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## PATENT SPECIFICATION

(11) 1 417 014

- (21) Application No. 57395/72 (22) Filed 13 Dec. 1972  
 (31) Convention Application No. 209 673 (32) Filed 20 Dec. 1971 in  
 (33) United States of America (US)  
 (44) Complete Specification published 10 Dec. 1975  
 (51) INT CL<sup>2</sup> H02K 3/02  
 (52) Index at acceptance H2A 11B 1C6A2 1C6B 9D



## (54) INDUCTIVE DEVICES

(71) We, GENERAL ELECTRIC COMPANY, a corporation organised and existing under the laws of the State of New York, United States of America, residing at 1 River Road, Schenectady 12035,<sup>1</sup> State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to inductive devices in general and is especially applicable to motors and stator assemblies for motors for use in applications wherein various desirable motor characteristics during starting conditions of a motor are at least partly derived from the characteristics of an auxiliary winding.

Single phase, alternating current induction motors of various types conventionally include a main (e.g., running) field winding and an auxiliary (e.g., starting) field winding, the two windings being angularly displaced on a stator core member. Upon energization of the two windings, phase displaced currents in the windings result in starting torque for the motor.

In one type of single phase induction motor, referred to as a resistance split-phase motor, the main winding is arranged in stator core slots to have relatively high inductance and relatively low resistance, whereas the auxiliary winding is arranged to have a relatively low inductance and relatively high resistance. By preselecting the difference between the resistance-to-reactance ratios of the main and auxiliary windings, a desired phase displacement in winding currents and thus starting torque may be obtained. With this type of motor, the auxiliary winding is desirably de-energized when a predetermined operating condition is attained, e.g. when the motor attains a predetermined speed.

In many applications, de-energization of the auxiliary winding is effected by control means in the form of a centrifugal switch mechanism which is directly responsive to the attained speed of the motor. In other applications other

means are used. For example, in hermetically sealed motor applications, it is desirable to use types of control means that are located outside the hermetically sealed motor chamber.

One particular type of auxiliary winding circuit control means that has been used heretofore has included a commercially available current responsive relay, with the relay coil connected in series with the main field winding and with normally open contacts of the relay connected in series with the auxiliary winding. In operation, the main winding current during an initial energization interval energizes the relay coil and the relay contacts close, thereby to energize the starting winding. Thereafter, as the motor speed increases from standstill, the main winding current is reduced in magnitude and the relay contacts open. Thus, the auxiliary winding is deenergized when the main winding current falls to a predetermined relay dropout current value. This will desirably occur at a predetermined speed, generally selected to be around 3200 r.p.m. in the case of a two pole motor energized by a 60 hertz voltage source.

For a given main winding arrangement, care must be taken to ensure that the contacts of a given relay will close when the locked rotor current of the main winding flows through the relay coil; and to ensure that the main winding current (and relay coil current) will decrease an amount sufficient to cause the relay to drop out, i.e. open its contacts, only after the motor has accelerated to a preselected speed. Thus, it is desirable that the relay drop out only after sufficient time has elapsed to permit the attainment of the preselected speed. In addition, it will be appreciated that, for a given main winding arrangement and current relay, the main winding current at a given speed during starting conditions is a function of (among other things) the reactance of the auxiliary winding. Relay characteristics are also described in U.S. Patent 3,633,507.

One factor which must be considered in the overall design of a resistance split-phase motor that is to be used with a start relay is the dropout torque of the motor, i.e., the torque

supplied by the motor at the time when the relay drops out, the dropout torque also being a function of the resistance-to-reactance ratios of the main and auxiliary windings. It has been determined that the main winding current of a resistance split-phase motor will, in general, cause desirable relay operation, when the resistance of the effective starting winding turns is high relative to the resistance of the effective main winding turns. For a specified main winding arrangement, therefore, desirable relay operation will normally occur when the resistance of the starting winding circuit is relatively high. However, while relatively high winding resistances are desirable for relay operation, such high resistance conditions are undesirable for other reasons.

For example, relatively high winding resistances may result in relatively high temperature rises in the start winding. While high temperature rises are objectionable in general, they are particularly objectionable in those applications where the permissible temperature rise of a motor winding should be relatively low. One type of such application are those where the winding would be confined in a closed container, e.g., a hermetically sealed enclosure.

It is known that the temperature rise of a motor winding is a function of (among other things) the current density within the motor winding conductors. It will thus be appreciated that, for a given winding conductor material and a given winding current, a desired increase in winding resistance may usually not be accomplished by merely decreasing the diameter of the winding material because of an undesired winding temperature rise that would result from the increased current density in the winding conductors.

Still another relationship that should be kept in mind when considering the temperature rise of a motor winding is the resistivity, density, and specific heat of the winding material, in view of the fact that temperature rise or rate of such rise of a conductor is generally proportional to the product of the current density squared times the resistivity, divided by the product of the density and specific heat of the conductor. The temperature rise of a winding is of course important by itself or when a motor user specifies a maximum temperature rise or rate of temperature rise that will be acceptable to such customer. However, temperature rise may also be important due to the increase in winding resistance that one normally expects to be associated with an increase in winding temperature and the corresponding reduction in locked rotor torque that in turn results from increased start winding resistance in resistance split-phase motors.

In the early development of the motor art, including the hermetic motor art; both the main and starting windings were formed of

copper wire. However, particularly in the case of hermetic motor parts, a starting winding having a desired number of turns formed of copper wire with a sufficiently small diameter to provide a desired resistance for preferred relay operation would have resulted in an excessive winding temperature rise. For this reason, external resistors were employed in series with the starting winding in order to provide a desired high starting circuit resistance while forming the starting winding per se from copper conductors sufficiently large in size so that the winding current density and rise would not exceed acceptable levels. For example, some motor users specify that current density should not exceed 25,000 or 30,000 amps. per square inch of conductor and a maximum temperature rise rate of about 13° F (7° C) per second. Other users, on the other hand, may find current densities of 50,000 or 60,000 amps. per square inch acceptable.

Later, in order to eliminate the external resistor, attempts were made to utilize phosphor bronze wire as the starting winding conductor. In theory, the resistivity and weight density of phosphor bronze materials could be attained so that a desired high winding circuit resistance could be attained without an external resistor and so that starting winding current densities and temperature rise would remain within acceptable limits. For example phosphor bronze having a by weight copper content of about 98.75% copper and a by weight tin content of about 1.25% would have a conductivity of about 44% that of commercial copper electrical conductors; a weight density of about 8.89 gms/cc (about .321 lbs/in<sup>3</sup>); and a specific heat at about 25° C of about .09 cal/°C/gm (about 170.9 joules/°C/lb).

However, it will be understood that use of phosphor bronze wire would add appreciably to the cost of a motor because of the cost of the material. For example, one pound (or Kg) of the alloy would contain about .99 of a pound (or Kg) of copper. In addition, the resistivity of 1.25% phosphor bronze wire is known to vary to such an extent from lot to lot, that it would be necessary to vary the diameter of the wire from lot to lot in order to obtain wire having a desired or specified resistance per unit length of wire.

It will be understood that the necessity of establishing a different diameter of wire for each lot of wire, depending on the resistivity of the material, would be expensive in practice. Moreover, variations in wire size from one lot to another would be troublesome to motor manufacturers who design motors so that core slots will have a desired winding space factor and who utilize winding generating and handling equipment whose satisfactory operation under a given set of conditions would be more consistent with a single, predictable, wire diameter.

For these and other reasons, a "backlash" winding rather than a phosphor bronze approach has been used extensively in practice. The general backlash approach that was first adopted is still followed today.

By way of background, backlash winding provides a motor design engineer with a technique of obtaining an essentially continuously variable winding resistance for a given number of effective winding turns. In practice, the backlash approach involves winding a desired number of inductive turns and then adding an additional or excess length of winding in order to establish a total winding resistance desired for a particular motor design.

In other words, wire having a sufficiently large diameter to avoid excessive current densities and temperature rise is employed in a sufficient length to provide the desired resistance. The length of wire in excess of that needed for the desired number of inductive turns is accommodated in a "backlash" winding section. The backlash winding section includes equal numbers of forward and reverse turns with the inductance of the reverse wound turns cancelling out the inductance of the forward wound turns.

While the backlash winding approach has provided a means of attaining a desired winding resistance and winding temperature rise characteristic for many years, the approach has been expensive in practice because lengths of winding material are provided purely for the sake of increasing the over-all winding resistance. These extra turns do not otherwise contribute to the motor performance. The "backlash" technique thus adds appreciably to the over-all cost of a motor.

In addition, if the backlash winding coils are manually arranged, an operator must be sure to reversely dispose half of the turns in the backlash section. On the other hand, if a winding machine is programmed to wind the reverse or backward turns, the machine must come to a halt after winding all of the forward turns, reverse directions, and then wind the reversely disposed turns in the backlash section. This also is costly because of the expense associated with more complex winding equipment and the expense of extra machine and operator time that is required due to stopping and reversing the winding direction of the winding equipment. It will thus be appreciated that it would be desirable to reduce, if not eliminate, the number of backlash winding turns that have heretofore been considered to be necessary for a given winding arrangement in many given motor designs.

Based on economic considerations, e.g., the relative cost of copper vis-a-vis aluminum winding materials, it is expected that the substitution of aluminum wire for copper wire for both main and auxiliary windings will become increasingly desirable. However, the

resistivity (sometimes also called specific resistance) of aluminum is about 2.828 micro-ohm centimeters at 20° Centigrade as compared with about 1.724 for copper. Thus, about 1.6 times more volume of aluminum wire per unit length must be employed in order to obtain the same winding resistance as would be obtained with a unit length of copper wire. Thus, for unit lengths of copper and aluminum wire that are each to have a given resistance, the cross-sectional area of the aluminum wire must be 1.6 times greater than the cross-sectional area of the copper wire. It will therefore be appreciated that, particularly for aluminum winding motor designs, winding turns in a "backlash" section (which do not contribute to running performance of a motor) would occupy space which could otherwise be used to accommodate winding turns that could contribute to the running performance of the motor.

However, even when following known teachings, it has not been possible to convert many copper motor designs to aluminum winding designs. At least some of this problem is due to the need for aluminum backlash windings in such designs. Thus, in at least some designs wherein aluminum main windings have been utilized, it has still been necessary to use copper starting winding coils rather than aluminum because of the lack of available magnetic core slot space or volume. For example, in one existing aluminum main winding motor design which has been examined, a copper starting winding having a total of 208 turns were used and of the 208 turns, 68 turns (or over 32%) of the total turns were the forward and reverse turns of a backlash winding section. Assuming that the number of turns in the backlash winding section could be reduced or eliminated, the winding slot space that would then be made available could desirably be utilized to accommodate the increased volume of an aluminum conductor and result in a savings due to the change in winding material as well as due to the reduction or elimination of manufacturing costs associated with backlash winding sections.

It will be understood therefore from the foregoing, that it would be generally desirable to provide motor winding arrangements for various motor part designs wherein the number of winding turns in a backlash winding section of a wound stator core are reduced, if not eliminated.

In addition, it would be desirable to provide new and improved arrangements for resistance split-phase motor parts whereby the number of backlash winding turns, needed for a desired level of operational performance while utilizing copper starting windings, may be reduced (if not eliminated) while retaining a nominal starting winding electrical resistance, and temperature rate of rise so that savings associated

positioned in corresponding slots 14 on the with reduced or eliminated backlash winding turns may be realized without a sacrifice or reduction in motor operational performance.

According to the present invention there is provided an inductive device comprising a magnetic core having coil accommodating regions and a plurality of winding turns supported thereon, and wherein at least some of the winding turns are formed from a winding material having a characteristic ratio  $R$  greater than 6 where.

$$R = \frac{\rho}{CpD}$$

and:

$\rho$  is the electrical resistivity of the material at 20° C in micro-ohm centimetres,

$Cp$  is the specific heat of the material at 25° C in calories per °C per gram, and

$d$  is the density of the material at 20° C in grams per cubic centimetre.

An embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:—

FIGURE 1 is a partly schematic end view showing a typical two pole, resistance split-phase, alternating current induction motor stator assembly and is useful as an aid in describing prior arrangements as well as embodiments of the present invention;

FIGURE 2 is a diagram schematically showing the electrical connections of the main and starting windings of the stator assembly of FIGURE 1 and also showing, within a phantom line enclosure, one arrangement of backlash windings known and used heretofore;

FIGURE 3 is a graph illustrating a locked rotor torque curve for a two pole, resistance split-phase motor incorporating aluminum main windings and copper starting windings with backlash winding sections; and

FIGURE 4 is a locked rotor torque curve of the general type shown in FIGURE 3, but for a motor embodying the present invention.

Referring now to FIGURE 1 of the drawings, there is shown a stator assembly for a two pole, resistance split-phase, alternating current induction motor. The stator assembly, generally indicated at 10, comprises a stator core member 11 which may be formed of a plurality of stacked relatively thin laminations of magnetic material. Core member 11 includes yoke portion 12 having a plurality of teeth 13 extending radially inwardly therefrom to define winding slots 14 therebetween, inner ends 15 of teeth 13 mutually defining a bore 16 for receiving the usual squirrel cage rotor member (not shown). In the exemplification, the teeth 13 have been shown as being equally

spaced apart and bounding twenty-four equally spaced apart and similar winding slots 14, but it will be understood that the invention may also be practiced with cores made with laminations having what are known as graded slots or graded teeth and including those having nonradial teeth, as well as other slot configurations that may be desired.

A main or running field winding is provided disposed in certain predetermined slots 14 so as to form two diametrically opposite main poles aligned on the axis shown by the dashed line 17. The main winding is divided into two section 18a and 18b each forming one of the main poles. In the assembly 10, each of the main winding sections 18a, 18b comprises five concentric coils of progressively greater pitch respectively designated  $M_1$ ,  $M_2$ ,  $M_3$ ,  $M_4$ , and  $M_5$ . As shown in FIGURE 2, main winding sections 18a and 18b are connected in parallel, however, in certain applications the main winding sections may be serially connected.

Considering main winding section 18a, the sides of the smallest pitched coil  $M_1$  respectively occupy a pair of slots 14—2 on opposite sides of axis 17 with slots 14—1 therebetween. The sides of main winding coils  $M_2$ ,  $M_3$ ,  $M_4$ , and  $M_5$  respectively occupy pairs of slots 14—3, 14—4, 14—5 and 14—6. The sides of main winding coils  $M_1$  through  $M_5$ , for convenience, are respectively positioned at the bottoms or closed ends of the pairs of slots 14—1 through 14—6. The main winding coils  $M_1$  through  $M_5$  of the other main winding section 18b are similarly positioned in corresponding slots 14, as shown in FIGURE 1.

An auxiliary or starting field winding is similarly disposed in certain predetermined slots 14 and forms two diametrically opposite auxiliary or starting poles aligned about an axis (angularly spaced in quadrature or non-quadrature relationship to axis 17) shown by dashed line 19. The starting winding is divided into two serially connected sections 20a, 20b which respectively form the diametrically opposite auxiliary or starting poles. In the illustrated embodiment, each of the starting winding sections 20a, 20b comprises four concentric coils of progressively greater pitch respectively designated  $S_1$ ,  $S_2$ ,  $S_3$ , and  $S_4$ .

Referring now to starting winding section 20a, the sides of coil  $S_1$  share the pair of slots 14—4, on opposite sides of axis 19, with the sides of coils  $M_3$  of main winding sections or parts 18a, 18b. The sides of coil  $S_2$  share slots 14—3 with the sides of coils  $M_2$  and the sides of coils  $S_3$  share slots 14—2 with the sides of coils  $M_1$ . The sides of the largest pitched coil  $S_4$  are the sole occupants of the pair of slots 14—1, and the sides of coils  $S_1$ ,  $S_2$  and  $S_3$  are respectively wound or placed over the respective sides of coils  $M_3$ ,  $M_2$  and  $M_1$ . The starting winding coils  $S_1$  through  $S_4$  of the other starting winding section 20b are similarly

opposite side of stator core 11 as shown in FIGURE 1.

The sides of coils  $M_1$ ,  $M_2$  and  $M_3$  of main winding sections 18a, 18b which respectively share slots with sides of starting winding coils  $S_3$ ,  $S_2$ , and  $S_1$  are preferably, but not necessarily, pressed back to facilitate accommodation of the starting winding coil sides. Particularly when the main windings are formed of aluminum wire, it may also be desirable to compact the main windings prior to placement of the start windings.

Referring additionally to FIGURE 2, ends 22 of main winding sections 18a, 18b are shown connected to external terminal 23 having coil 24 of current responsive relay 25 connected in series therewith. Ends 26 of main winding sections 18a, 18b are shown connected together at a common connection to lead 27 with end 32 of the starting winding section 20b. This common connection is often buried, and common lead 27 may then be used to provide means for making the common connection. End 28 of starting winding section 20a is connected to external terminal 29 having contacts 30 of relay 25 serially connected therewith.

Although FIGURE 2 does not clearly illustrate the fact, it is sometimes necessary, according to prior practice, to distribute a backlash winding in several slots, i.e., arrange or wind two or more coils (such as coils  $S_3$  and  $S_4$  in FIGURE 2) so that each will include some forward and backward turns of a backlash winding section. This is done, for example, when such a large number of backlash turns are needed that the outermost coil slots cannot physically accommodate all of the backlash turns.

In a previously known two pole, resistance split-phase alternating current induction motor incorporating a main winding formed of .0380 inch (.96mm) diameter EC (electrical conductor) grade aluminum wire having a resistance of about 3.22 ohms per pole or section, the starting winding was formed of .0179 inch (.457mm) diameter copper wire having a resistance of 12.6461 ohms. Coils  $M_1$ ,  $M_2$ ,  $M_3$ ,  $M_4$ , and  $M_5$  of each winding section or pole 18a, 18b, respectively had 34, 50, 50, 68, and 68 turns for a total of 270 turns per pole or section. Each of the coils  $S_1$ ,  $S_2$ , and  $S_3$  of each starting winding section 20a, 20b respectively had 21, 30, and 34 turns; and coils  $S_4$  of each starting winding section 20a, 20b had 67 forward wound turns and 39 reverse wound turns for a total of 106 turns in each of coils  $S_4$ . The total number of turns per starting winding section was thus 191 turns. Of the 106 turns in each coil  $S_4$ , 78 turns (i.e., 39 forward wound plus 39 reverse wound) were backlash turns, leaving 28 net effective turns in coil  $S_4$ . Thus about 40% of each 191 start turns were backlash turns.

The material used in fabricating the stator assembly for this motor included about .777 pounds (.351 Kg) of EC aluminum wire in the main winding with a conductor length of about 276 feet (84 meters) per main pole; and about .386 pounds (.175 Kg) of copper wire in the auxiliary or starting winding with a conductor length of about 192 feet (59 meters) per pole and a resistance of about 12.6 ohms. Main winding resistance per pole was about 3.22 ohms.

This stator assembly, when built into a motor and tested, provided a locked rotor torque curve or trace A as shown in FIGURE 3. Using three seconds after beginning the tests as a reference, the maximum locked torque was about 11.0 ounce feet; the minimum locked rotor torque was about 8.4 ounce feet; the average locked rotor torque was about 9.7 ounce feet. The slope of the lines A—1 and A—2, fitted to trace A in FIGURE 3 indicate that the drop off in locked rotor torque due to heating was about .2 ounce feet per second. The trace A (as well as trace B to be described in conjunction with FIGURE 4 hereinafter) was made by a test procedure using a test rotor and pair of test bearings that supported the rotor for rotation in the bore of the stator assembly under test.

The windings of the stator assembly to be tested were then connected to a conventional nominal 110 volt alternating current source. However, the rotor was restrained from freely rotating because it was connected, through a LeBow solid state torque transducer (as will be understood) to the output of a 400:1 gear reduction motor with an output speed of 8:8 r.p.m. Essentially the only criteria concerning the selection of the gear reduction motor was that it have sufficient torque to restrain the test rotor so that the test rotor turned at a substantially constant speed of 8.8 r.p.m.

The output of the torque transducer, which represented a varying resistance, was then amplified in a conventional manner to provide a time varying d.c. output voltage that thus varied as the output torque of the rotor varied during each revolution (about 6.82 seconds per revolution) thereof. Because of the low speed of the rotor, the output torque thereof was taken, as will be understood, to be the locked rotor torque thereof.

The time varying d.c. output voltage was then visually displayed on an oscillograph and recorded on an oscillogram as a torque versus time trace. Traces made in this manner were then used to make FIGURES 3 and 4 herein. The same test procedures and conditions were followed; and the same rotor and bearing system were used to test the motors for which the trace data of FIGURES 3 and 4 were obtained.

An improved stator assembly embodying the invention was made and built into an improved motor that, upon testing, produced a locked

rotor torque curve or trace B as shown in FIGURE 4. Before considering trace B in detail, the winding arrangements for this stator assembly and materials used therein will first be described. This improved, stator assembly was also wound as a two pole, resistance split-phase alternating current stator and was designed to have, as near as possible, the same operating and starting (i.e., performance) characteristics as the stator just described. Accordingly, the same core lamination design was used and the same stack height, i.e., 1 3/4 (one and three-quarters) inches (4.45 cm) was used. The bore was about 2 3/8 (two and three-eighths) inches (6.05 cm).

Accordingly, the main winding was formed of .0380 inch (.962 mm) EC aluminum wire, it being noted that the conductivity of EC aluminum wire is known to be about 62% of the conductivity of the International Annealed Copper Standard. Thus, EC aluminum is commonly identified as having a conductivity of 62% IACS or as having a relative electrical conductivity (i.e., relative to copper) of .62.

The main winding coils in each pole or section 18a, 18b, were formed so that the coils M<sub>1</sub>, M<sub>2</sub>, M<sub>3</sub>, M<sub>4</sub>, and M<sub>5</sub> each had, respectively, 28, 43, 57, 67, and 70 turns for a total of 265 turns. About .774 pounds of EC aluminum wire was used with a conductor length of about 275 feet per main pole and a resistance of about 3.21 ohms per pole.

However, the starting or auxiliary winding was formed from a material that was preselected to have an electrical conductivity, with reference to IACS of about 0.40 or less and to have what will be referred to herein as a "characteristic ratio 'R'" of a value described below, where "R" is defined by the equation:

$$R = \frac{\rho}{C_p d}$$

In the above equation that defines the ratio "R",  $\rho$  is the electrical resistivity of the material at 20° C; as expressed in micro-ohm centimeters. Also,  $d$  is the density, at 20° C, in grams per cubic centimeter (gm/cc or gm/cm<sup>3</sup>), and  $C_p$  is specific heat, at 25° C, of the preselected material and expressed in the cgs units of calories per gram per degree centigrade (cal/gm °C).

For purposes of information, it is noted that copper (of the type used in the starting winding of the previously described motor) would have a density of about 8.9 gm/cm<sup>3</sup>; a resistivity of about  $1.72 \times 10^{-6}$  ohm centimeters or 1.72 micro-ohm centimeters, and a specific heat of about .092 cal/gram °C so that the "characteristic ratio" or R for such copper material would be about 2.2. The dimensional units for R may be readily

ascertained from the above equation as being (micro-ohms) (°C) (cm)<sup>4</sup>/(cal); but will not be again referred to herein. It is also noted that EC aluminum would have an R value of about 5 when the resistivity, specific heat, and density are about (in the units referred to above), respectively: 2.78, .2, and 2.6. It would be generally desirable to preselect starting winding material having a conductivity of about 40% IACS or less and having physical and electrical properties such that the characteristic ratio R for the material is greater than 6, e.g., 6.5; it being noted that at least one material (copper-clad steel or copper-coated steel) having an "R" equal to about 6.8 could be useable to advantage in some inductive device applications.

Additional materials will be specifically identified hereinafter that have the desired properties; but, for purposes of exemplification, an aluminum alloy material was chosen for which R was calculated to be about 10.6. The selected conductor material, to be described in more detail hereinafter, had an electrical conductivity of about 29% IACS at 20° C. One commercial source of an aluminum alloy material having these desirable characteristics is Aluminum Company of America, and such material is marketed by that company and is more conventionally used for rivets and zipers and is relatively "springy".

This material was obtained as .0269 (.684 mm) diameter wire, insulated with magnet wire varnish or enamel in the usual manner, and used to form the starting winding of the improved stator assembly. Accordingly, the starting winding sections 20a, 20b were formed of .0269 (.684 mm) diameter aluminum alloy wire. The coils S<sub>1</sub>, S<sub>2</sub> and S<sub>3</sub> of each starting winding section 20a, 20b respectively had 21, 21 and 33 turns; whereas coils S<sub>4</sub> of each starting winding section 20a, 20b respectively had 42 forward turns and 6 reverse turns for a total of 48 turns (12 backlash and 36 effective) and a grand total of 123 turns per winding. Compared to the earlier described motor, a startling reduction in backlash turns was accomplished since less than 10% of the start turns were backlash turns.

About .167 pounds (.076Kg) of this alloy material was used in this starting winding, with a conductor length, per starting section or pole, of about 118 feet (36 meters) and a resistance of about 12.4 ohms. Somewhat surprisingly and unexpectedly, this improved motor exhibited improved starting torque characteristics as revealed by trace or curve B in FIGURE 4.

For example, with reference to the three second torque values for curve B, the maximum locked rotor torque again was 11 ounce feet, but the minimum torque was increased to 9.6 ounce feet, the average torque increased to 10.3 ounce feet, and the drop off in torque due to heating was also improved and only

about .13 ounce feet per second. Drop off in torque is, of course, important because; in the event that a rotor for a resistance start motor does not start moving when the motor is first energized (e.g., when the rotor is "locked" or "stalled"), the locked rotor torque will undesirably continue to decrease as shown by curves A and B. The drop off torque for curve B was determined from the slope of lines B—1 and B—2, which were fitted to curve B, as will be understood.

For completeness of description, some of the published properties and characteristics for the above alloy, known as 5056 alloy, and other alloys having relative conductivities and characteristics within the above mentioned preferred ranges will be presented hereinafter in tabular form. For this same reason, published data generally describing the material content of each of the tabulated alloys is also presented in tabular form.

For purposes of clarifying terminology used herein, it should also be noted that when the term "relative resistivity" is used herein, the term means the reciprocal of the relative conductivity. Also, for ease of conversion of dimensional units, it is noted that a specific heat of about .22 cal/gram °C is about equivalent to 410 joules/lb °C.

It will be noted from the tables presented

below that the density and specific heat of the tabulated alloys are generally comparable to those characteristics of EC aluminum. It will therefore be understood that since the selected alloy has a relatively high relative resistivity of 345% IACS (i.e., 1/.29 IACS), as compared to EC aluminum which has a relative resistivity of about 1/.62 IACS or 162% IACS; alloy wire having a larger diameter and thus larger cross-sectional area as compared to EC aluminum wire will be used. Thus, for a given current the current density would be less in the alloy than in EC aluminum for a specified or given temperature rise. Therefore, larger diameter and therefore generally stronger wire may be used in a starting winding as compared to an EC aluminum conductor. This in turn can result in various manufacturing advantages as will be discussed in more detail hereinafter.

The following Table I sets forth, inter alia, some of the properties of the aluminum based alloys referred to above and identified by alloy numbers 2219, 5056, 5083, 5356 and 5456 in the Alcoa Aluminum Handbook published by Aluminum Company of America in 1959, 1962, and 1967. It will, of course, be borne in mind that any material selected, whether based on aluminum, copper, steel, tungsten, silver, etc., is to be drawn into relatively thin wire.

TABLE I

| Alloy | Density (d) at 20°C |          | Melting Range, approximate °F | Electrical Conductivity at 20°C, % of IACS | Specific heat (C <sub>p</sub> ) at 25°C cal/gm °C |
|-------|---------------------|----------|-------------------------------|--------------------------------------------|---------------------------------------------------|
|       | g/cm <sup>3</sup>   | lb/cu in |                               |                                            |                                                   |
| 2219  | 2.832               | 0.1023   | 1010-1190                     | 28                                         | .207                                              |
| 5056  | 2.642               | 0.0954   | 1055-1180                     | 29                                         | .216                                              |
| 5083  | 2.660               | 0.0961   | 1075-1185                     | 29                                         | .214                                              |
| 5356  | 2.643               | 0.0955   | 1060-1180                     | 29                                         | .216                                              |
| 5456  | 2.652               | 0.0958   | 1055-1180                     | 29                                         | .215                                              |

According to the above referenced Alcoa publication, these alloys further have nominal chemical compositions as shown in Table II below.

TABLE II

| Alloy | % Si                  | % Fe | % Cu             | % Mn               | % Mg             | % Cr               | % Zn | % Ti               | % Other |
|-------|-----------------------|------|------------------|--------------------|------------------|--------------------|------|--------------------|---------|
| 2219  | 0.20                  | 0.30 | 5.8<br>to<br>6.8 | 0.20<br>to<br>0.40 | 0.02             |                    | 0.10 | 0.02<br>to<br>0.10 | 0.15    |
| 5056  | 0.30                  | 0.40 | 0.10             | 0.05<br>to<br>0.20 | 4.5<br>to<br>5.6 | 0.05<br>to<br>0.20 | 0.10 |                    | 0.15    |
| 5083  | 0.40                  | 0.40 | 0.10             | 0.30<br>to<br>1.0  | 4.0<br>to<br>4.9 | 0.05<br>to<br>0.25 | 0.25 | 0.15               | 0.15    |
| 5356  | 0.50 Si<br>plus<br>Fe |      | 0.10             | 0.05<br>to<br>0.20 | 4.5<br>to<br>5.5 | 0.05<br>to<br>0.20 | 0.10 | 0.06<br>to<br>0.20 | 0.15    |
| 5456  | 0.40 Si<br>plus<br>Fe |      | 0.10             | 0.50<br>to<br>1.0  | 4.7<br>to<br>5.5 | 0.05<br>to<br>0.20 | 0.25 | 0.20               | 0.15    |

In Table II above, only the alloying materials are listed. It will be understood that aluminum comprised the balance or remainder of each listed alloy and that "other" represented impurities (on a percent by weight basis) or non-analyzed materials.

It will be recalled that the motor having characteristics shown by curve B exhibited, after three seconds, an increase in minimum torque of about 15%; an increase in average torque of about 5%; and a desirable 36% reduction in torque drop off due to heating. This motor also, somewhat surprisingly, exhibited a reduced third harmonic dip in the speed torque curve as compared to the motor from which the curve A data was obtained.

A further desirable feature of the alloy material used in the exemplification described above is that its resistance may be expected, with a 90% confidence level, to vary not more than about 3% from lot to lot with the same wire diameter. Thus, it would not be necessary to vary wire diameter, from lot to lot, in order to provide wire having a desired total resistance per unit length of wire. This desirable feature is believed primarily to be due to the fact that the alloying constituents (i.e., non-aluminum constituents) were about 4% or more of the total alloy on a weight basis and, therefore, probably more readily controlled.

It will be understood that with the use of preselected auxiliary winding material as taught above, backlash turns may be completely eliminated in both new and at least some existing motor designs; i.e., motors having a specified winding arrangement.

For example, one existing two pole, resistance split-phase induction motor design had an .0359 inch (.906mm) diameter EC aluminum main winding with .563 pounds (.255 Kg) of conductor arranged in 257 turns per pole with a resistance of 5.78 ohms per pole. Coils  $M_1$ ,  $M_2$ ,  $M_3$ ,  $M_4$ , and  $M_5$  of each main winding section or pole had 38, 43, 51, 63, and 62 turns, respectively. An .0179 inch (.455mm) diameter copper start winding was utilized with .352 pounds (.16 Kg) of conductor arranged in 208 turns per pole, and with a resistance of 11.5 ohms.

Coils  $S_1$ ,  $S_2$ , and  $S_3$  had 22, 38, and 54 turns respectively. Coil  $S_4$  in each pole was provided with a total of 94 turns. Of these, 60 turns were forward turns and 34 turns were backward turns. Thus, coil  $S_4$  had 26 net effective turns and 68 backlash section turns.

For purposes of comparison, a stator assembly for a motor embodying the present invention was then designed to have operating characteristics similar to those of the motor just described and, except for unexpectedly improved characteristics of the type discussed hereinabove with FIGURE 4, similar starting characteristics so as to provide desired start relay characteristics.

The stator assembly so designed employed .0359 inch (.906mm) diameter EC aluminum wire for the main winding with 256 turns and a total conductor weight of about .563 pounds (.255 Kg). The resistance of the main winding was 5.78 ohms. The start winding was made of .0269 inch (.68mm) diameter 5056 aluminum alloy wire with 139 turns per pole, a conductor weight of about .156 pounds

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(.071 Kg), and a resistance of about 11.6 ohms. Coils  $M_1$ ,  $M_2$ ,  $M_3$ ,  $M_4$  and  $M_5$  of each main winding section respectively had 37, 41, 53, 63, and 62 turns. The coils  $S_1$ ,  $S_2$ ,  $S_3$  and  $S_4$  of each starting winding section respectively had 24, 34, 39, and 42 turns for a total of 139 turns per pole or section. None of these turns were used as backlash winding turns.

By comparison of the materials used in the two stator assemblies just described, it will be appreciated that utilization of the present invention can result in extremely large savings, both in amount of material used, types of material used; as well as in improved winding arrangements.

There are still further advantages resulting from the use of conductor material other than EC copper or EC aluminum wire for the starting windings where such conductor material has a relatively high resistivity. The very substantial reduction in the number of backlash turns (or complete elimination thereof) provides a reduction in the internally induced start winding voltage. This reduction has been estimated to be, on the average, about 65%. Furthermore, since the diameter of a relatively high resistivity wire will be greater than that of an EC conductor wire that would provide the same total resistance in a given motor design, the wire of preselected material would better withstand stresses during manufacturing that might break a smaller diameter wire. In addition, a wire of relatively high resistivity may now be selected to have a higher tensile strength per diameter increment than heretofore. In the case of the alloy used in the above described preferred exemplification, the tensile strength may be expected to be from about 44,000 to about 52,000 psi; and this increased strength will permit the material to be wound at relatively high speeds on automatic equipment and yet withstand the stresses associated with operation of such equipment.

It should be noted that materials which would be particularly attractive to use are those that are alloys of well-known conductive materials (e.g., copper and aluminum), primarily because of the relatively economical commercial availability of such conductive materials. However, other materials, such as copper plated steel, might also be selected. Based on investigations that we have made of different existing motor designs utilizing conventional start windings with backlash sections, the material actually selected would preferably have a relative conductivity for those designs of less than about 40% IACS, and, desirably, from about 18% to about 34% IACS. Although a relative conductivity greater than about 40% IACS may be desirable for some applications, it should be noted that at least when an aluminum alloy material is used, the relative conductivity would be less

than that of EC aluminum, i.e., less than about 60% IACS.

The characteristic ratio  $R$  would preferably be greater than the predetermined number discussed hereinabove. For example, we have determined that materials having an  $R$  value of 15 or more and also meeting the other selection criteria mentioned above may be advantageously used.

Although the resistivity or specific resistance is used above in the calculation of the ratio  $R$  for preselected materials, it may occur that the published or given data concerning a material under consideration will be expressed in terms of conductivity or in terms of conductivity relative to copper at 20° C. In this event, it will be helpful to recall that resistivity may be determined by dividing the known value for conductivity at about 20° C of the material relative to IACS, (expressed in decimal form) into 1.72 micro-ohm centimeters. Furthermore, when the conductivity is stated in terms of mhos per centimeter, the resistivity (in ohm-centimeters) will be the reciprocal of the conductivity and may then be easily expressed as micro-ohm centimeters to determine the  $R$  ratio given above.

Although the invention has been described in connection with specific exemplifications of single phase motor stator assemblies having a main (or first) and an auxiliary (or second) winding, the polar axes of the windings may be angularly displaced in quadrature or non-quadrature relationship. It will thus be understood by those skilled in the art that the invention and benefits derived therefrom may be incorporated in other types of dynamoelectric machines or assemblies having other winding arrangements and different numbers of poles comprised of one or more coil groups having one or more coils therein of at least one turn each. In addition, although all of the stator assemblies actually constructed as described hereinabove had a bore of about 2.4 inches (6 cm) in diameter and an outer diameter approximately in the neighborhood of 4 3/4 (four and three-quarters) (12 cm) to 4 7/8 (four and seven-eighths) inches (12.4 cm); assemblies embodying the invention may be of any selected size.

Moreover, although the invention has been described with extensive reference being made, for purposes of exemplification, to inductive devices in the form of induction motor stator assemblies (e.g., wound stator cores); and although extensive reference has been made to one specific preselected material for the same reasons; it will be understood that the invention may be used to benefit in connection with various inductive devices; such as, e.g., thermally responsive relays. Furthermore, various materials, preselected as taught hereinabove may be utilized.

## WHAT WE CLAIM IS:—

1. An inductive device comprising a magnetic core having coil accommodating regions and a plurality of winding turns supported thereon, and wherein at least some of the winding turns are formed from a winding material having a characteristic ratio R greater than 6 where

$$R = \frac{\rho}{Cpd}$$

10 and:

$\rho$  is the electrical resistivity of the material at 20° C in micro-ohm centimetres,

Cp is the specific heat of the material at 25° C in calories per °C per gram, and

15 d is the density of the material at 20° C in grams per cubic centimetre.

2. An inductive device as claimed in Claim 1 wherein the tensile strength of the pre-selected winding material is greater than the tensile strength of a conductor formed of EC aluminum of the same diameter as a said winding turn.

3. An inductive device as claimed in Claim 1 or Claim 2 wherein at least some of said plurality of winding turns are arranged to establish first polar axes; and other one of said plurality of winding turns establish other polar axes angularly displaced from the first polar axes.

4. An inductive device as claimed in Claim 1 or Claim 2 including first and second windings that each comprise a plurality of coils having at least one said winding turn each.

5. An inductive device as claimed in Claim 4 wherein the first and second windings are auxiliary and primary windings which are arranged to be connected in parallel circuit relation; the resistance-to-reactance ratios of the primary and auxiliary windings are selected to establish phase displaced winding currents in the primary and auxiliary windings during concurrent excitation of said windings; and wherein the auxiliary winding turns in each auxiliary winding pole provide an electrical resistance of magnitude thereby to reduce the need for auxiliary winding turns arranged in subtracting magnetic relation in an auxiliary pole relative to other auxiliary winding turns in the same auxiliary pole, when excited.

6. An inductive device as claimed in any one of Claims 1 to 5 wherein said winding material is an aluminum alloy.

7. An inductive device as claimed in Claim 6 wherein said aluminium alloy includes at least 4% by weight of an alloying metal.

8. An inductive device as claimed in Claim 7 wherein said alloying metal is magnesium.

9. An inductive device as claimed in any one of Claims 1 to 8 wherein said winding material is a wire material having a nominal electrical conductivity of from 18% I.A.C.S. to 40% I.A.C.S.

10. An inductive device as claimed in Claim 9 and substantially as described herein with reference to relevant portions of Figs. 1, 2 and 4 of the accompanying drawings.

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