Feb. 20, 1962 R. HYINK 3,022,449

ALTERNATING CURRENT ELECTROMAGNETIC DEVICE

Filed Dec. 21, 1956 2 Sheets-Sheet 1

Fig. 1

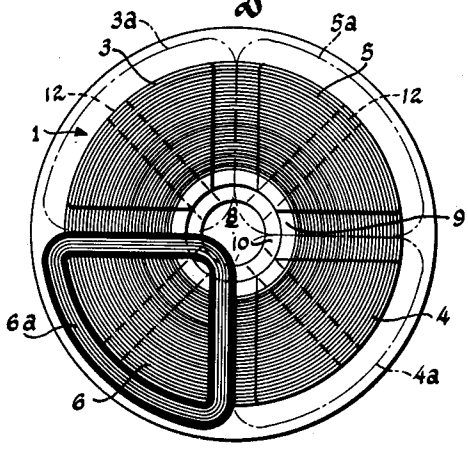


Fig. 2

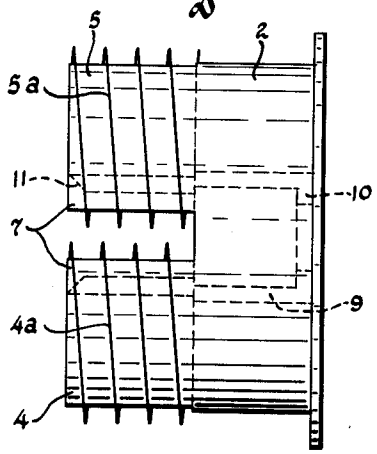


Fig. 3

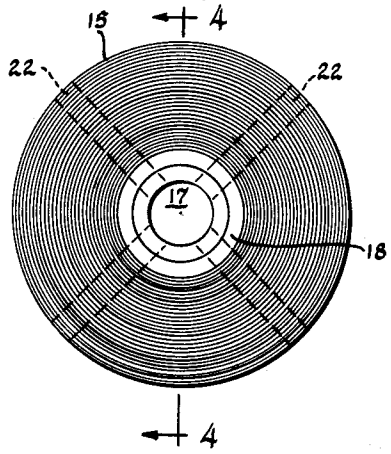
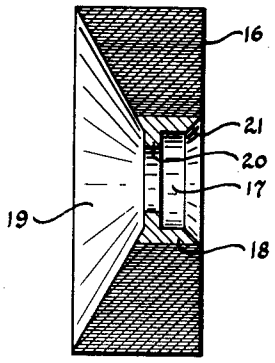


Fig. 4



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Feb. 20, 1962 R. HYINK 3,022,449

ALTERNATING CURRENT ELECTROMAGNETIC DEVICE

Filed Dec. 21, 1956 2 Sheets-Sheet 2

Fig. 5

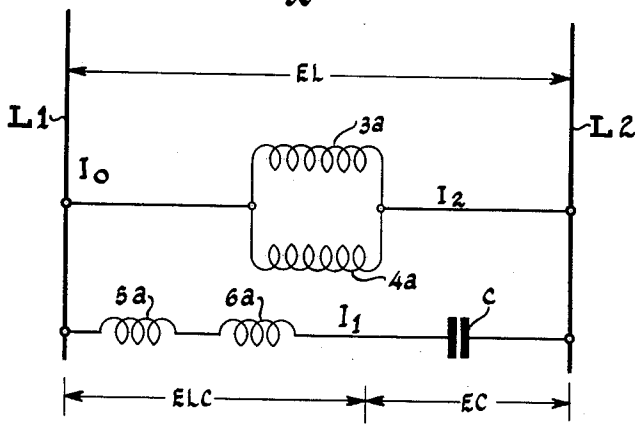
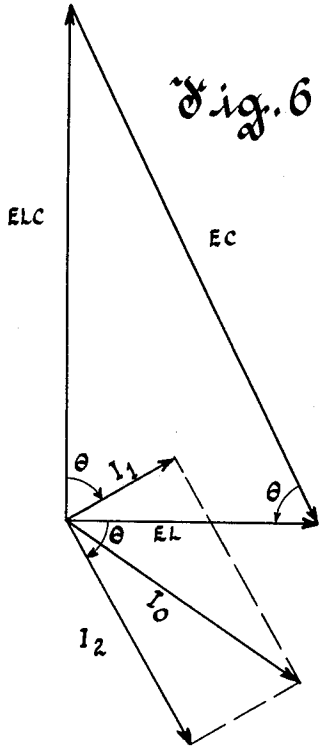


Fig. 6



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ALTERNATING CURRENT ELECTROMAGNETIC DEVICE

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15 Claims. (Cl. 317—123)

This invention relates to improvements in electromagnetic devices.

While not limited thereto, the invention is especially applicable to alternating current contactors and relays operated at high ambient temperatures in control systems of aircraft and the like where good quality of performance and low noise are required.

Irwin W. Cox application Serial No. 626,471 filed December 5, 1956, now Patent No. 2, 925,540, dated February 16, 1960, and assigned to the assignee of the present application, discloses a cylindrical electromagnetic device constructed by winding a strip of magnetic material onto an arbor and milling across one end to produce four angularly spaced pole pieces. Preformed coils surrounding the pole pieces are energized from an alternating current supply source having a frequency in the range of approximately 180 to 1,000 cycles so that pairs of diametrically opposite coils have a phase displacement of approximately 90 degrees. It has been found desirable to wind the strips of magnetic material for both the core and the armature on tubular internally flanged nonmagnetic arbors which can be left in the finished products to provide internal support for the laminations. It is also desirable to construct both the core and armature without use of organic materials to bind the laminations to provide an electromagnetic device capable of withstanding extremely high temperatures. It is further desirable to reduce the weight of the armature to the lowest possible value without decreasing the efficiency of the device.

Accordingly, an object of the present invention is to provide improved means affording the aforementioned and other results.

A more specific object of the invention is to provide an improved split-phase alternating current electromagnetic device for operation in the range of frequencies between 180 and 1,000 cycles having minimum size and weight.

A still more specific object of the invention is to provide improved means for simply and economically affording and maintaining a desired phase displacement between the operating coils of such device.

A further specific object of the invention is to provide an improved electromagnetic device of the aforementioned type operable at a standard power supply voltage wherein such desired phase displacement is afforded by a capacitor having a minimum voltage rating without the use of extraneous elements such as resistors and the like.

Other objects and advantages of the invention will hereinafter appear.

While the device hereinafter described is effectively adapted to fulfill the objects stated, it is to be understood that I do not intend to confine my invention to the particular preferred embodiment of electromagnetic device disclosed, inasmuch as it is susceptible of various modifications without departing from the scope of the appended claims.

In the accompanying drawings:

FIGURE 1 is an end view of an electromagnetic device constructed in accordance with the present invention;

FIG. 2 is a side elevation view of the electromagnetic device of FIG. 1;

FIG. 3 is an end view of an armature constructed in accordance with the present invention;

FIG. 4 is a cross-sectional view taken along lines 4—4 of FIG. 3;

FIG. 5 shows diagrammatically an electrical energizing circuit for the electromagnetic device of FIG. 1; and

FIG. 6 is a vector diagram graphically depicting directive and quantitative characteristics of the electrical circuit of FIG. 5.

Referring to FIGS. 1 and 2 there is shown a cylindrical electromagnet indicated generally as **1** comprising a cylindrical core **2** having integrally formed at one end thereof four angularly spaced pole pieces **3**, **4**, **5** and **6**. Surrounding the respective pole pieces are four preformed operating coils *3a*, *4a*, *5a* and *6a* for introducing magnetic fields adjacent pole faces **7**. Core **2** has an axial bore **8** which is lined with a sleeve **9** secured in the bore frictionally or by other appropriate means. Sleeve **9** has an internal flange **10** at one end for securing the magnet to a base (not shown) while the other end of sleeve **9** adjacent the pole faces **7** has a chamfer **11** to facilitate assembly of the preformed coils on the pole pieces. Sleeve **9** is formed of stainless steel or other non-magnetic material having a greater resistance to wear than core **2**. Thus, sleeve **9** at its chamfered end adjacent pole faces **7** is slightly shorter than core **2** so that a small amount of wear of the pole pieces will not leave sleeve **9** extending beyond the surfaces of the latter to prevent sealing of an armature. The core laminations are welded together at the end away from the pole pieces as indicated at **12** to produce a unitary structure.

Electromagnet **1** is constructed by winding a ribbon-like strip of silicon steel or other magnetic material onto a preformed non-magnetic arbor similar to sleeve **9** to produce a cylindrical core **2** having a plurality of thin laminations separated by an oxide layer or coating on the lamination stock material or by a suitable commercial insulating coating capable of withstanding high temperatures without failure. The completely wound core assembly is held together by mechanical means such as a clamp or binding wire while it is annealed to remove stresses caused by bending the lamination material or otherwise during the winding operation. It is essential that the assembly be annealed at this time to relieve stresses which otherwise would become fixed during the ensuing welding operation. The core assembly is then welded in perpendicular directions across the end away from the pole pieces as indicated at **12** in FIG. 1 to fasten the laminations together in a unitary structure. The well known heliarc process is preferably employed wherein the welding is performed in a medium of argon gas or the like and without addition of welding metal which might affect the magnetic characteristics of the core. Thus, a unitary core structure is produced within the device itself without introducing auxiliary fastening means into the flux path. Coil slots are produced by machining in perpendicular directions across one end of the core including sleeve **9** to a desirable depth axially of the core. The machining operation produces four pole pieces of substantially triangular cross-section each having a long outer convex surface and two straight converging surfaces ending in a short concave surface defined by a portion of the axial bore of the core. Alternatively, the coil slots can be produced by punching to remove rectangular portions from one edge of the lamination strip during the winding operation. The pole faces are ground to produce smooth surfaces for sealing with an armature hereinafter described. In the event the coil slots are produced by the aforementioned machining operation the core is annealed a second time to relieve internal stresses caused thereby, followed by final grinding to produce finished sealing surfaces. The two grinding operations hereinbefore described are required due to the heat evolved in removing a large amount of metal. If

only a small amount of metal need be removed to produce smooth sealing surfaces, the first mentioned grinding operation may be omitted. The assembly is then etched by applying a highly volatile acid such as diluted hydrochloric acid or the like to remove grinding burrs which might shunt the laminations of the core, and thereafter baked to remove excess acid. Alternatively, such burrs can be removed by lapping which would obviate the necessity for the baking operation.

It should be noted that no organic materials are used to bind the core laminations so that the magnet can be used at extremely high temperatures without failure, limited solely by the maximum temperature that the coil including its insulation can withstand. Lamination stock material is provided with a thin insulating coating and during the usual manufacturing operations added insulation of the magnet laminations is obtained by applying a finely divided powder of magnesium oxide or the like before winding the core. It has been discovered that the use of such additional insulating powder may be omitted because inclusion thereof resulting in a reduction of energy losses would necessitate addition of resistance in the coil circuits to correspondingly increase the energy losses to maintain the voltage at an acceptable value as hereinafter described.

Referring to FIGS. 3 and 4 there is shown a cylindrical armature **15** for cooperation with the electromagnet of FIG. 1. Armature **15** is comprised of spirally wound laminations of magnetic material such as silicon steel or the like and has a smooth surface **16** at one end for sealing with pole faces **7**. The other end of armature **15** has a frusto-conical internal surface **19** obtained by cutting out a portion to afford a reduction in its weight without a corresponding decrease in efficiency. In electromagnets of the character hereinbefore described, the effective cross-sectional area of the armature need be no more than 70 percent of the cross-sectional area of its associated pole piece. The aforementioned relation accrues from the fact that localized parts of the armature carry one-half of the combined fluxes of two of the pole pieces with approximately 90 degrees phase displacement therebetween.

Extending axially through the armature is a bore **17** lined with a sleeve **18** of non-magnetic material such as stainless steel or the like to provide support for the extremely thin laminations. Sleeve **18** has an internal flange **20** at the end immediately adjacent the conical surface **19** to facilitate attachment of the armature to a driven element such as a contact actuator or the like while the other end of sleeve **18** is internally chamfered at **21** and extends to an area slightly short of sealing surface **16** to prevent irregularity in such surface as a result of armature wear, sleeve **18** having a greater resistance to wear than the laminations.

Armature **15** is constructed in the manner of electromagnet **1** by winding a ribbon-like strip of silicon steel or other magnetic material onto a preformed non-magnetic arbor similar to sleeve **18**. In the manufacture of both the electromagnet and the armature the arbor is left in the finished product to provide supporting and securing means for the respective parts. Armature **15** is annealed, machined to form the conical surface **19**, welded along the conical surface as indicated at **22** in FIG. 3 and ground to produce a smooth sealing surface **16**. The armature is annealed to relieve internal stresses caused by the aforementioned machining and welding operations followed by final grinding to produce a finished surface and application of diluted hydrochloric acid or the like to remove any grinding burrs which otherwise might shunt the laminations of the armature. Thereafter the armature is baked to remove excess hydrochloric acid.

As described in connection with electromagnet **1**, the number of grinding operations required depends upon the amount of metal that must be removed to produce a smooth sealing surface **16**. If the winding operation

leaves a surface requiring the removal of only a small amount of metal, grinding may be limited to the last mentioned final grinding operation. Likewise, removal of grinding burrs by lapping in preference to etching would obviate the necessity for the final baking step.

The process hereinbefore described produces an armature which can be used without failure in ambient temperatures up to the Curie point of the steel of which it is formed. For best results armature **15** should be oriented relative to electromagnet **1** so that welds **12** and **22** are superimposed in the axial direction.

There is shown in FIG. 5 a circuit diagram for energizing the aforementioned operating coils **3***a*, **4***a*, **5***a* and **6***a* of the electromagnet in FIG. 1. It may be assumed that supply lines **L1** and **L2** are connected to an alternating current supply source (not shown), such as 400 cycles used in aircraft systems, through suitable switches well known in the art. Coils **3***a* and **4***a* which surround first oppositely disposed pole pieces **3** and **4**, respectively, are connected in parallel across lines **L1** and **L2** to be energized in a given phase relative to the phase of the supply source. Coils **5***a* and **6***a* which surround second oppositely disposed pole pieces **5** and **6**, respectively, are series connected with a phase shifting capacitor C across lines **L1** and **L2**.

To obtain maximum quiet sealed pull in magnet **1** the flux in two diametrically opposite pole pieces must be equal to and displaced approximately 90 degrees in phase relative to the flux in the other two diametrically opposite pole pieces. Such phase displacement is obtained by use of the aforementioned capacitor C in series connection with operating coils **5***a* and **6***a*.

In order to obtain the most efficient operation with a given core, the electrical values of the operating coils and capacitor are ascertained in a manner hereinafter described. Referring to the vector diagram in FIG. 6, first let it be assumed that the phase angle Θ of coils **3***a* and **4***a* is ascertained. Since the phase of voltage E_{LC} must be displaced approximately 90 degrees relative to the phase of voltage E_L to obtain the hereinbefore described flux relations, voltage vectors E_{LC} and E_L can be drawn as shown. Thus, the position of current vector I_1 is found because its phase angle is determined by the iron losses in the core and these losses have the same value for each identical pole piece. Voltage E_C must be at a 90 degree phase relation to I_1. Since

$$E_{CL}+E_C=E_L \tag{1}$$

then

$$\frac{E_{LC}}{E_L}=\tan\Theta \tag{2}$$

Since the magnitude of the flux in each pole piece is the same in order to produce the aforedescribed results, the above Relation 2 determines the number of turns required in each coil. Let it be assumed that

$$\text{Tan }\Theta=2 \tag{3}$$

Therefore, four identical coils can be used if they are connected as shown in FIG. 5. For a given value of flux in each pole piece, the same magnitude of current will flow in each coil. Therefore

$$I_1=\frac{I_2}{2} \tag{4}$$

Since

$$\cos\Theta=\frac{E_L}{E_C} \tag{5}$$

and consequently

$$E_C=\frac{E_L}{\cos\Theta} \tag{6}$$

and

$$(7) \qquad X_C=\frac{E_C}{I_1}=\frac{1}{2\pi fC}$$

Then

$$(8) \qquad C=\frac{I_1}{2\pi fE_C}=\frac{I_2\cos\theta}{4\pi fE_L}$$

If

f=400; tan θ=2; θ=63.5 degrees; and cos θ=.436

$$(9) \qquad C=\frac{.436I_2}{4\pi 400E_L}=\frac{89(10^{-6})I_2}{E_L}$$

Let it be assumed that

$$I_2=.05 \text{ and } E_L=80$$

Then

$$(10) \qquad C=\frac{89(.05)10^{-6}}{80}=.056 \text{ microfarad}$$

If the magnitude of current I_2 should increase slightly due to improper seal of armature **15** to the pole faces, it will be apparent from Equations 9 and 10 above that the size of capacitor C will have to be larger. A capacitor having a value of approximately .07 microfarad should be sufficiently large to compensate for such line current variation and to maintain the desired phase relation.

The voltage across capacitor C is E_L divided by cos θ or 2.24 E_L. This will give a maximum voltage E_C of 278 volts R.M.S. or 391 volts peak for a line voltage of 124 volts. As hereinbefore mentioned, applicant omits the use of additional insulation in the laminations of the core in order to maintain the voltage at this desired value. Thus, applicant can use a capacitor having a standard voltage rating of 400 volts peak rather than a 600 volt capacitor with a corresponding increase in size and cost, and can omit the resistor previously employed in series connection with the capacitor for the purpose of maintaining the voltage at a desired value.

I claim:

1. In an alternating current electromagnetic device having a cylindrical core with a plurality of angularly spaced pole pieces at one end thereof and operating coils surrounding said pole pieces, a ring shaped armature for attraction by the magnetic forces developed adjacent said pole pieces, said armature having a radial flux path cross-sectional area approximately seventy percent of the cross-sectional area of a pole piece sealing face and of substantially similar geometrical configuration as said pole piece sealing face.

2. In an alternating current electromagnetic device comprising a cylindrical core having a plurality of angularly spaced pole pieces at one end thereof having pole faces in the form of segments of an annulus and operating coils surrounding said pole pieces, a cylindrical armature for attraction by the magnetic forces developed adjacent said pole pieces, said armature having a bore therethrough terminating in a frusto-conical internal surface diverging toward one end of said armature.

3. In an alternating current electromagnetic device comprising a cylindrical core having a plurality of angularly spaced pole pieces at one end thereof and energizing coils surrounding said pole pieces, a cylindrical laminated armature comprised of a spirally wound strip of magnetic material and having an axial bore therethrough terminating in a conical surface diverging toward one end of said armature, said armature having a radial cross sectional area approximately 70 percent of the area of a pole piece sealing face and a tubular member having an internal flange in said bore for fastening said armature to a driven element.

4. In an alternating current electromagnetic device comprising a cylindrical core having a plurality of angularly spaced pole pieces at one end thereof and energizing coils surrounding said pole pieces, a cylindrical laminated armature comprised of a spirally wound strip of magnetic material on a tubular non-magnetic arbor, portions of one end of said armature being fused at points of minimum flux to fasten the laminations together and thereby provide a unitary structure.

5. The combination according to claim 4 wherein the radial cross-sectional area of a portion of said armature overlying a pair of pole pieces is not less than seventy percent of the cross-sectional area of one pole piece sealing face of said pair.

6. In an alternating current electromagnetic relay for operation in a range of approximately 180 to 1,000 cycles, in combination, a cylindrical core having a plurality of angularly spaced pole pieces at one end thereof having pole faces in the form of segments of an annulus, operating coils surrounding respective ones of said pole pieces, a cylindrical armature having a sealing surface at one end and a conical cutout portion at the other end whereby the armature radial cross-sectional configuration is substantially similar to a pole piece sealing face configuration and the armature weight is reduced to a minimum without decreasing its efficiency, and means for energizing pairs of said coils in phase quadrature.

7. The combination according to claim 6, wherein the last mentioned means comprises means for maintaining the phase displacement between said pairs of coils at approximately ninety degrees under varying line current conditions.

8. In an electromagnetic device for operation in high temperatures, in combination, a laminated core and a laminated armature, each comprised of a spirally-wound strip of magnetic material forming a cylindrical member, each said member having radial fused portions at one end at points of minimum flux for fastening the laminations together to provide a unitary member without addition of extraneous material into the magnetic path.

9. The combination according to claim 8, wherein said device comprises a plurality of angularly spaced pole pieces at one end of said core, energizing coils surrounding respective ones of said pole pieces, and means for energizing said coils from a single phase alternating current source with an approximately ninety degree phase displacement between pairs of said coils, said means including a capacitor in series connection with one pair of said coils, and said fused portions being in the plane of the center line of each pole face.

10. The combination according to claim 9, wherein the last mentioned means comprises means for connecting one pair of said coils in parallel across said source and for connecting another pair of said coils in series with said capacitor across said source.

11. The combination according to claim 10, wherein said capacitor has a value of capacitance relative to the inductance of the pair of coils series connected therewith sufficient to prevent alteration of said phase displacement from approximately ninety degrees in response to variation in the value of line current due to improper armature seal.

12. In an electromagnetic device for operation in high temperatures, in combination, a laminated core having pole pieces at one end thereof and a laminated armature, each comprised of a spirally-wound strip of magnetic material forming a cylindrical member, each said member having radial welded portions at one end for fastening the laminations together without use of organic binding materials to provide a unitary member without introducing extraneous material into the magnetic path, said welded portions being at points of minimum flux which points are in the planes of the center lines of the pole faces.

13. In an alternating current electromagnetic device for efficient operation from a power supply source having a higher than commercial frequency in the range of approximately 180 to 1,000 cycles a second, said device having minimum weight and sufficient flux traversing cross-sectional area for efficient operation, in combination, a

cylindrical laminated core having an axial bore and a plurality of angularly spaced pole pieces at one end thereof symmetrically arranged around the axis of said core, said core being formed from a ribbon-like strip of magnetic material wound onto an arbor, said pole pieces being defined by a plurality of diametrical slots having parallel sides and intersecting at the axial bore thereby affording planar pole faces each having the configuration of a segment of an annulus, identical operating coils surrounding said pole pieces, an alternating current source having a predetermined voltage and a frequency in the range of 180 to 1,000 cycles a second, means comprising a capacitor element in series circuit with a first pair of said coils for connecting said source to energize a first oppositely disposed pair of said coils with a phase displacement of substantially 90 degrees relative to the phase of a second oppositely disposed pair of said coils, and a cylindrical armature formed from a wound ribbon-like strip of magnetic material and having an axial bore and a substantially planar face opposite said pole faces for attraction toward the latter under the influence of the magnetic force developed in the air gaps by said coils, said armature having a flux path cross-sectional area approximately 70 percent of the area of a pole face, and the cross-sectional area of said armature having a substantially trapezoidal configuration wherein the longer parallel side is adjacent to and has a dimension approximately 70 percent of the outer convex side of a pole face and the shorter parallel side is adjacent to and has a dimension approximately 70 percent of the inner concave side of the pole face whereby the magnetic flux of each lamination of a pole piece flows in the corresponding lamination of the armature and does not traverse the laminations thereof.

14. The invention defined in claim 13, wherein the coils of said second oppositely disposed pair thereof are connected in parallel across said source, and each of said coils has the same number of turns.

15. In an alternating current electromagnetic device having a core and at least two pairs of pole pieces with the pole pieces of each such pair being symmetrically arranged on the core and operating coils of like number of turns surrounding said pole pieces to afford two pairs of operating coils corresponding to said two pairs of pole pieces, an armature arranged for attraction by said electromagnetic device, means for energizing said coils comprising a single-phase alternating current power supply source, means for connecting the coils of one of said pair in parallel across said source and means for connecting the coils of the other pair in series and a capacitor connected in series with said other pair of coils across said source, said operating coils being provided with such number of turns and said capacitor having a capacitance value for given values of supply voltage and frequency such that in attracted position of the armature the current through the parallel connected coils is substantially equal to and ninety degrees out of phase with the current flowing through the series connected coils.

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