of up to about one horsepower to one pound (see, for example, U.S. Patent No. 3,275,863). In addition, cooling of a motor, to increase power handling capability, using a gas, liquid, or a mixture of a gas and liquid, is well known (see, for example, U.S. Patent No. 4,128,364).

While various arrangements for electromagnetic transducers have therefore been heretofore suggested and/or utilized, such transducers have not been found to be completely successful for at least some uses, including providing a lightweight transducer that is capable of providing high power.

In particular, the prior art does not teach the necessity to disperse the conductors to enable high speed operation, due, at least in part, to a widely taught theory that the magnetic field is very low in the conductors. With conductors built according to conventional teachings, however, it has been found that torque, at constant current, decreases with increasing speed, which result is contrary to the conventional expectation that torque would remain high as speed increases (which is the result achieved by this invention).

Summary of the Invention

This invention provides, in one aspect, an improved electromagnetic transducer that is lightweight and yet provides high power conversion due to the high power density capability of the transducer, with the transducer being capable of operation as a highly efficient motor, alternator or generator, with the transducer of this invention being capable of continuous operation at high power densities in excess of 1.0 horsepower per pound.

High power density per unit weight is effected by utilization of an armature assembly having dispersed conductors which are separated by dispersed-phase flux carrying means in a manner such that low opposing induced currents are created, as well as low eddy currents, to enable operation of the transducer at high efficiency with high torque being maintainable during high speed operation.

As the armature moves relative to a magnetic flux producing assembly, currents (which are often referred to as eddy currents) are established in the electrically conductive portions of the armature and these currents lead to heating and skin effects (which are collectively known as eddy current losses). However, these currents also produce another effect not heretofore realized, which currents are herein referred to as opposing induced currents since these currents alter the magnetic flux pattern and act to reduce the torque with speed increase. This power conversion capability reduction with speed increase can occur even when the losses due to these currents are acceptable, and conventional practice would not suggest dispersing the conductors as has been done in the electromagnetic transducer of this invention.

It is therefore an object of this invention to provide an improved electromagnetic transducer, and an improved armature for an electromagnetic transducer.

It is another object of this invention to provide an improved electromagnetic transducer that is lightweight and yet provides high power so that the transducer has high power density.

It is still another object of this invention to provide an improved electromagnetic transducer that operates at high efficiency.

It is still another object of this invention to provide an improved electromagnetic transducer having high power density per unit weight capability.

It is still another object of this invention to provide an improved electromagnetic transducer having a high power to weight ratio.

It is still another object of this invention to provide an improved electromagnetic transducer capable of use as a highly efficient motor, alternator or generator.

It is still another object of this invention to provide an improved electromagnetic transducer that is capable, at least in a preferred embodiment, of continuous operation at high power densities in excess of one horsepower per pound.

It is still another objection of this invention in one or more preferred embodiments to provide an improved electromagnetic transducer having an optimum thickness armature assembly which represents a balance among the effects of heat transfer to the cooling medium, heat production from resistance heating and other sources, and torque production.

With these and other objects in view, which will become apparent to one skilled in the art as the description proceeds, this invention resides in the novel construction, combination, and arrangement of parts substantially as hereinafter described, and more particularly defined by the appended claims, it being understood that changes in the precise embodiments of the herein disclosed invention are meant to be included as come within the scope of the claims.

Brief Description of the Drawings

The accompanying drawings illustrate complete embodiments of the invention according to the best mode so far devised for the practical application of the principles thereof, and in which:

FIGURE 1 is an exploded isometric view of a rotary implementation of the electromagnetic transducer of this invention;

FIGURE 2 is a side sectional view of the assembled electromagnetic transducer as shown in FIGURE 1, along with additional elements illustrated in block form to better illustrate the invention;

FIGURE 3 is a partial isometric view illustrating use of the electromagnetic transducer of this device configured as a traction motor to drive a wheel of an associated vehicle;

FIGURE 4 is a partial isometric view showing the arrangement of the dispersed conductors and flux carrying elements of the electromagnetic transducer shown in FIGURES 1 and 2;

FIGURE 5 is a diagram illustrating a typical arrangement of a two layer winding formed by the dispersed conductors and illustrating the flux carrying elements positioned between turns of the windings;

FIGURE 6 is a sectional view taken through lines 6-6 of

FIGURE 2, with the magnetic flux path in the transducer also being illustrated;

FIGURE 7 is a partially cut-away view similar to that of FIGURE 6 but illustrating an alternate embodiment of the electromagnetic transducer of this invention;

FIGURE 8 is a partially cut-away view similar to that of FIGURE 6 but illustrating another alternate embodiment of the electromagnetic transducer of this invention;

FIGURE 9 is a partial cut-away view similar to that of FIGURE 6 but illustrating still another alternate embodiment of the electromagnetic transducer of this invention;

FIGURE 10 is a partial cut-away view similar to that of FIGURE 6 but illustrating yet another alternate embodiment of the electromagnetic transducer of this invention;

FIGURE 11 is a partial end view illustrating a dispersed conductor, as best shown in FIGURE 4, and illustrating the insulation layer around the conductor;

FIGURE 12 is an end view similar to that of FIGURE 11 but illustrating an alternate embodiment of the armature structure wherein the conductors have a coating of a flux carrying means (iron) thereon utilizable in lieu of the flux carrying elements as illustrated in FIGURES 4 through 10;

FIGURE 13 is an end view similar to that of FIGURES 11 and 12 but illustrating another alternate embodiment of the armature structure wherein insulated conductors have a coating of a flux carrying means (iron) thereon utilizable in lieu of the flux carrying elements as illustrated in FIGURES 4 through 10;

FIGURE 14 is a partial view illustrating the use of the embodiment of either FIGURE 12 or FIGURE 13 as the armature without use of separate flux carrying elements;

FIGURE 15 is a partial view similar to that of FIGURE 14 but illustrating use of alternating sections of dispersed conductors and dispersed conductors coated as shown in the embodiment of FIGURE 12 or FIGURE 13;

FIGURE 16 is a side sectional view of an alternate embodiment of the electromagnetic transducer as shown in FIGURE 2, and illustrates the armature fixed to the shaft as may be convenient to a brush commutated transducer;

FIGURE 17 is an exploded isometric view of another alternate embodiment of the electromagnetic transducer of this invention, and illustrates a cylindrically symmetric linear implementation thereof;

FIGURE 18 is an exploded isometric view of still another alternate embodiment of the electromagnetic transducer of this invention, and illustrates a flat linear implementation thereof;

FIGURE 19 is a graph illustrating the relationship between torque and speed for a conventional transducer b and for the transducer of this invention a; and

FIGURE 20 is a graph illustrating tested eddy current, hysteresis and windage losses at different speeds of one example of the transducer of this invention.

Description of the Invention

A novel electromagnetic transducer is particularly described herein, including alternate embodiments thereof. It is meant to be realized that the electromagnetic transducer of this invention may be utilized as a motor (ac or dc), alternator or generator, depending on whether an electrical signal is conveyed to the armature (commonly through a commutator or equivalent structure), to create a force causing movement of the magnetic flux producing structure relative to the armature thus driving the shaft, or whether the shaft is rotated to thereby cause movement of the magnetic flux producing structure relative to the armature to create an electromotive force which, in turn, can cause movement of current along the conductors of the armature to be coupled from the conductors as an electrical signal, as is well known.

Electromagnetic transducer 35, as best shown in FIGURES 1 and 2, is lightweight and yet is capable of delivering high power, with the transducer being a high power density device that is particularly well suited, for example, for use in conjunction with self-propelled vehicle applications, such as passenger cars, although the invention is not meant to be restricted thereto.

When used for vehicle propulsion, a permanent magnet, hollow cylinder electromagnetic transducer 35 may be utilized as an efficient wheel mounted traction motor, and may, as indicated in FIGURE 3, be mounted directly at each wheel 37, adjacent to axle 39, with drive being preferably achieved through gear reduction mechanism 41.

As shown in FIGURES 1 and 2, electromagnetic transducer 35 includes an outer cylindrical housing 43, which housing has front and rear end plates 45 and 46 positioned at the opposite ends of the cylindrical housing by means of snap rings 48 and 49.

A shaft 51 has a central portion 52 extending through the cylindrical housing with the shaft being mounted in central hubs 54 and 55 (hub 55 is shown only in FIGURE 2) of end plates 45 and 46, respectively, by means of bearings 57 and 58 so that the central portion of the shaft is coaxially positioned with respect to the cylindrical housing, the reduced diameter rear portion 60 of the shaft is mounted in bearing 58, and the front portion 62 of the shaft extends forwardly of front end plate 45, with seal 64 being positioned in hub 54 adjacent to bearing 57.

As also shown in FIGURE 2, blower 65 is positioned adjacent to back, or rear, end plate 46, which plate includes offset air intake aperture 66 and a plurality of exhaust apertures 67 spaced about and near the periphery of the end plate. When so used, the transducer thus operates in a gas (air) medium (as opposed to a fluid medium which could include oil or the like, for example, as do some known transducers). In addition, an arcuate aperture 68 is positioned to allow armature conductor connections through end plate 46.

As best shown in FIGURE 2, rotor 70 has a double shell configuration provided by inner and outer spaced cylindrical portions 72 and 73 which extend normally from mounting disk 75 so that cylindrical portions 72 and 73 are coaxial with, and inside, cylindrical housing 43. Mounting disk 75 has an annular mounting portion 77 which is received on splined portion 78 of shaft 51 inwardly of bearing 57.

Inner cylindrical portion 72 of rotor 70 has magnetic elements 80 mounted thereon, which magnetic elements are shown to be permanent magnets (but electromagnets could be utilized, if desired). Cylindrical portions 72 and 73 are formed of highly magnetically permeable with low hysteresis loss magnetic material (such as iron or steel, for example), and mounting disk 75 is formed of non-magnetic material (such as plastic or aluminum, for example), while magnetic elements 80 are high strength permanent magnets, which magnets are preferably formed of neodymium boron ferrite (NdFeB), but may also be formed of barium ferrite ceramic (BaFe Ceramic), samarium cobalt (SmCo), or the like.

Armature 82 is fixed with respect to housing 43, and is mounted on rear end plate 46, as indicated in FIGURE 2, so that rotor 70 rotates relative to armature 82 (as well as to housing 43). Armature 82 is thus a stationary cylindrical shell element that extends through the length of cylindrical housing 43 between the inner and outer cylindrical portions 72 and 73 of the rotor.

It is important to this invention that armature 82 include dispersed conductors 84, as best shown in FIGURE 4, different sections 85 of which are positioned between flux carrying elements 86 as best shown in FIGURE 6. Dispersed conductors 84 are preferably formed from a bundle of small diameter copper wires 87 surrounded by insulating material 88 (as best shown in FIGURE 11), with conductors 84 being wound into a linking pattern, as indicated by way of example in FIGURE 5, with the opposite ends of the wire bundles being connected to connectors 89 extending through aperture 68 in end plate 46, as indicated in FIGURE 2.

Conductors 84, as best shown in FIGURE 4, are formed into a bundle throughout the armature (as by being wound in a ring, for example), and each turn of the wire windings has a flux carrying element 86 therebetween, as shown in FIGURES 5 and 6, with a typical winding being conceptually illustrated in FIGURE 5.

Flux carrying elements 86 are preferably iron (at least in part), and extend between the active length of conductors 84. Conductors 84 also have end turns that extend beyond the active lengths to connect the active lengths to each other in an appropriate pattern, such as a wave winding as shown, by way of example, in FIGURE 5. The flux carrying elements are preferably dispersed-phase flux carrying members to handle the high frequency magnetic field reversals with low opposing induced currents and low eddy current losses. The dispersed-phase flux carrying members have a composition and orientation so as to minimise creation of eddy currents or opposing currents in different dimensions or phases. For example, the powdered iron flux carrying elements 86 of figure 6 provide three-dimensional phase dispersion. Because iron is electrically conductive, it must be dispersed to avoid (or at least minimise) the creation of opposing induced currents. It has been found that a suitable flux carrying element can be pressed from fine (10-100 m kron) iron powder previously reactively coated with phosphate insulation and using "B" stage epoxy and wax as binders.

By providing conductors comprising a plurality of small diameter wires with dispersed-phase flux carrying elements between turns of the wires, opposing induced currents are minimised sufficiently so as to allow operation of the electromagnetic transducer at high speeds and at high torque with such operation being conductable at high efficiency. In a working embodiment, a stationary armature shell incorporating windings of copper with powdered iron bars to carry the magnetic flux, and permeated with glass re-enforced novolac epoxy insulation material cast between the windings and bars, has been successfully utilised.

In this invention when used as a motor, at constant current, it has been found that the torque output can be maintained nearly constant even with increases in rotor speed, as illustrated in FIGURE 19 by line a. This is quite unlike prior art devices wherein torque was found to drop off rapidly with increased speed when solid bars were utilized as conductors and as flux carrying elements, as illustrated in FIGURE 19 by line b. The combination of high torque and high speed, made possible in the electromagnetic transducer of this invention, produces high power density.

As shown in FIGURE 6, armature 82 (formed by the dispersed conductors 84 and flux carrying members 86) are closely spaced with respect to magnets 80 positioned about the inner cylindrical wall 72, and also closely spaced with respect to cylindrical wall 73, with walls 72 and 73 providing inner and outer return paths, respectively, for the magnetic flux. Some typical flux paths have been illustrated in FIGURE 6. As shown, these flux paths are loops each of which penetrates the armature twice passing principally through the flux carrying members 86. The flux carrying members thus allow a thick armature to maintain a high flux density which is essential to high torque.

As indicated in FIGURE 7, the electromagnetic transducer may also be configured by placing magnets 80 on outer wall 73 (rather than on inner wall 72). As indicated in FIGURE 8, the electromagnetic transducer may also be configured by placing magnets 80 on both inner and outer walls 72 and 73.

As indicated in FIGURE 9, an armature 82 can also be provided at both sides of magnets 80. In addition, while not specifically shown, it is also to be realized that the electromagnetic transducer could be configured by placing additional layers of armature-rotor elements radially inwardly and/or outwardly of that shown in the drawings. The flux carrying members may also be configured by utilizing a non-rectangularly shaped member such as, for example, an I-shaped member 91 (as indicated in FIGURE 10) having dispersed conductors 84 extending therebetween.

The armature can also be configured as shown in FIGURE 12 such that flux carrying elements 93 are formed as a coating of highly permeable magnetic material (such as iron) on some or all of the dispersed conductors 94. As indicated in FIGURE 13, conductors 94 can also have an insulation layer 95 thereon so that insulation layer 95 is between the conductor and the flux carrying element. In either case, an insulating layer 96 covers the flux carrying element (unless it is, of itself, electrically non-conductive).

When the flux carrying elements are formed as coatings on the dispersed conductors (as indicated in FIGURES 12 and 13), the flux carrying bars (shown in FIGURES 4 through 10) need not be utilized. The dispersed conductors 94 with the flux carrying elements coated thereon can be utilized as the only elements of the armature (as indicated in FIGURE 14) or can be alternated with dispersed conductor sections 85, i.e., dispersed conductors having no flux carrying element coating thereon (as indicated in FIGURE 15).

Powdered iron utilized as flux carrying elements 86 (as indicated in FIGURE 6) provide three-dimensional phase dispersion, while flux carrying elements 93 coated on the dispersed conductors (as indicated in FIGURES 12 and 13) provide two-dimensional phase dispersion (iron lamination bars, on the other hand, when used as flux carrying elements provide only one-dimensional phase dispersion).

The electromagnetic transducer of this invention thus includes a magnetic flux producing assembly (having at least one pair of poles which can be embodied by using permanent magnets or electromagnets), and an armature assembly (which intercepts the magnetic flux produced by the magnetic flux producing assembly and has an alternating structure of conductive windings and flux carrying elements, which flux carrying elements can be referred to as armature iron). A winding can be used as the principal component of the armature with the winding consisting of bundles of separate conductors (which are referred to herein as dispersed conductors), with the use of dispersed conductors of fine wire permitting high speed rotation of the rotor when used in conjunction with dispersed-phase flux carrying elements.

The use of multiple, parallel extending, insulated conductors to reduce heating losses at high currents has been heretofore suggested (see, for example, U.S. Patent No. 497,001), and it is well known in the motor art as a method to reduce skin effect losses in motors. Skin effect, however, causes losses at load only, whereas eddy current losses, which would be experienced when known devices are rotated at high speed, occur at no load. This distinction is as to the mechanism of the effect.

In the case of conductors of large cross section or conductive flux carrying elements of large cross section, as used at least in some prior known devices, as the frequency of the magnetic field reversal increases, the magnitude of the induced currents in the bars increases, and the induced currents react with the magnetic field to create a resisting torque which opposes the increase of rotational speed. Thus, known shell type devices are inherently limited to low speed by the reaction torque, and cannot be rotated at high speed and are therefore not suitable, for example, for use as traction motors in most practical applications.

When used as a motor, a means to displace (i.e., rotate) the magnetic field relative to the armature at high speed must, of course, also be provided so that electric power can be converted into mechanical power in a manner similar to that used by known motors. As indicated in FIGURE 2, this can be accomplished by connecting leads 97 between connectors 89 of armature 82 and current generator and controller unit 98 so that unit 98 which provides current to conductors 84 to cause rotation of rotor 70, with rotation of rotor 70 causing rotation of shaft 51 to drive a load 99.

When used as an alternator or generator, actuator 99 causes rotation of shaft 51 which rotates rotor 70 to induce a voltage on conductors 84 and thereby generates electrical current flow from conductors 84 to a load 98. While not specifically shown in FIGURES 1 through 15, it is to be realized that the current generator and controller unit (or alternately the armature) includes necessary electric commutation devices, including those devices wherein commutation is performed electronically (as in a brushless DC motor, for example), as well as those devices which employ rectifiers instead of commutation (as is often used in power generating applications).

FIGURE 16 illustrates an embodiment of the electromagnetic transducer of this invention in which armature 82 is connected with shaft 51 by mounting disk 101, and inner and outer cylindrical walls 72 and 73 are fixed to housing 43. In this embodiment, the armature thus becomes the rotor with electric power being communicated with the armature by means of brushes/slip rings 102 (with brushes being utilized in the case of a DC machine, and slip rings being utilized in the case of an AC machine). The embodiment shown in FIGURE 16 is preferred for some applications, particularly in the case of a DC commutated machine.

The transducer of this invention has a significant advantage over a conventional motor by utilization of a minimum amount of iron which undergoes flux reversal. That is, only the iron in the flux carrying elements in the armature is subject to the reversing flux as each pole is passed, and thus low hysteresis losses are experienced. In addition, the effects of flux leakage are reduced so that all of the armature windings experience the total flux change and thus are equally useful at producing torque.

The device of this invention also has significant heat transfer advantages. For this reason, the superior high power to weight ratio is further enhanced. A thin armature is made possible by the armature being made up entirely of insulated conductors except for the necessary volume of the flux carrying members. It is therefore possible to provide cooling to both the inner and outer surfaces of the armature.

By the principles of heat transfer, heat buildup in an armature, with constant surface temperature and uniform internal heating per unit volume, depends on the square of its thickness. For example, compare an armature 0.25 inches thick (as is possible in this invention) to a solid rotor, five inches in diameter (as is common in known devices). The heat buildup in such known devices is some 400 times as great as that of the transducer of this invention with such an armature. Clearly, the electromagnetic transducer of this invention can dissipate more heat than any known conventional transducer of similar power rating.

The electromagnetic transducer of this invention can be produced in several topological variations of the basic design. In addition to the rotating cylindrical shell configuration, by changing the orientation of the magnets and the windings, the motor can be made to produce a linear motion. Other variations (not shown) include pancake and conical configurations.

FIGURE 17 illustrates a linear reciprocating implementation of the electromagnetic transducer of this invention wherein the magnetic flux producing section moves linearly with respect to the armature in a cylindrical configuration. To accomplish this end, armature 105 has dispersed conductors 106 and flux carrying elements 107 wound radially about shaft 51 (rather than extending parallel thereto as in the embodiment shown in FIGURE 1), and rotor 109 has magnets 110 thereon that extend circumferentially around inner cylindrical wall 72 (rather than extending parallel to shaft 51 as in the embodiment shown in FIGURE 1).

FIGURE 18 illustrates another linear reciprocating implementation of the electromagnetic transducer of this invention in which the structure is flat. As shown, magnets 113 are mounted on flat lower return plate 114. Armature 115 is provided with dispersed conductors 116 and flux carrying elements 117 in the same manner as described hereinabove with respect to the other embodiments illustrated except that the armature is essentially flat rather than cylindrical. An upper return plate 118 is also provided, and armature 115 is movable linearly with respect to, and between, lower and upper plates 114 and 118 by means of rollers 120 mounted on the edges of upper plate 118 and rollers 121 mounted in roller mounting boxes 122 (carried by lower plate 114).

The basic configuration and geometry of a prototype transducer constructed according to the principles of this invention and based upon computer calculations are as follows (based upon the use of 24 magnets, conductors 0.008 inches in diameter, and 144 flux carrying elements as brought out more fully hereinafter):

Power (at 10,000 rpm)	40 HP
Voltage	72 volts dc
Current	425 amps dc
Diameter	6.5 inches
Armature total thickness	0.28 inches
Length	3.5 inches
Weight	15.0 lbs.
Efficiency (calculated at 10,000 rpm)	97.6 %

More specifically, the motor calculations as set forth hereinabove are based upon the following motor calculations:

Geometric Parameters

L1 = .125 L2 = .02 L3 = .25 L4 = .02
L5 = .3 L6 = .125 L9 = 2 R1 = 2.488
M1 = .684 M2 = .513 M3 = .171 M5 = .109 M6=.054
XI = .5 M4 = .75

Material Properties

R9 = .075 U9 = .0000004 DE = .054 R0 = 1.7241
BR = 11500 UR = 1.05 HD = 5000 MD = .3
WD = .323 KM = .000001 N1 = 2

Winding Variables

DW = 0.008 PF = .42 VO = 72 IM = 425 NP= 3
NM = 24 NS = 2 NL = 2 SR = 1 YD = 2
NT = 1 MI = 2

Magnetic Fields

BA = 8000 BM = 10053 HM = 1378 BS = 16000
B - Inner RP = 15181 B - Outer RP = 17136
B - Back at 425 amps = 754 Max current at HD = 2042
P(1) = 7.3 P(2) = 1.2 P(3) = .3 P(4) = 3.7

Weights of the Component Parts

Copper = .72 Epoxy = .30 Magnets = 2.22
Stator iron = 1.11 Return paths = 2.32 Housing = 5.87
Shaft = 2.46 Total weight = 15.0

Electrical Parameters

Resistance = .0027 R per phase = .004
No load speed = 11164.7 rpm
Ft-lb at stall (36154 amps) = 1644
Wires/conductor = 56 Effective length = 48

Stat. vol = 7.8 cubic inches Conductor size is 0.054 by 0.125.

Calculated Performance as a Function of Speed

Losses in watts

rpm	ft-lb	amps	I2R	eddy	hyst's	wind	hp	eff (%)
1116	19.3	425	359.6	2.5	9.3	.1	4.1	89.2
2233	19.3	425	359.6	10.2	18.6	.6	8.2	94
3349	19.3	425	359.6	22.9	27.9	1.3	12.3	95.7
4466	19.3	425	359.6	40.7	37.2	2.6	16.4	96.5
5582	19.3	425	359.6	63.6	46.5	4.3	20.5	97
6699	19.3	425	359.6	91.6	55.8	6.6	24.6	97.3
7815	19.3	425	359.6	124.6	65.1	13.3	28.7	97.4
8932	19.3	425	359.6	162.8	74.4	18.6	32.9	97.6
10048	19.3	425	359.6	206	83.7	25	37	97.6
11033	19.3	425	359.6	248.4	91.9	31.7	40.6	97.6
11099	9.7	213	89.9	251.3	92.5	32.2	20.4	97

wherein:

Units of length are inches
Fields are in Gauss B, Oersteds H
Losses are in watts
Forces are lb as are weights
P( ) = Gauss-in/Oersted, permeances of the flux paths
R = Resistance, ohms

and wherein:

Parameter	Definition
L1	Inner return path 72 thickness
L2	Inner air gap
L3	Armature 82 thickness
L4	Outer air gap
L5	Magnet 80 thickness
L6	Outer return path 73 thickness
L9	Magnet 80 length
MI	Option, 1 for magnets inside, 2 for out, 3 for both
M1	magnet pitch
M2	magnet width
M3	gap between magnets at pitch line
M4	M2 as a fraction of M1
M5	Armature iron pitch
M6	Armature iron width
XI	Iron fraction
NS	Iron pieces 86 per phase and per pole
NT	# of conductors 84 per iron piece 86
NL	# of layers of winding
NC	Total # of conductors 84 per phase
SR	# of conductors per phase in series
NP	# of phases
YD	Option, 1 for wye and 2 for delta
NW	# of wires per conductor
NM	# of magnets 80
PF	wire packing factor
DW	wire diameter
WD	density of wire material
DE	density of epoxy potting material
VO	Applied voltage
IM	Maximum current
	NR is no load speed
R1	Mean armature radius
RO	wire resistivity, microohm-cm
KM	Hysteresis loss constants
R9	Gas/fluid density, lbm/cubic foot
U9	Viscosity, lbf-sec/square foot
MG	Magnet option, 1 for ceramic, 2 for NdFeB
HC	pseudo coercive intensity = BR/UR
BR	residual flux density
MD	density of magnetic material
UR	recoil permeability
HD	coercive intensity at the knee

For motor torque verification, the electromagnetic force was measured in an actual test in a linear configuration similar to that illustrated in FIGURE 18, built to test computer simulation of a rotary configuration. A current of 125 amps produced a force of 50 lb.

The measured magnetic field (using Type 8 ceramic magnets) was 3500 gauss. The active conductor length spanned three of the four poles and consisted of twenty bars of copper, each 0.150 x 0.3125 inches in cross section. Each of the 3 x 20 = 60 conductors had an active length of three inches. Thus the total active conductor length was 3 x 60 = 180 inches. Using these values, the force was calculated to be 45 lb. The measured force of 50 lb compares well with the calculated force of 45 lb considering the accuracy of the test (for example, the magnetic field is not absolutely uniform everywhere, and fringing field effects were not considered).

Measured eddy current, hysteresis and windage losses for a transducer constructed according to the principles and description herein are shown in the graph of FIGURE 20. This motor delivered 16 horsepower at 7800 RPM in preliminary testing.

As can be appreciated from the foregoing, the electromagnetic transducer of this invention is thus able to provide an output power to weight ratio that is greater than one horsepower to one pound in a cooling gas medium (using air as the cooling medium), and is believed to be greater than five horsepower to one pound in at least some cooling mediums (with a five to one ratio being calculated for the prototype motor as set forth herein). It should be further appreciated from the foregoing that this invention provides an improved electromagnetic transducer that is lightweight, compact, efficient and yet capable of delivering high power.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:-

1. A lightweight electromagnetic transducer having high power output capability, said transducer comprising:

   magnetic flux producing means including a plurality of spaced magnetic elements; armature means ~~position~~ positioned to receive magnetic flux produced by said magnetic flux producing means, said armature means comprising spaced sections of dispersed conductors formed from insulated fine wires and a plurality of dispersed-phase flux carrying means positioned between said sections of dispersed conductors, said dispersed conductors and said flux carrying means being configured and dispersed so as to create low opposing induced currents and low eddy currents; and actuation enabling means for interconnecting said magnetic flux producing means and said armature means and enabling movement of one of said magnetic flux producing means and said armature means relative to the other of said magnetic flux producing means and said armature means such that said relative movement therebetween in at least one mode is at a rate of speed sufficiently high such that said high power output from said transducer is greater than one horsepower for each pound of weight of said transducer.

2. The transducer of claim 1 wherein said actuation enabling means enables said movement at a rate of speed sufficiently high such that said high power output from said transducer is at least as great as five horsepower for each pound of weight of said transducer.

3. The transducer of any one of the preceding claims

herein said magnetic flux producing means is made from one of neodymium boron ferrite, barium ferrite ceramic and samarium cobalt.

4. The transducer of any one of the preceding claims wherein said dispersed conductors of fine wire are formed into a winding different turns of which form said spaced sections of said dispersed conductors, and wherein said dispersed-phase flux carrying means are positioned between said turns of said winding.

5. The transducer of claim 4 wherein said magnetic flux producing means and said armature means are cylindrical, and wherein said actuation enabling means enables said magnetic flux producing means and said armature means to rotate relative to one another to provide said high power output from said transducer.

6. The transducer of claim 1 wherein said magnetic flux producing means and said armature means are cylindrical, and wherein said actuation enabling means enables said magnetic flux producing means and said armature means to undergo linearly reciprocating movement relative to one another to provide said high power output from said transducer.

7. The transducer of claim 1 wherein said magnetic flux producing means and said armature means have substantially flat adjacent surfaces, and wherein said actuation enabling means enables said magnetic flux producing means and said armature means to move such that said flat adjacent surfaces are moved linearly relative to one another to provide said high power output from said transducer.

8. The transducer of claim 1 further comprising rotor means and wherein said magnetic flux producing means is mounted on said rotor means for movement in a predetermined rotational path upon rotation of said rotor means; and wherein said armature means is in the form of a thin shell.

9. The transducer of claim 8 wherein said transducer is operated as a motor, and wherein said actuation enabling means includes means adapted to supply a current to said dispersed conductors to enable said rotation of said rotor means at a sufficiently high rate of speed such that the power output from said motor is greater than one horsepower for each pound of weight of said motor when said motor is operated in a cooling gas medium.

10. The transducer of claim 8 wherein said transducer is operated as an electrical power generating means, and wherein said actuation enabling means includes means for causing rotation of said rotor means at said rate of speed sufficient to create said high power density operation of said transducer.

11. The transducer of claim 8 further comprising housing means; shaft means having a portion within said housing means; and mounting means for mounting said rotor means on said shaft means and wherein said rotor means includes cylindrical means coaxially positioned with respect to said shaft means so that said cylindrical means and said shaft means are constrained to common rotation; and wherein said dispersed conductors constitute a winding formed into a thin shell and said flux carrying means is provided by a plurality of flux carrying elements providing at least two-dimensional phase dispersion,

different ones of said flux carrying elements being positioned between different turns of said winding formed by said dispersed conductors.

12. The transducer of claim 11 wherein said rotor means includes second cylindrical means, and wherein said cylindrical means and said second cylindrical means provide flux return paths.

13. The transducer of claim 1 wherein said plurality of flux carrying means comprises pressed iron powder.

14. The transducer of claim 1 wherein said spaced sections of said dispersed conductors are wires, and wherein said flux carrying means are coatings of highly magnetically permeable material on said wires.

15. The transducer of claim 14 wherein said wires have insulation material thereon, and wherein said coatings of highly permeable material are placed over said insulated coating on said wire.

16. A lightweight high power electromagnetic transducer, substantially as hereinbefore described with reference to the drawings.

17. An armature for an electromagnetic transducer, said armature comprising:

conductor means having a plurality of discrete active regions for carrying electrical current which are spaced apart and have a substantially rectangular cross-section to provide a plurality of discrete elongated open space areas between said active regions, said active regions comprising a plurality of parallel conductive wires insulated from one another; and

a magnetic flux carrying means comprising a multiplicity of discrete flux carrying members formed of compressed iron powder interposed in said open space areas between said active regions of said conductor means, and a bonding agent to hold together said flux carrying means and said conductor means.

18. An electromagnetic transducer, comprising:

(a) magnetic flux producing means for producing a magnetic flux;

(b) an armature means for intercepting said magnetic flux, said armature means including conductor means having a plurality of discrete active regions for carrying electrical current which are spaced apart and have a substantially rectangular cross-section to provide a plurality of discrete elongated open space areas between said active regions, said active regions comprising a plurality of parallel conductive wires insulated from one another, and magnetic flux carrying means comprising a multiplicity of discrete flux carrying members formed of compressed iron powder interposed between said active regions of said conductor means, and a bonding agent to hold together said flux carrying means and said conductor means;

(c) a movable member having one of said magnetic flux producing means and said armature means secured thereto; and

(d) means for mounting the other of said magnetic flux producing means and said armature means to allow said movable member to move relative thereto, whereby said magnetic flux producing means and said armature means are able to move relative to one another.

19. The transducer of claim 18 further comprising cooling means for passing cooling air across said armature means to remove heat and thereby enhance high power output of said transducer.

20. The transducer of claim 18 wherein said magnetic flux producing means is made from one of neodymium boron ferrite, barium ferrite ceramic and samarium cobalt.

21. The transducer of claim 18 wherein said transducer produces electrical power, and further comprising actuation means for causing movement of one of said magnetic flux producing means and said armature means relative to the other of said magnetic flux producing means and said armature means to cause an induced voltage to be produced on said conductor means during said movement.

22. The transducer of claim 18 wherein said magnetic flux producing means and said armature means are cylindrical and wherein said magnetic flux producing means and said armature means are rotated relative to one another to provide high power output from said transducer.

23. The transducer of claim 18 wherein said magnetic flux producing means and said armature means are cylindrical, and wherein said magnetic flux producing means and said armature means are moved linearly reciprocating relative to one nother to provide power output from said transducer.

24. The transducer of claim 18 wherein said magnetic flux producing means and said armature means have substantially flat adjacent surfaces, and wherein said magnetic flux producing means and said armature means are moved such that said flat adjacent surfaces are moved linearly relative to one another to provide power output from said transducer.

25. The transducer of claim 18 wherein said transducer includes a commutator and brushes.

26. The transducer of claim 18 wherein said transducer includes slip rings.

27. The transducer of claim 18 wherein said transducer is operated as one of a motor, generator and alternator.

28. A brushless, high-speed, high torque electric motor, comprising:

a housing;

a shaft mounted on said housing to rotate relative thereto;

a magnetic field-generating rotor secured to said shaft to rotate therewith, said rotor having a mounting disk connected to said shaft and one of (i) a first annular wall means having a magnetic means mounted thereon for generating a magnetic flux and (ii) a second annular wall means comprising an outer annular wall and an inner annular wall both supported by said mounting disk and spaced radially apart to define an annular gap therebetween, said inner wall being spaced radially apart from said shaft, and a magnetic means for generating a magnetic flux mounted on at least one of said inner wall and said outer wall; and

an armature, for intercepting said magnetic flux, fixed to said housing, said armature comprising an annular member positioned to be disposed one of (i) radially adjacent said first annular wall means and (ii) at least partially within said gap between said inner wall and said outer wall of said rotor, said armature including (i) a plurality of spaced sections of electrical conductors, each section including a plurality of separate conductive wires insulated from each other and (ii) a plurality of magnetic flux carrying elements interposed between said sections of conductors, each flux carrying element comprising a member pressed from highly magnetically permeable particles and a binder material for binding said particles together.

29. The motor of claim 28 further comprising actuation means for causing rotation of said shaft at a rate of speed sufficiently high to create a high power density operation of said motor.

30. The motor of claim 28 wherein said wires have insulation material thereon, and wherein said flux carrying elements comprise highly permeable material placed over said insulation material on said wires.

31. The motor of claim 28 wherein said housing includes means causing air to be passed through said housing adjacent to said armature to dissipate heat and thereby improve operation of the motor.

~~32.~~ A brushless DC electric motor suit~~able for use as a~~ traction motor on a vehicle comprising:

an annular winding structure of generally cylindrical shape with two flat ends at which the winding conductors are reversed in direction and an active area between said flat ends;

a plurality of circumferentially spaced discrete elongated openings in said active area;

a plurality of discrete elongated flux carrying bars of pressed powdered iron inserted into said elongated openings so as to act as flux carrying means; said flux bars having radially inner and radially outer elongated edges;

a bonding agent surrounding said winding structure and said flux bars;

a magnetic flux producing means for producing a magnetic flux;

a movable member having said magnetic flux ~~producing means secured thereto; and~~

~~means for mounting s~~ [illegible] ~~nding structure and~~
flux bars to allow ~~sai~~ [illegible] vable member to move
~~relative thereto.~~

Dated 29 June, 1990.

UNIQUE MOBILITY, INC.
By its Patent Attorneys
DAVIES & COLLISON

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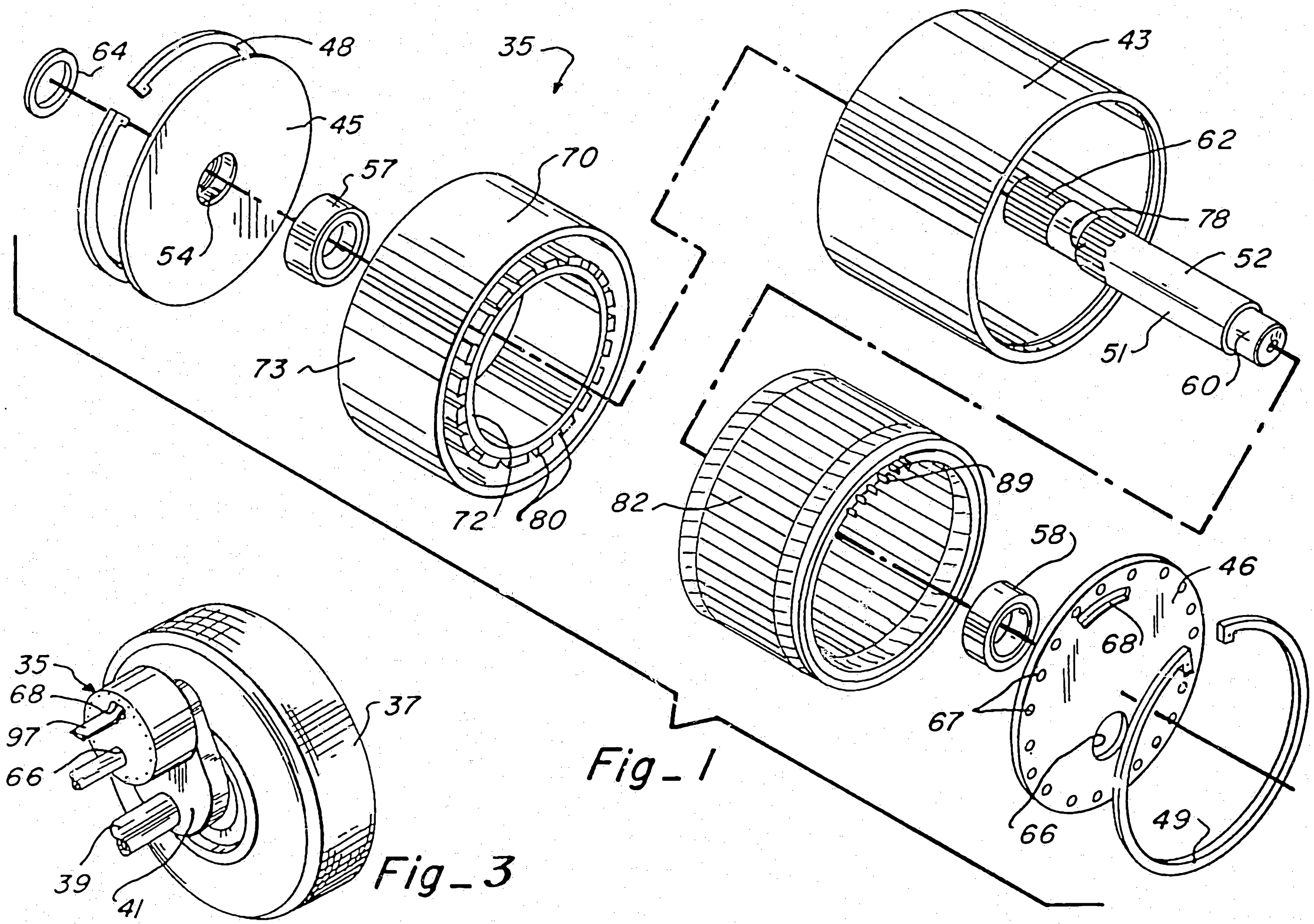

Fig_1

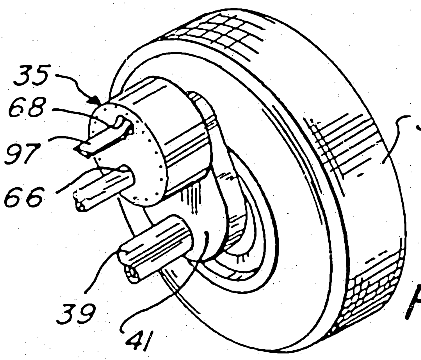

Fig_3

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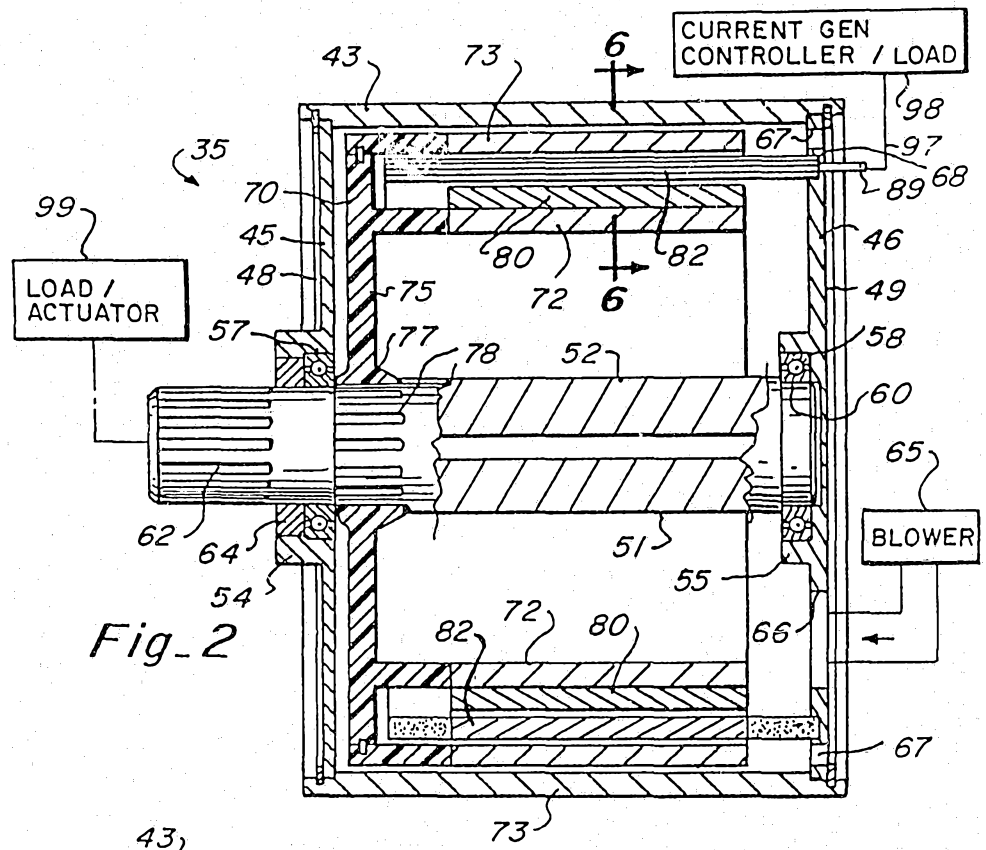

Fig_2

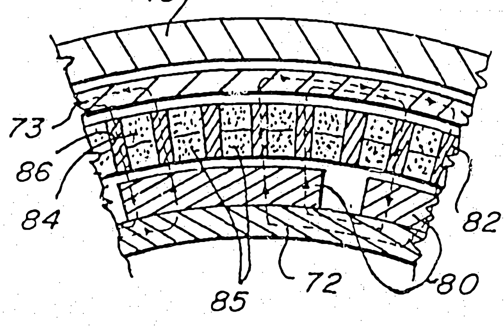

Fig_6

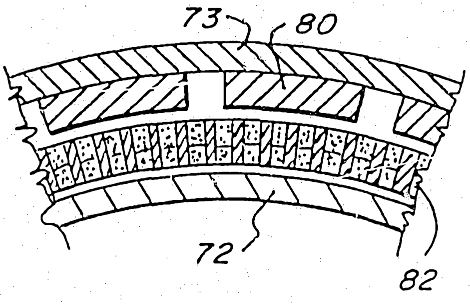

Fig_7

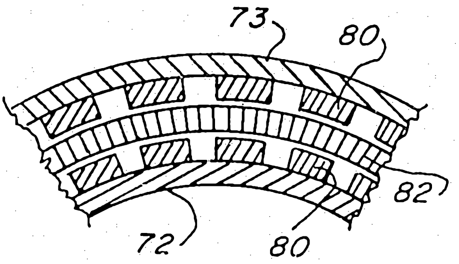

Fig_8

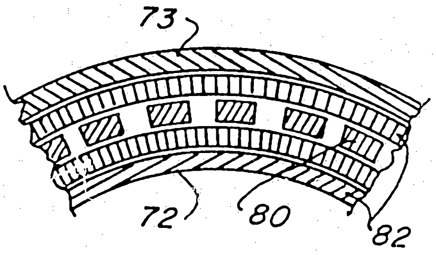

Fig_9

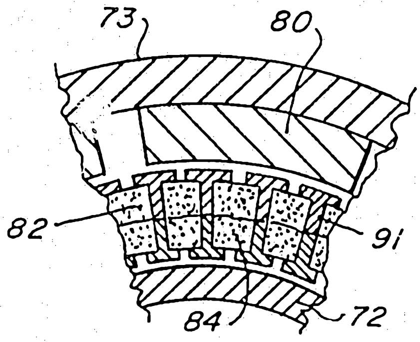

Fig_10

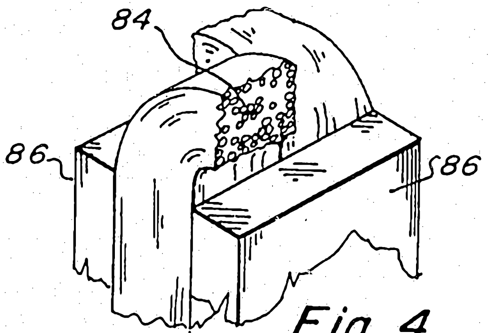

Fig_4

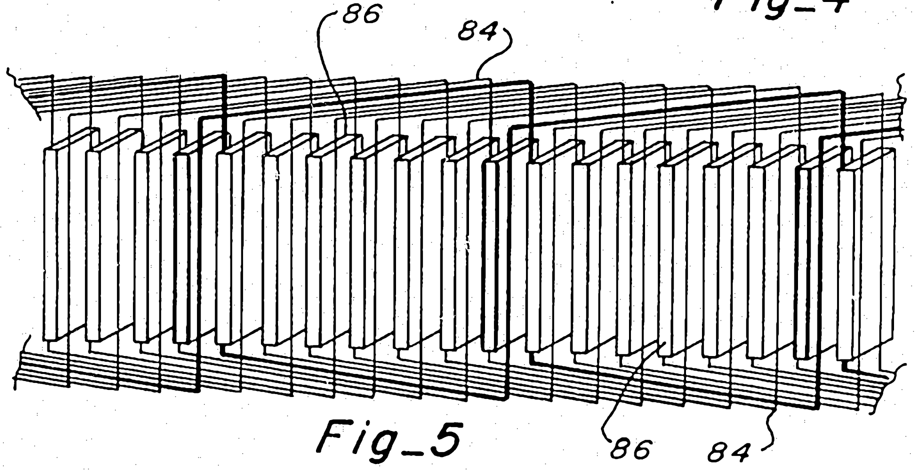

Fig_5

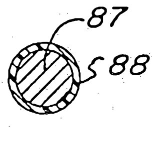

Fig_11

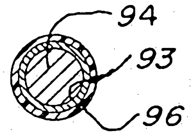

Fig_12

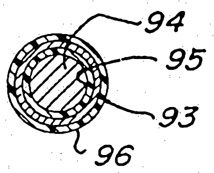

Fig_13

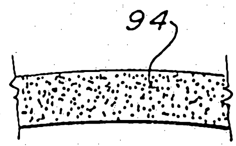

Fig_14

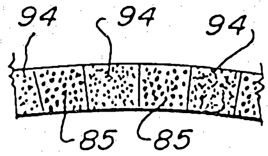

Fig_15

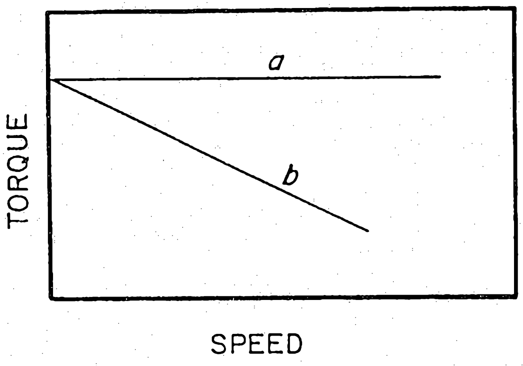

Fig_19

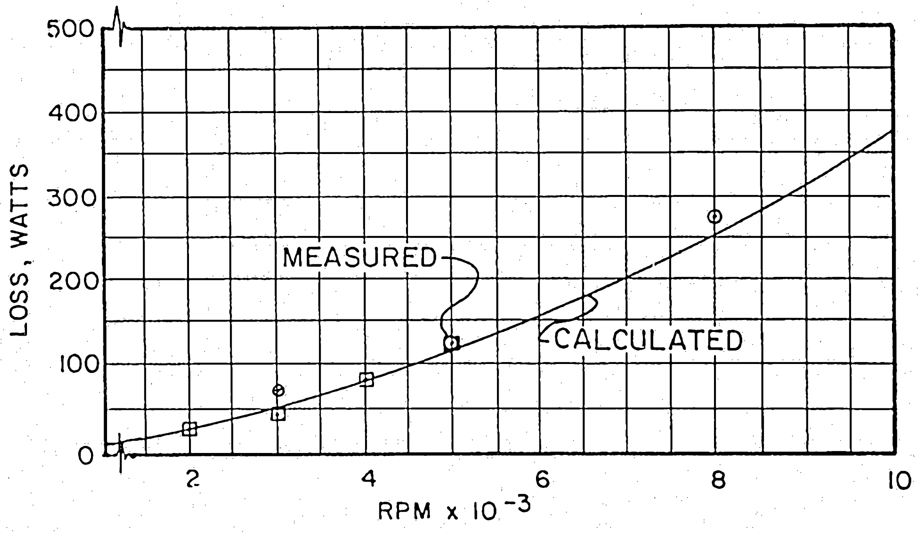

Fig_20

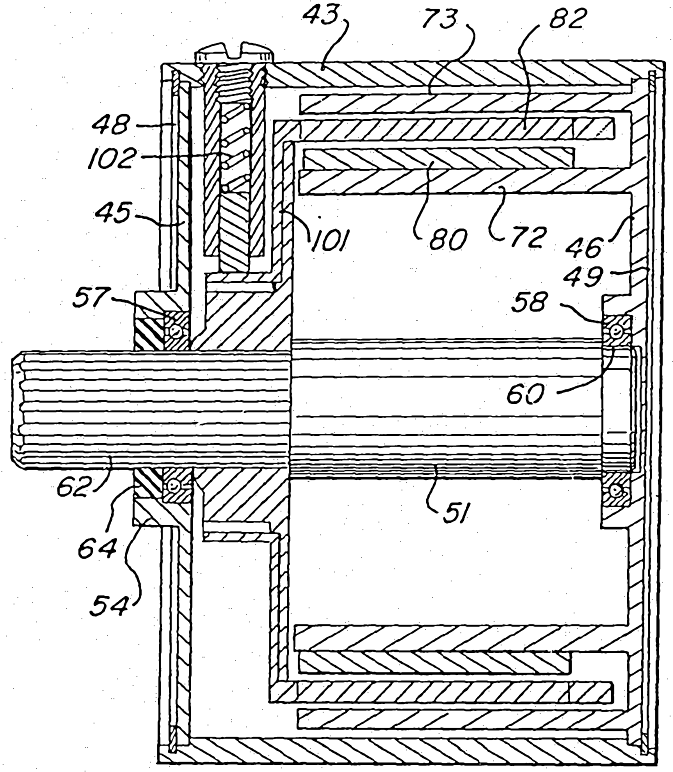
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Fig_16

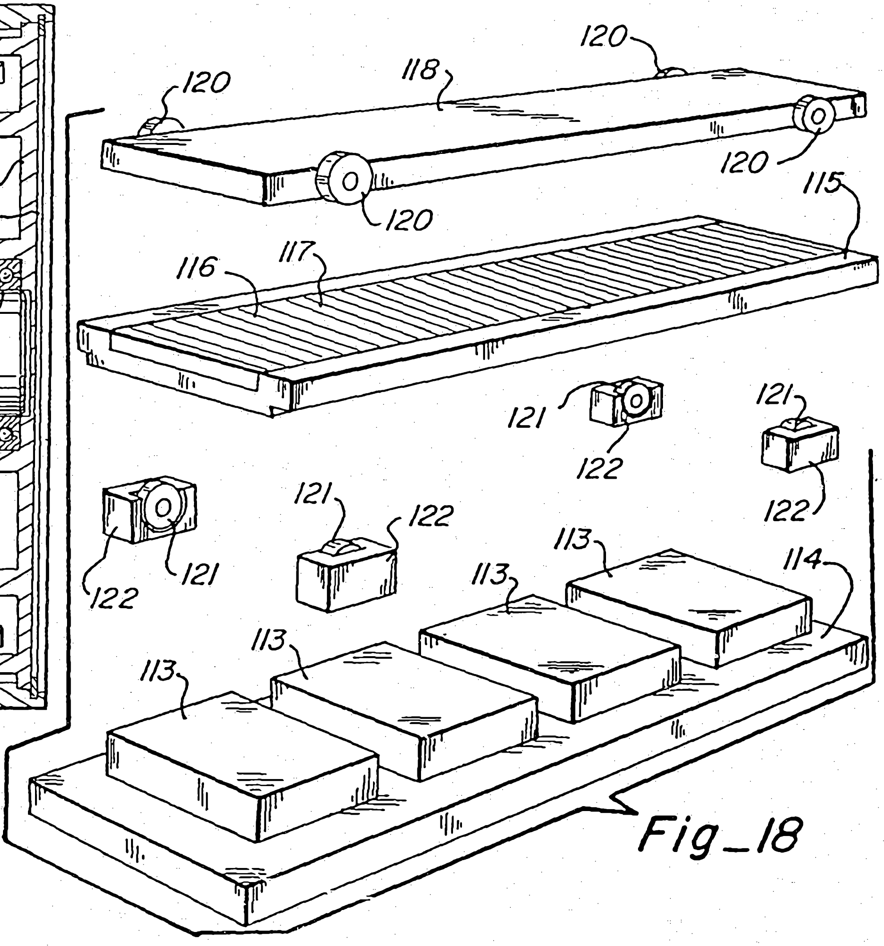
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Fig_18

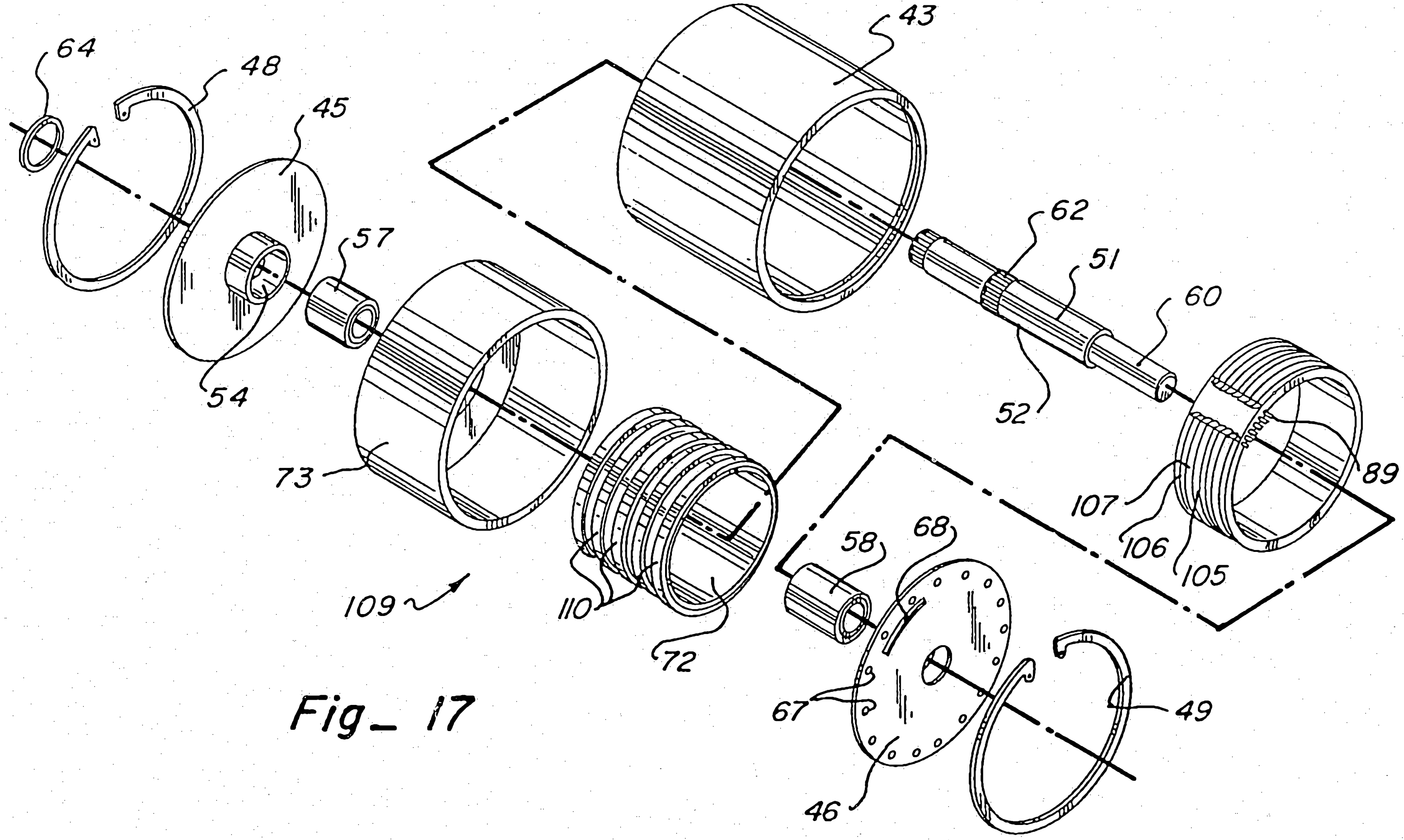
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Fig_ 17