F. F. FOWLE.

ELECTROMAGNET.

APPLICATION FILED DEC. 15, 1910.

1,193,678.

Patented Aug. 8, 1916.

2 SHEETS—SHEET 1.

Fig. 1.

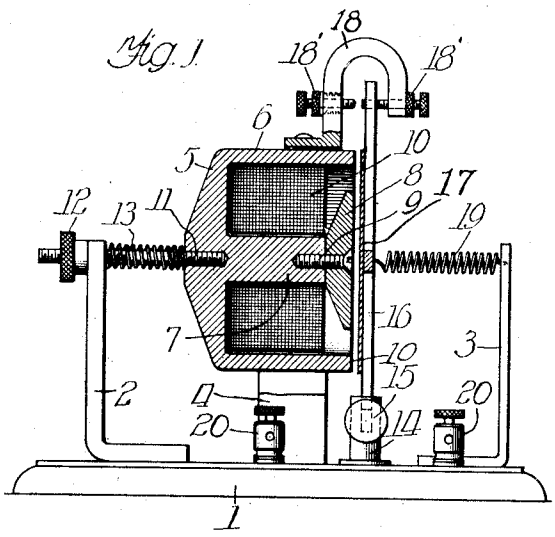


Fig. 2.

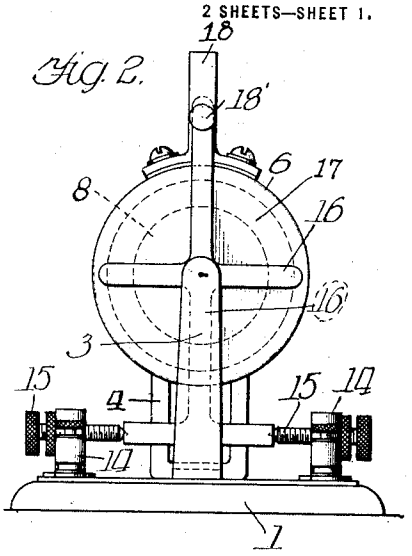


Fig. 3

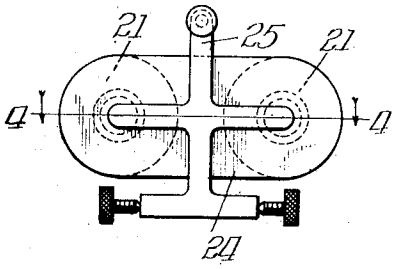


Fig. 4.

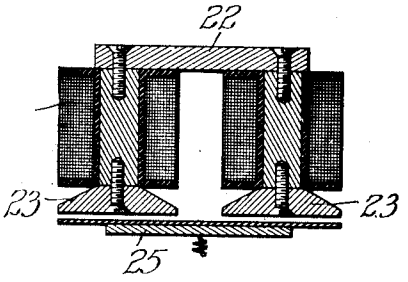


Fig. 5.

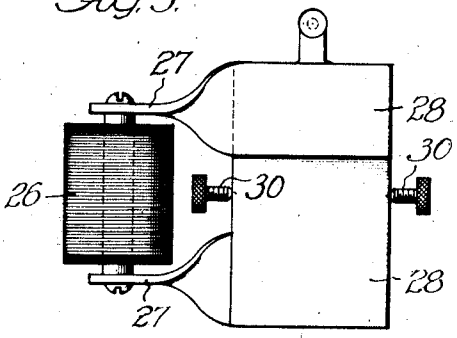
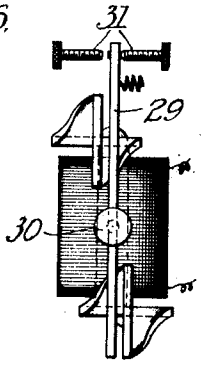


Fig. 6.



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2 SHEETS—SHEET 2.

Fig. 8.

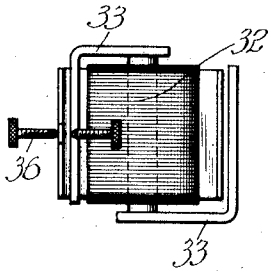


Fig. 7.

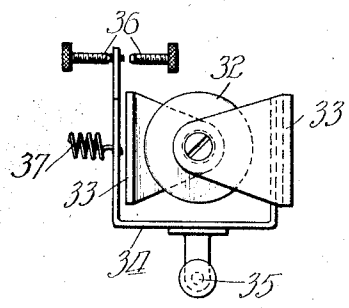


Fig. 10.

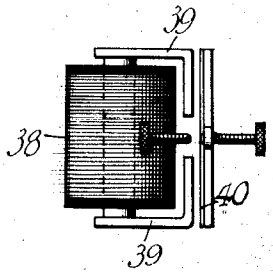


Fig. 9.

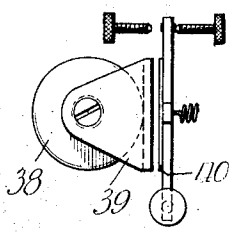


Fig. 11.

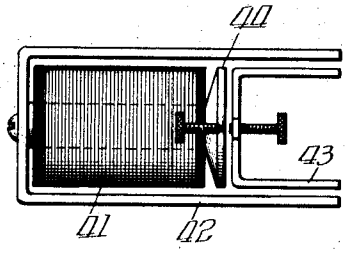


Fig. 12.

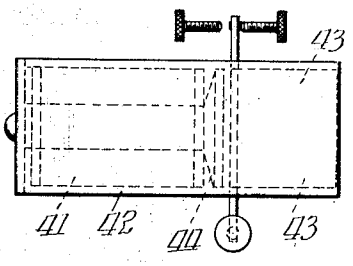
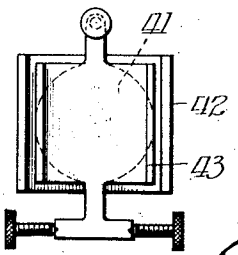


Fig. 13.



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ELECTROMAGNET.

1,193,678. Specification of Letters Patent. Patented Aug. 8, 1916.

Application filed December 15, 1910. Serial No. 597,471.

To all whom it may concern:

Be it known that I, FRANK F. FOWLE, a citizen of the United States, residing at Chicago, in the county of Cook and State of Illinois, have invented new and useful Improvements in Electromagnets, of which the following is a full, clear, concise, and exact description, reference being had to the accompanying drawing, forming a part of this specification.

My invention relates to electromagnets.

Among the objects of my invention I aim to so improve the design of devices of this character as to greatly increase their efficiency and extend their usefulness along commercial lines.

The invention embodies the application of fundamental laws relating to magnetic circuits. These fundamental laws are, of course, well understood. An investigation of these laws, directed along a particular line, however, studied and interpreted in terms of tangible elements and compared with existing accepted commercial devices based on electromagnetic operation, has disclosed to me what I believe to be a novel expression of the relation between the various component parts of electromagnetic devices from the standpoint of the designer, or at least an expression of a relation which, if heretofore apparent to others, has never been acted upon and applied to experimental or commercial apparatus in such a manner as to derive any resulting benefit therefrom, as far as I am aware.

In view of the nature of the investigation referred to, it is desirable not only to describe the various devices which I have selected as illustrative of typical embodiments of my invention and of the fundamental principles underlying the same, but also to outline briefly the investigation itself from which these principles were evolved. While the application of these principles is very general, my own application thereof has been directed more particularly toward improving the design of electromagnetic relays, and for this reason the discussion which follows is developed along these lines.

The force of magnetic attraction between a magnetic pole or pole piece and an armature, exerted across an air-gap, depends upon the density of magnetic lines, the area of the pole and the length of the air gap. When the armature is in flat contact with the flat pole piece, the tractive force that must be overcome to pull the armature away is stated by authorities to be

$$P=\frac{B^2A}{8\pi}$$

if P is the force in dynes, B is the number of lines of magnetic flux per square centimeter of pole area, A is the pole area in square centimeters and π is equal to the ratio of the circumference of a circle to its diameter.

When the armature and the pole are not in contact, but are separated only by a small air gap, it is true that the force of attraction is proportional to the expression above, that is,

$$P\propto B^2A$$

if P, B and A mean the same as before and an air gap of unvarying or constant length is assumed in each case. If ϕ is the entire magnetic flux, then

$$\phi=BA$$

or

$$B=\frac{\phi}{A}$$

Therefore the force of attraction varies as,

$$P\propto\frac{\phi^2}{A}$$

According to the well known law of the magnetic circuit, the number of ampere-turns required to overcome the reluctance of the air gap and establish the flux ϕ therein is

$$nI=\frac{\phi L}{1.257A}$$

or

$$\phi=\frac{1.257}{L}AnI$$

but as L, the length of air gap, is constant,

it can be said that $P \propto n^2 I^2 A$ or the force of magnetic attraction varies as the product of the square of the ampere-turns expended in overcoming the reluctance of the air-gap and the cross-sectional area of the air-gap. Therefore, when the force of attraction is regarded as a constant, the fewest ampere-turns will be needed when the area of the air-gap is made as great as possible. To secure a large area of air-gap, enlarged pole faces and correspondingly large armature are employed. The cross-sectional area of the core being relatively small, there is a resulting economy of material in this respect. More important, however, is the economy resulting from the reduced electrical resistance of the winding by virtue of the reduced number of ampere-turns required.

As the air-gap area is made larger, the reluctance of the gap is diminished at the same time. In ordinary electromagnetic relays the air-gap reluctance is usually a very large proportion of the total reluctance because the area is restricted and the permeability is unity as compared with a great many times unity in soft iron or soft steel. There is a large gain in increasing the area of the gap, which gain may be utilized as increased force or pull on the armature or as diminished ampere-turns. There is, of course, a practical limit to increasing the area indefinitely which occurs when the air-gap reluctance is made so small as to be a negligible part of the total reluctance of the whole magnetic circuit.

I have shown experimentally that the addition of flat extended pole pieces to a common telegraph relay of a type now in general use and the substitution of a correspondingly large armature, diminished considerably the working current required for a given force or pull between the poles and the armature for an equal length of gap in each case.

It is very essential that the magneto circuit be substantially closed except for the small gap between the pole pieces and the armature in order to obtain the advantageous results specified Dr. Julius Dub made the experiment in about 1850, of adding pole pieces or enlarged poles to straight or bar electromagnets and found that the pull on an armature was thereby decreased. His experiments are described in Prof. Sylvanus P. Thompson's *Lectures on the Electromagnet*. The result he obtained is well understood to be the result of augmented magnetic leakage. My investigations have been entirely with substantially closed magnetic circuits and for this reason, together with other reasons, the results obtained have been applied advantageously to commercial structures instead of disadvantageously.

It is apparent that the broad principles of my invention enumerated above may be very generally applied and are not limited in their application to any particular structure or type of structure. For the purpose of calling attention to a few concrete embodiments of the invention, however, I have illustrated in the accompanying drawings a number of different forms of electromagnetic relays. These forms will suggest to those skilled in the art, many other adaptations and applications of the underlying principles.

Referring to the drawings:—Figure 1 is an elevation, partly in section, of a telegraph relay. Fig. 2 is an end view thereof. Fig. 3 is an elevation of a modified form of electro-magnetic relay. Fig. 4 is a longitudinal section thereof on the line 4—4, Fig. 3. Fig. 5 is a further modification of a relay. Fig. 6 is an end view thereof. Fig. 7 is an elevation of another modification. Fig. 8 is a top plan view thereof. Fig. 9 is another modification. Fig. 10 is a top plan view thereof. Fig. 11 is a top view of a still further modification. Fig. 12 is an elevation of the same. Fig. 13 is an end view thereof.

In the modifications shown in Figs. 1 and 2, I have illustrated a complete telegraph relay, the electromagnet of which is of a type which has many practical advantages. The relay consists of a suitable base 1 upon which is mounted at one end a standard 2, at the opposite end a standard 3 and having an intermediate standard 4, which latter supports the electromagnetic casing 5 of general cup-shaped outline and provided with an annular flange 6 and a concentric central core 7. The core is provided with an enlarged pole piece or beveled disk 8, preferably secured thereto by a screw 9. The pole piece could, of course, be integral with the core but is made removable for the purpose of facilitating the winding of the coil 10 upon said core 7, as said winding may be separately wound and later slipped over said core. The outer annular face of the flange 6 constitutes one pole piece and the circular flat face of the member 8 constitutes the other pole piece of the electromagnet. It should be noted that the area of said circular pole piece is greatly in excess of the cross-sectional area of the core 7. While I do not, of course, limit myself to any of the relative dimensions suggested by Figs. 1 and 2, I consider such dimensions very satisfactory and particularly well adapted for commercial work.

The body of the magnet 5 is movable lon-

gitudinally with respect to the supporting standard 4 by means of the adjusting screw 11 and nut 12, the spring 13 normally impelling said magnet away from the standard 2.

Two upright members 14—14 are mounted on the base 1, each provided with an adjustable spindle 15 which pivotally support a frame 16, which frame may be of any suitable outline. A thin circular disk 17 of magnetic material such as iron, is secured to said frame and is mounted opposite the pole pieces of the electromagnet in close proximity thereto, so that when said electromagnet is energized, a substantially closed magnetic circuit is provided, there being a short air-gap and a minimum magnetic leakage.

Mounted on the annular flange 6 and preferably insulated therefrom in a well known manner, is a bracket or arm 18 provided with suitable adjustable stops 18′ for the purpose of limiting the throw of the frame 16 and the armature carried thereby. One of these stops is adapted for use as a circuit terminal of a relay as will be apparent to those skilled in the art. The frame 16 is also provided with the usual adjustable spring secured to the standard 3 for the purpose of normally holding the armature away from the magnet and for withdrawing the same from the magnet when it is deënergized. The head of one of the spindles 15 is adapted for use as a binding post and constitutes the other circuit terminal of the relay. The usual binding posts 20—20 for the electromagnet are also provided.

A relay constructed as indicated above is much more sensitive than any of the relays now in operation and may be constructed either to operate with the customary current, making use of a less number of ampere-turns in the winding 10 or with the same number of ampere-turns the usual pull on the armature may be obtained by the use of a weaker current, thereby adapting the instrument for use on a much longer line having greatly increased resistance.

In the modification illustrated in Fig. 3 there is shown a common form of electromagnet having the usual spools 21 connected at one end by the bar 22 and having in addition to the usual features, the enlarged disks or pole pieces 23 adapted to cooperate with the armature 24 pivotally mounted on the frame 25. A substantially closed magnetic circuit is secured by this arrangement also.

In Fig. 5 there is illustrated a single electromagnetic winding 26 having secured thereto flat parallel extensions or pole pieces 27, each of which is twisted through an angle of 90 degrees so that the outer ends 28 thereof lie parallel to the movable armature 29 and on opposite sides thereof, which will be apparent from Fig. 6. The armature 29 is pivoted at 30 and provided with the usual stops 31. Although only a single electromagnet is employed in this construction, it will be apparent that the pole pieces are of such configuration that a substantially closed magnetic circuit is secured.

Figs. 7 and 8 illustrate a further adaptation of pole pieces to a single electromagnetic winding 32. In this case the pole pieces 33 take the form of L-shaped extensions whose pole faces are arranged on opposite sides of the winding 32. The armature 34 is pivoted at 35 and has its ends bent into parallel planes, whereby said ends may lie adjacent to the pole faces 33 and thereby provide a substantially closed magnetic circuit. The usual stops 36 and retractile spring 37 are also illustrated.

In Figs. 9 and 10 the electromagnetic 38 is provided with L-shaped extensions 39 which extend inwardly toward each other and coöperate with the pivoted armature 40, forming a substantially closed magnetic circuit.

In Figs. 11, 12 and 13 there is illustrated an electromagnet 41 having secured to one end a U-shaped extension 42 within the ends of which there is pivoted a U-shaped armature 43 coöperating therewith and with the enlarged pole piece 44 to form a substantially closed magnetic circuit.

It is apparent that all the above modifications are shown merely by way of illustration and I do not limit myself to the details thereof nor to the general application of my invention to relays as such. The principles of the invention may obviously be applied to telephony and to many other lines of commercial work.

For the purpose of illustrating more fully the advantages of my improved design over prior structures, I give herewith, in some detail, a comparison of the particular form of device illustrated in Figs. 3 and 4 with a construction similar to said figures in every respect, but with the enlarged pole pieces omitted. Assume that the cylindrical cores of the ordinary horse-shoe magnet of Figs. 3 and 4 have a diameter of 1.0 centimeter, are 5.0 centimeters long and joined at one end by a yoke having a transverse breadth and thickness of respectively 1.2 centimeters and 0.6 centimeter, with the core axes parallel to each other at a distance of 4. centimeters, and at the opposite end an armature separated from the ends of the cores by 0.2 centimeter so as to form two air-gaps of this length, with an armature

breadth of 1.0 centimeter and a thickness of 0.15 centimeter, both the armature and the yoke being thin flat bars in shape, with rounded ends to fit the cores, and 5.0 centimeters in extreme length,—the reluctance of the magnetic circuit may be calculated substantially as follows:—The reluctance of any uniform portion of the circuit is expressible by the formula,

$$R=\frac{L}{\mu A} \quad (1)$$

Now for each core,

$$R'=\frac{5.0}{.785\mu'} \quad (2)$$

For the yoke,

$$R''=\frac{4.0}{.72\mu''} \quad (3)$$

For the armature,

$$R'''=\frac{4.0}{.15\mu'''} \quad (4)$$

For each air-gap,

$$R''''=\frac{0.2}{.785\mu''''}=.255 \quad (5)$$

If the iron is of such a quality that under these conditions the magnetic permeability is substantially 1,000. then the total reluctance will be as follows:—

Two cores, at .00637 each	.01274
Yoke	.00556
Aramture	.0267
Two air-gaps, at .255 each	.510
Total	.55500

The air-gap reluctance is here a very large part of the whole, amounting to about 92% of the total. If the total number of ampere-turns in the winding is N turns, then the magneto-motive-force is expressed as

$$F=\frac{4\pi N}{10}=1.257N \quad (6)$$

The total magnetic flux is

$$\phi=\frac{F}{R} \quad (7)$$

If there are 500. ampere-turns the total flux ϕ, neglecting the magnetic leakage, will be

$$\phi=\frac{628.5}{.555}=1,130. \quad (8)$$

The flux density B in the air-gaps will be

$$B=\frac{1130}{.785}=1,440 \quad (9)$$

The pull on the armature will be proportional to the product of the square of B and the cross-sectional area A, or

$$P\propto B^2A$$
$$P\propto(1,440)^2\times.785 \quad (10)$$
$$P\propto 1,630,000.$$

If now the pole-tips formed by the circular ends of the cores are enlarged to thin flat cylinders 3.0 centimeters in diameter and the width of the armature is made equal to this, the respective reluctances will be, if the permeabilities are unchanged,

Two cores, at .00637 each	.01274
Yoke	.00556
Armature	.00889
Two air-gaps, at .0283 each	.0566
Total	.08379

The air-gap reluctance is here only about 66% of the total, as compared with 92% before. If the pull on the armature remains constant, the value of B^2A must remain unchanged. Whence the new value of B is

$$B'=\sqrt{\frac{1,630,000}{9.\times.785}}=480. \quad (11)$$

and the new total flux is

$$\phi'=BA=3,390. \quad (12)$$

The total flux in the second case is about three times as great as before, but the total reluctance is only a small fraction of its former value. The required ampere-turns in the second case are

$$N=\frac{\phi R}{1.257}=\frac{3,390\times.0838}{1.257}=226. \quad (13)$$

which compares with 500. before, or only 45.2% of the same. The magnetic circuit has been unchanged except for increasing the size of the pole-pieces and the armature, and the cross-sectional area of the air-gap.

The stray lines of magnetic flux or leakage will be greater in magnitude in the second case than the first, but not sufficiently to vitiate the principle of increasing the area of the air-gap to reduce the ampere-turns without affecting the pull or attraction on the armature, which I have proved experimentally with a relay of generally similar proportions and but slightly larger in dimensions.

I favor the arrangement of magnetic circuit shown in Fig. 1 for some purposes, because the magnetic leakage is made thereby very small comparatively.

The reduction in the ampere-turns effected by increasing the area of the air-gap is a matter of degree and after the reluctance of the air-gap has been sufficiently decreased so as to make it a small part of the whole reluctance, the gain obtained by further in-

creasing the gap area will be slight for the particular form of magnetic circuit in such case considered.

From the above discussion it will be apparent that my invention is not limited to the particular details of any of the devices described, nor is it limited to electromagnetic relays in general, nor to any other of the suggested applications or uses. I desire therefore, to cover any suitable means embodying the broad principle of the invention, for accomplishing the desired result and coming within the scope of the appended claim.

What I claim as new and desire to secure by Letters Patent of the United States is:—

An electromagnetic relay comprising a base, an inclosed cylindrical electromagnet mounted thereon and adjustable longitudinally with respect thereto, said electromagnet having an inclosing annular shell, one edge of which constitutes one of the pole faces of said electromagnet, and having a central concentric core having an enlarged disk, the outer side of which constitutes the other pole face of said electromagnet, an electromagnetic winding located between said core and said annular shell, a frame pivotally supported by said base and having stops to limit its oscillation, a thin disk of magnetic material mounted on said frame adjacent to said pole faces and of a size to at least overlap the edge of said shell whereby a nearly closed magnetic circuit is formed, and a spring for normally withdrawing said frame and said armature from said pole faces.

In witness whereof, I have hereunto subscribed my name in the presence of two witnesses.

FRANK F. FOWLE.

Witnesses:
GEO. B. JONES,
F. H. DRURY.