Journal of Electrical Engineering and Science, Vol. 3(2) 2017, pp. 1-10

RESEARCH ARTICLE

A Novel Double Rotor without Stator Electric Motor: Theoretical and Functional Aspects

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Received- 7 February 2017, Revised- 31 May 2017, Accepted- 5 June 2017, Published- 19 June 2017

ABSTRACT

Conventional electromagnetic motor contains two components - stator and rotor. In this present case, both the components of an electromagnetic motor are allowed to remain free, i.e. both the components are allowed to rotate. Thus, there is no stationary stator in the mechanism. The mechanical output of the two counter rotating shafts is collected through a common transmission shaft via either gear mechanism or a combination of gear and belt mechanism. Although dual rotor counter rotating motor has been recently disclosed in an US Patent, the present one is an innovation designed to trap the maximum potentiality of such an electric motor. Depending upon the type and size of the motor, there will be a net increase in energy efficiency in between 25 to 125 per cent over their respective conventional variants. This has huge implication in the field of electrical power generation and consumption.

Keywords: Double-Rotor-Electric-Motor, Universal-Motor, AC-Induction-Motor, Permanent-Magnet-DC-Motor, Stator.

1. INTRODUCTION

The present invention is an energy efficient model of the basic electric motor. This is a novel invention that for the first time is deviced to trap the full potential of a double rotor only electric motor. This will not only change the basic definition of an electric motor that is conventionally understood to be consisted of two components, i.e. stator and rotor, but also will bring revolution in future electricity generation and consumption in the world. The principle of double rotor only electric motor can be applied to all three major genera of electric motors, i.e. (i)AC induction motor, (ii)DC permanent magnet motor, and (iii)AC series or AC/DC Universal motor. In case of AC induction motor, the speed of the motor will be reduced to half as compared to its equivalent conventional variants, but the total combined torque output will be atleast doubled. There will be no change in speed in case of the other two types of motors, provided that the 'mass' is not changed. Thus, there will be a net gain in absolute momentum in such cases. The speed reduction in AC induction motor, however, will not affect the back EMF, as the relative speed of the two rotating components, moving in opposite direction, will not decrease.

The power of the two counter rotating components of such a motor can be harnessed either separately through separate output shafts or collectively through a common output shaft through the application of gears or pulley/belts. Different combination of gear/pulley ratio to transmit power from the two opposite rotating components of the motor to a common output shaft can be used to get the desired output by compromising between torque and speed.

The history of conventional electric motors is quite extensive. Recently during the last 10/15 years several new versions of electic motors and motor applications have been patented in the form of levitated ceiling fan and motor, wind turbine, etc. Of these developments, the double rotor electric motor with stator [1-3] and without stator [4, 5] are

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Double blind peer review under responsibility of DJ Publications
https://dx.doi.org/10.18831/djeee.org/2017021001

the latest addition in the field. The double rotor electric motors, although are not yet very popular in the industry, possibly for their constructional complexity, are now a well-known art disclosed in several patent publications as well as in other literatures. The double rotor electric motors can be classified under the following broad categories.

(a) Double rotor with stator (one or more) electric motor in which both the rotors rotate in a single direction, while the stator is stationary as in any conventional electric motor.

(b) Double rotor without stator (i.e. rotors only) electric motor in which both the armature and the field coil rotate in counter directions and the work output generated in the two rotating shafts are used independently to drive separate mechanical provisions.

(c) Double rotor without stator (i.e. rotors only) electric motor in which both the armature and the field coil rotate in counter directions and the work output generated in the two counter rotating shafts are transmitted to a common transmission shaft by using gear/pulley & belt provision.

Of these categories, the dual rotor with stator electric motors, particularly as a permanent magnet DC machine, recently has become popular as traction motor in electric motor vehicle system [6-9]. Double rotor permanent magnet motor has become a research topic especially for electric vehicle driving system, as this kind of motors can provide higher torque generation in comparison to the conventional interior permanent magnet motors [10]. Several kind of dual rotor motors of this sort have been reported in recent literatures, such as: (i) double-sided slotted axial flux motor having two outer permanent magnet rotors and one inner winding stator [11, 12]; (ii) dual rotor motor consisting of an outer stator, inner wound rotor and outer permanent magnet rotor [13]; (ii) dual rotor motor consisting of double stator as well as double rotor for electric moving vehicle that structurally seems to be two independent motors integrated into one [9]; (iii) dual rotor motor consisting of one inner and one outer permanent magnet rotors and one winding stator at the centre [10]; (iv) dual rotor motor consisting of one inner and one outer permanent magnet rotor and one toroidally wound stator at the centre [14], and the like. There are also literatures on dual rotor induction motor [15, 16].

The double rotor without stator electric motors, as mentioned under 2nd category above, are also now gaining popularity as traction motor for electric moving vehicles, as propulsion motor for water vehicles as well as in other applications. Published literatures describing this type of motors are still very few, but are not rare. There are theoretical descriptions about double rotor without stator permanent magnet machine [17, 18]. The counter rotating induction motors are also discussed [19, 20]. There are a good number of patent publications that claimed this category of electric motor design and applications, as discussed under review of patent disclosures.

Compared to the above two categories, the 3rd category to which the present invention falls has not been reported in published literatures or known in teachings, except a recent disclosure made in the US Patent 8,253,294 B1 [5]. The present invention is a novelty, as for the first time the actual theoretical principle behind the working of a double rotor without stator or counter rotating electric machine has been discussed and described, and the appropriate design has been suggested to explore the actual potentiality of this kind of electric machine.

2. A REVIEW OF THE RELEVANT PATENT DISCLOSURES

(a) US Patent 2,391,103 [21] describes a single motor for driving the two axles of an electric vehicle, one axle being driven by the armature shaft, the other axle being driven by the field and frame of the same motor in which a motor having practically the same weight as that of one of the motors of a conventional street car but which will develop twice the speed of a single motor. By rotating both the field and the armature in opposite directions, the magnetic speed there between is doubled without increasing the absolute armature speed.

(b)US Patent 4,056,746 [22] relates to electric motors having the armature and the field arranged for counter-rotation to apply total generated force to dynamic use. The objective is to arrange the stator of an electric motor for rotation, providing planetary gearing between the rotating armature and the now rotating field whereby counter-rotation of the field is achieved.

(c)In US Patent 8,198,773 B2 [23] a counter-rotating electric motor is described. The objective claimed is to provide a counter-rotating electric motor for use on a water-vehicle (e.g. boat) in which the armature rotates in a first direction and the stator rotates in an opposite second direction about a common central axis and then their opposite rotations are linked to appropriately configured propellers to move the vehicle through the surrounding water in a common direction. As claimed, since both the armature and the stator rotate in opposite directions, the torsional forces normally lost by utilizing a traditional motor in which the stator is fixed within the motor housing are conserved in this kind of operation. It has been claimed that the system can be used extensively in place of the conventional electric motor.

(d)In US Patent 8,253,294 B1 [5] described a dual rotational electric motor/generator in which the armature rotates in a first direction and the stator rotates in an opposite second direction about a common central axis and then their opposite rotations are linked to create an output common rotational direction. The device is to improve the efficiency of an electric motor/generator by accessing torsional forces normally lost to stationary motor/generator mounts that hold the stator in a fixed position.

(e)The US Patent 8,531,072 B2 [24] describes a counter-rotating electric motor for application in electric motor system that operates with dual-mode capabilities in that it may be reversibly converted from a counter-rotating motor into a traditional motor mode upon demand. Counter rotation minimizes the creation of heat during operation and accessing torsional forces normally lost by utilizing a traditional motor in which the stator is fixed within the motor housing and the armature rotates.

(f)In U.S. Pat. No. 3,738,270 [25] a brushless electric DC motor for a torpedo is disclosed. To maintain stability during its course in water to its target, oppositely rotating propellers are beneficial. The design utilizes a stationary stator around which two independent armatures rotate in opposite directions to drive the associated propellers in corresponding opposite directions.

(g)A rotating-field machine is described in U.S. Pat. No. 4,645,963 [26] in which the armature is attached to the axle and is utilized for output work. The stator rotates, but is attached to nothing but the supporting bearings, and is spinning to simply rotate the field and not to produce work.

(h)U.S. Pat. No. 5,067,932 [27] discloses a dual-input motor in which two armatures rotate either together or in opposite directions within a stationary/fixed outer stator. The stator is rigidly affixed to a suspension member or other stationary anchor.

(i)A dual rotary AC generator is described in U.S. Pat. No. 5,089,734 [28]. This disclosure presents, basically, a motor run in reverse, thereby becoming a generator in which both the magnetic field and armature rotate in opposite directions.

(j)U.S. Pat. No. 4,375,047 [29] presents a torque compensating electrical motor. This device is comprised of two motors, either next to one another in a serial connection or inside one another. The armature is attached to the axle and is utilized for output work. The stator rotates, but is attached to nothing but the supporting bearings, and is spinning to simply eliminate internal torque and not to produce work. The subject invention utilizes both the rotating armature and the rotating stator to generate work.

3. DOUBLE ROTOR WITHOUT STATOR AC SERIES OR AC/DC UNIVERSAL MOTOR

3.1. Construction

In conventional AC Series motor or AC/DC universal motor, the field winding stator is fixed while the winding rotor (armature) is allowed to rotate within it. The corresponding segments of the field winding stator and the winding rotor are connected in series through commutator and brush assembly, which are excited either by Alternate Current (AC) or by Direct Current (DC). The rotor rotates by the interacting forces of electromagnets of the stator and the rotor fields. The construction of a conventional universal motor is very similar to the construction of a DC Motor, except that the permanent magnets in a DC Motor are replaced by electro-magnets in the form of stator (i.e. field windings).

Here, both the components of the universal motor are allowed to remain free, and thus allowing both the components to move in opposite directions through the interactions of their respective electromagnetic fields. Here, since the field winding stator is not a stator, but also a rotor, this will be called “field winding rotor” (especially to maintain continuity with the conventional motor type) and the winding rotor will be called “armature rotor”.

The “field winding rotor” and the “armature rotor” are the two components of the motor connected in series, as in case of a conventional universal motor. The AC or DC current input will be supplied to the field windings rotor segment through rotating electrical connectors (i.e. slip ring and brush assembly) which then will pass to the armature rotor segment through a set of commutator and brush assembly, and then through the corresponding segments of the armature rotor and the field winding rotor. Thus, in the present invention there will be a set of rotating electrical connectors (i.e. slip ring and brush assembly) and a set of commutator and brush assembly to supply current to the field winding rotor and to the armature rotor.

The two rotating components of the motor will be rotated by both repulsion and attraction forces of the electromagnet poles. To facilitate efficient pulling and pushing forces of the magnets, the winding slots of the field winding rotor and of the armature rotor will be arranged in skewed alignment facing each other and towards their respective direction of motion as shown in figure A1. The South Pole (A) and the North Pole (B) of the field winding rotor will be repelled by the corresponding same pole interaction of South Pole (1 to 4) and North Pole (5 to 8) of the armature rotor. At the same time, the skewed projection of the leading slots of the armature rotor (8 & 4) and the field winding rotor (A & B) will attract each other due to their proximity. As the armature rotor and the field winding rotor move forward, the electric field of the armature rotor changes to set another cycle of repulsion and attraction episode to cause further movement of the rotors in their respective direction, and the cycle continues. The device can be fixed both in conventional way using ball bearings and in magnetic levitation structure or in a combination of both. In the latter case, there will be more advantage for the system being completely friction less.

Since both the components of the motor (i.e. “field winding rotor” and “armature rotor”) will rotate in opposite direction, the speed of the motor may be reduced due to mechanical factors (e.g. ‘friction’) compared to its equivalent conventional type. This, however, will not affect the back EMF production, but instead will enhance the same, as the relative speed of the armature rotor in relation to the field winding rotor will increase.

The total combined torque output of the rotating components will be increased. Separate mechanical or electrical loads can be driven separately by both the rotating components of the motor. Alternately, the torque produced in the two opposite rotating components of the motor can be transmitted to a single output shaft through gear or pulley/belt system. And in this way the combined torque can be harnessed through a single output shaft. Different combination of gear/pulley ratio to transmit power from the two opposite rotating components of the motor to a common output shaft can be used to get the desired output compromising between torque and speed.

3.2 Theoretical Analysis

If two attracting/repelling magnets of equal mass (when in case of unequal mass, particularly if one of the magnets is too heavy than the other, the lighter one only will move/displaced), each carrying the maximum possible unit of load, are allowed free, double the resultant power (i.e. the net load carrying together by the two magnets) will be produced by the force of attraction/repulsion of the pair of magnets, as compared to a condition when only one of the magnets is allowed free.

There will be a further gain that if two attracting magnets are allowed free, the resultant attractive force will increase compared to a situation when only one of the magnets is free. The force of attraction between two magnets increases exponentially, which is dependent on ‘distance’ between the two attracting magnets. In case of two free magnets attracting (i.e. approaching) each other, the distance between the magnets decreases at double the speed compared to a condition when only of the magnets is free.

Since the force of attraction between two magnets is same as between two opposite charges, by applying Coulomb's inverse-square-law, we get equation (3.1).

$$F = \frac{PQ}{x^2} + C \tag{3.1}$$

where F is the force of attraction between the magnets P and Q; X is the distance between them, and C is a constant, which is the force of attraction at ‘0’ distance.

Now, when one of the magnets is fixed and the other is allowed to move from the outermost edge of the magnetic field of attraction, the sum of the force of attraction can be calculated by integrating the equation (1)

Thus, we get equation (3.2).

$$F = \int \frac{PQ}{x^2}\,dx + C \qquad (3.2)$$

Now, when both the magnets are allowed to move from the outermost edge of the magnetic field of attraction, the sum of the force of attraction will be double, as the distance covered by time becomes half.

Thus, we get equation (3.3).

$$F = [2\,(\int \frac{PQ}{x^2}\,dx)] + C \qquad (3.3)$$

For the same reason, as explained above, but acting conversely, if two opposing magnets are set free, the resultant repulsive force will decrease by half as compared to a condition when only one of the magnets is free. Thus, there will be virtually no gain or loss in the resultant force, especially in a linear system of magnetic interactions, where both the attractive and repulsive forces are operating equally in opposition.

In a rotating system, if two closed rings of electro-magnets (or one electro-magnet and one permanent magnet) are rotating through their mutual magnetic interactions of repulsive force uniformly all through the path there will be no gain or loss in the net resultant repulsive force, irrespective of only one of the magnets is free or both are free, when the force of repulsion between the two interacting magnets locked in a circular path is same at any given point of location. The collective force (absolute momentum) of the two rotating magnets, however, will be twice that of one.

However, there will be a net gain in the attractive force if the two approaching electro-magnets (or one electro-magnet and one permanent magnet) are rotating through their mutual magnetic interactions of attraction force, compared to a condition when only one of the magnets is free, when the force of attraction is not same all through the path, as the force of attraction is not same at all the points of location.

Thus, there will be a net gain in the resultant force when two electro-magnets (or one electro-magnet and one permanent magnet) are rotating through their mutual magnetic interactions of “attraction and repulsion” or “primary attraction and secondary repulsion” or “only attraction”, as in case of a counter rotating electro-magnetic motor. The gain will be from: (i)the two rotating components instead of one driven by the same input power and (ii)torque gain from the two approaching magnets. There will be further gain in a counter rotating system in terms of (i)the power advantage from back EMF, and (ii)the torque gain from conservation of torsion force.

4. DOUBLE ROTOR WITHOUT STATOR PERMANENT MAGNET DC MOTOR

Construction of a permanent magnet DC motor can be made simply by replacing the two poles of the field winding rotor by the two poles of a permanent magnet.

5. DOUBLE ROTOR WITHOUT STATOR AC INDUCTION MOTOR

The torque and speed relation in an AC induction motor is not a lineal relation, which is quite unlike an AC series motor or a permanent magnet DC motor. In the present invention, since both the components of the motor will rotate in opposite direction, the speed of the motor will be reduced to half compared to its equivalent conventional type. This, however, will not affect in the back EMF production, as the relative speed of the rotating electromagnetic field in the winding rotor or the primary winding rotor in relation to the induction rotor or the secondary winding rotor will remain unchanged. The advantage of a double rotor AC induction motor however can be harnessed from the attraction forces of the two approaching magnets.

6. EXPERIMENTAL ANALYSIS & RESULT

In case of AC series or AC/DC universal motor, for any given motor the RPM vs load and the current consumption vs load are directly and lineally related. On increasing the load, RPM decreases, and as the RPM decreases the current consumption increases until it reaches to the maximum limit, the halting current (i.e. maximum current consumed when the motor is not running at all). Both these conditions are tested for a motor in its conventional mode of application (i.e. fixed stator and moving rotor) as well as in the double rotor only mode of application, as claimed here. The findings are presented in figures A2 and A3. It is clearly found that in the double rotor only mode of application the motor is efficient in terms of both current consumption as well as RPM/load carrying capacity. There is about 15 to 25 per cent less current consumption and about 80 to 100 percent increase in load carrying capacity (i.e. torque).

7. DISCUSSION

Recently counter rotating DC motor in which both the stator and the rotor rotates in opposite direction has become popular as traction machine, as in this method two wheels instead of one can be driven by one single motor allowing better traction torque, light weight and greater manoeuvrability of the vehicle. A dual rotor motor produces substantially equal tractaive forces on both driving wheels, while allowing different rotational speeds of the wheels during a turn of the vehicle. Another advantageous application for which these kinds of motors become popular in vehicle use is their combined use, both as a traction motor and as an alternator. The advantages of dual rotor counter rotating electric motor over their single rotor conventional variant have been well documented, and already are in commercial use. Nevertheless, in wider applications the single rotor machine is still preferred, particularly where the double rotor construction is not needed [13].

Although it has been practically well demonstrated, there is, however, no exclusive discussion, suggestion, implication, or teaching that, why the double rotor without stator electric motor will be more efficient in using less input energy and producing more output work. There are only a few published literatures that scarcely attempted to explain some of the possible reasons. The US Patents 8,198,773 B2 [23]; 8,253,294 B1 [5] and 8,531,072 B2 [24] explains conservation of torsional force in counter rotating system, which is otherwise wasted in conventional motors. This may be true, but does not explain the quantum advantages as recorded in this system. In another US Patent 2,391,103 [21] it has been claimed that by rotating both the field and the armature components in opposite directions the magnetic speed there between is doubled without increasing the absolute armature speed. Another US Patent 5,844,345 [30] claims that a homopolar dual rotor motor doubles the armature voltage at a given speed in comparison with prior homopolar motors using a stationary field core, and doubles the induced electromagnetic forces and power output of the motor for a given size. In yet another U.S. Patent 4,056,746 [22] the advantages of a counter-rotating motor are described as: (i) increasing the field cutting speed of the armature to increase power output of the motor, (ii) minimizing field collapse, and (iii) maintaining the angular rate of the armature which is compatible with the containment of the generated centrifugal forces.

In a DC or an AC series double rotor without stator electric motor, as is being discussed here, there would be a net gain in the resultant force when two electro-magnets (or one electro-magnet and one permanent magnet) are rotating through their mutual magnetic interactions of “attraction and repulsion” or “primary attraction and secondary repulsion” or “only attraction” forces. The gain would be from: (i)the two rotating components instead of one driven by the same input power, (ii)torque gain from the two approaching magnets, (iii)the power advantage from back EMF, and (iv)the torque gain from conservation of torsion force. A similar motor running as a generator will deprive off at least from the first two advantages, as mentioned above. In case of double rotor AC induction machine, the advantages will be further reduced, as in that case the speed (rpm) will be reduced to one half, while the torque will be twice of that of its single rotor equivalent. In a conventional AC induction motor, the current frequency is a limiting factor to rpm, and that the induction rotor moves at slightly less speed (slip) than the rotating electromagnetic field in the stator coil. In a double rotor AC induction motor, when both the rotor and the stator rotate in opposite direction, the speed of the rotating electromagnetic field reduces to half, resulting equivalent reduction in motor rpm. Thus, there will be no gain in net momentum (i.e. torque times rpm) of the motor. Therefore, a counter rotating AC induction motor, as claimed in the present invention, will not get any real advantage from the two counter rotating components, except that there will be some advantages from the magnetic attraction mode.

The advantages of double rotor motor, as discussed in literatures, are not exclusive and often are confusing or not accurately explained. In available literatures no distinction has been made with regard to the use of the system, either as electric motor or as generator or with regard to the type of electric motor in terms of AC induction motor, DC permanent magnet motor and AC series (or universal) motor, when these factors directly involve the output advantages of a double rotor counter rotating motor system. This is for the first time that the reasons for the increased efficiency of this kind of electric motors are being implicitly explained and discussed. This not only provides the actual theoretical explanations to the application, but also implicitly suggests appropriate designs for this kind of motors to optimize efficiency.

8. CONCLUSION

For more than 100 years of the invention of electric motor, only half of the total potential power of such a machine is utilized through the conventional definition and construction of electric motor consisting of a stationary stator and a dynamic rotor. Although recently several designs of double or multiple rotor electric motors are suggested and brought in use, the counter rotating motor in which both the stator and the rotor components of a motor rotate in different direction and the separate work outputs are brought in use through the common transmission shaft is a recent concept. The provision of the double rotor without stator electric motor as claimed in the Patents US 8,253,294 B1 [5]; 8,198,773 B2 [23] and 8,531,072 B2 [24] is a mere general claim, since the application of the provision (i.e. counter rotating motor) is not same for all the different genera of electric motors, and that the actual advantages of the provision can be harnessed only through the detail construction plan of the motor, as claimed in the present invention. The counter rotating or the double rotor only electric motors, as claimed in this present invention, not only will change the conventional definition of electric motors that is continuing since the days of their original invention but also will harness the total potential power of such a device. This present invention for the first time described and discussed the detail theoretical facts of a counter rotating double rotor without stator electric motor under all the three broad classifications of electric motors (i.e. AC, DC and universal motors), and thereby suggesting the exact appropriate design and functioning of the machine. Depending upon the type and the size of the motor, there will be a net increase in energy efficiency in between 25 to 125 per cent over their respective conventional variants. This has huge implication in the field of electrical power generation and consumption.

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APPENDIX

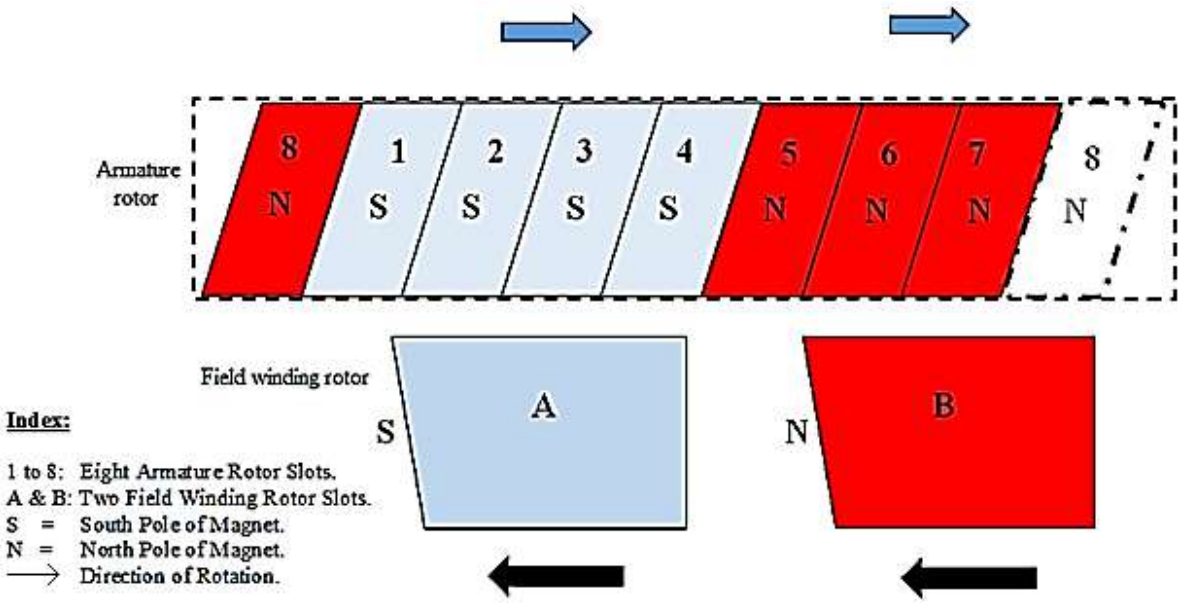
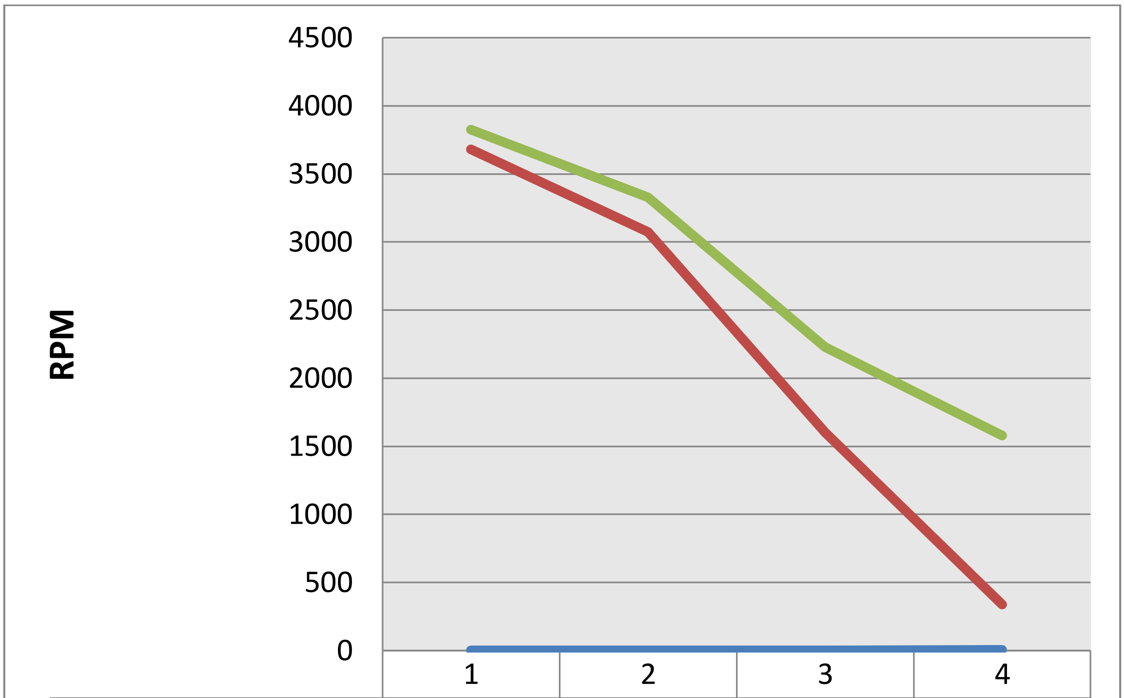
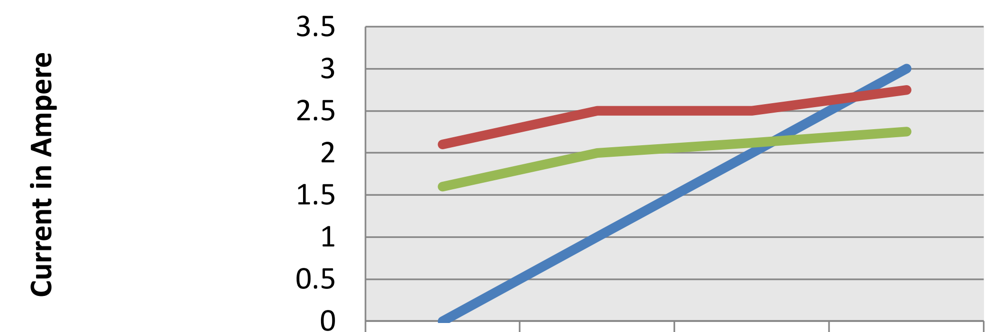


Figure A1.Armature and field winding rotors



	1	2	3	4
Load (in kg)	0	1	2	3
Conventional motor (rpm)	3,679	3,072	1,600	337
Double rotor only motor (rpm)	3,826	3,328	2,227	1,579

Figure A2.Universal motor, RPM and load



	1	2	3	4
Load (in kg)	0	1	2	3
Conventional motor (current)	2.1	2.5	2.5	2.75
Double rotor only motor (current)	1.6	2	2.12	2.25

Figure A3.Universal motor, current and load