DESIGN, CONSTRUCTION & OPERATING PRINCIPLES OF ELECTROMAGNETS FOR ATTRACTING COPPER, ALUMINUM & OTHER NON-FERROUS METALS

BY

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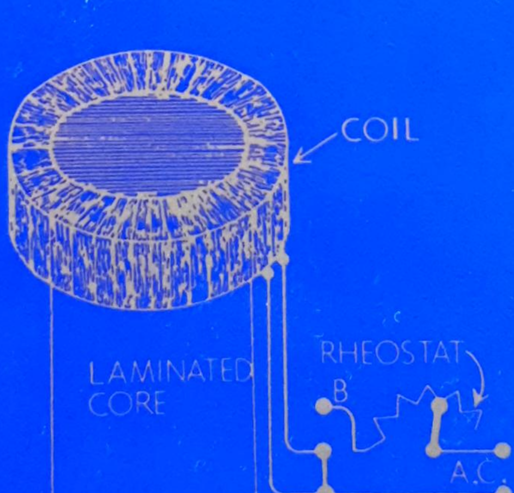

ELECTROMAGNETS OF SPECIAL CONSTRUCTION FOR THE ATTRACTION OF NON-FERROMAGNETIC METALS

Magnetism is one of the most interesting and mysterious as well as one of the most important physical phenomena known. Through its action we generate and utilize the enormous quantities of electrical power which make possible modern industry and modern living. Many important principles of electromagnetism can be understood from the study of an electromagnet, invented and designed by the author, which attracts non-ferromagnetic metals.

Everyone has experimented with magnets and observed their attraction for iron filings, nails, and other small articles of iron and steel. Some of you will have seen large electromagnets attached to cranes pick up tons of scrap steel and move it about with ease. Tons of iron are held firmly to the magnet with an invisible force and are released by the flip of a switch. You have also observed that while iron is attracted with such force, other metals such as aluminum, copper, and silver are unaffected. This principle is often used to separate iron from non-ferrous metals. No doubt you have used a magnet to determine whether a nickel plated screw had an iron or brass base. You may also have noticed that if alternating current is applied

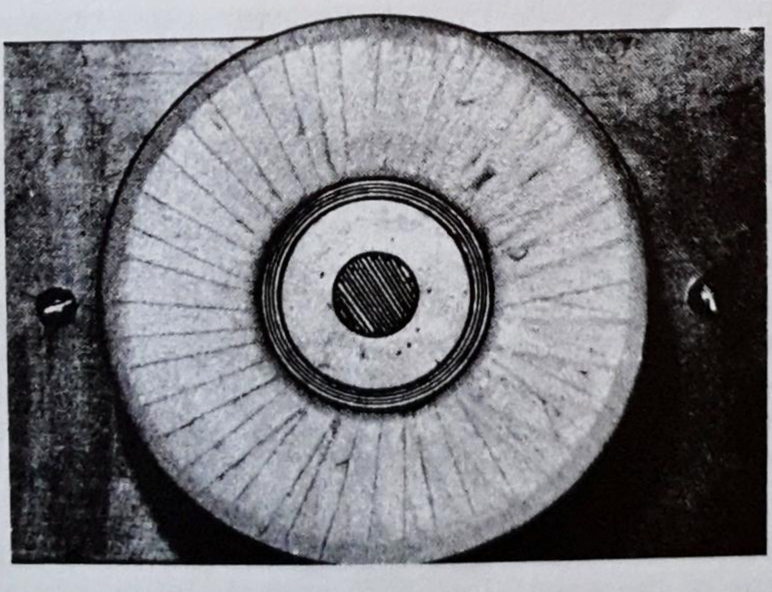

Figure 1

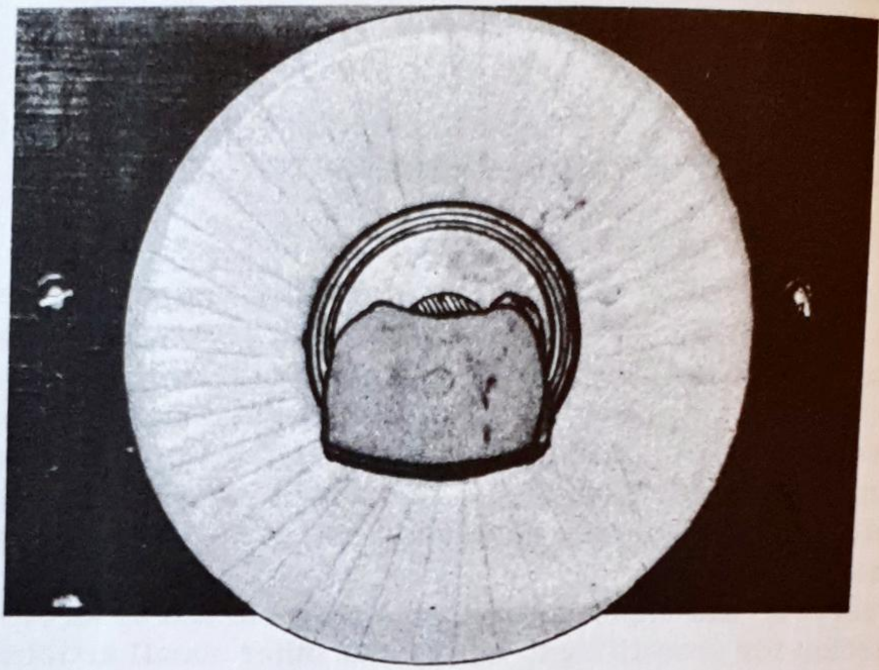

Figure 2

to an ordinary electromagnet, non-magnetic metals of good electrical conductivity will actually be repelled. In view of all of the above it will be most interesting to learn how magnetism can be used to attract non-ferromagnetic metals.

In 1934 the author designed equipment with which it was possible to demonstrate principles whereby non-ferromagnetic metals might be attracted by a special magnet. In 1940 the author completed the development and construction of an electromagnet which would actually attract metals such as aluminum, copper and silver. In fact the magnet would attract any metal of fair or good electrical conductivity. Toward the end of 1947 the author completed the design and construction of a much improved electromagnet for the attraction of non-ferrous metals, the details and description of which are included in this article. The special electromagnet is illustrated in Figure 1. In Figure 2 the magnet, with its axis horizontal, is shown supporting a heavy piece of copper. In Figure 3 two pieces of aluminum have been added to the original piece of copper. Figure 4 shows the magnet supporting two silver dollars. The size of the magnet is illustrated by comparison with the silver dollars. That the magnet may also be used to attract iron is indicated clearly in Figure 5.

Before considering the details of construction and principles of operation of the special electromagnet, let us review some of the basic principles of magnetism and electromagnetism.

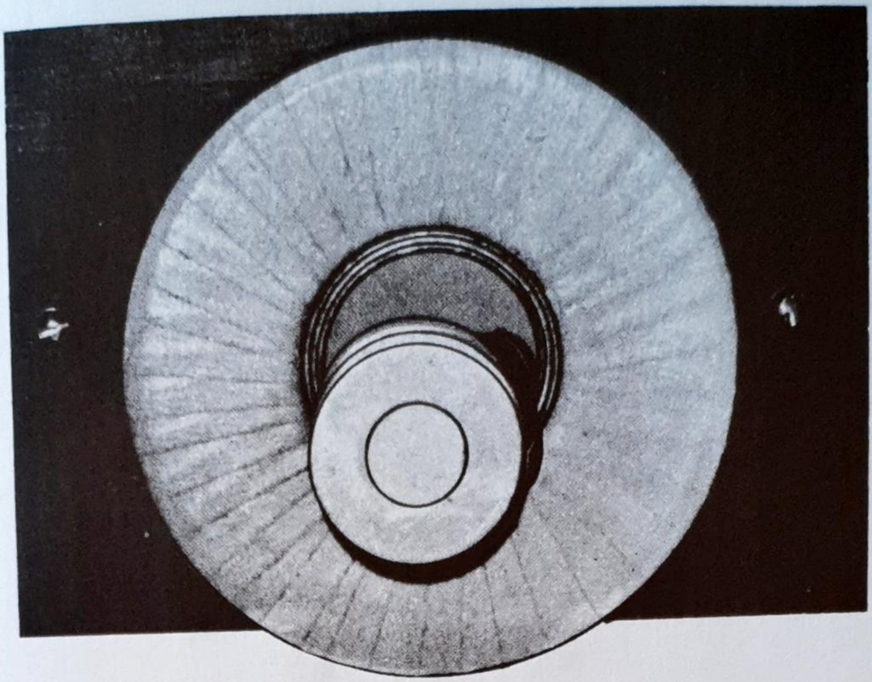

Figure 3

We will not only observe that non-ferromagnetic metals can be attracted to an electromagnet but will also gain the pleasure of understanding its principles of action.

Oersted in 1819 was the first to show that a current carrying wire was surrounded by a magnetic field. He discovered that a compass needle aligns itself at right angles to a wire carrying

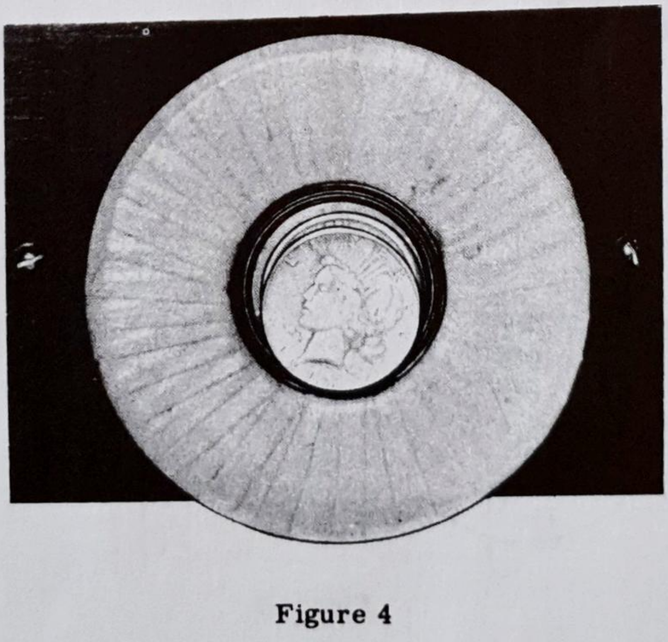

Figure 4

Let two washers be placed near the end of the electromagnet as in Figure 33. Some of the flux from the electromagnet will thread or cut through both of the washers, and at a particular instant currents in the two washers and in the electromagnet winding will have the directions indicated. Here we have one of the most important operating principles of the special electromagnet for attracting non-magnetic metals.

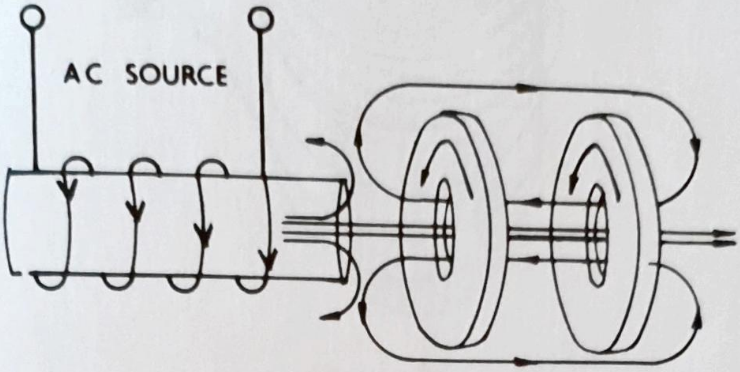

Figure 33

Compare the situation of the currents in the two washers of Figure 33 with the currents in the two coils of Figures 20 and 21. The currents are flowing in the same direction and as indicated in Figure 33, there will be flux lines linking the two washers which will tend to pull them together. However, since the force of repulsion between the a.c. electromagnet and both washers is very strong it is difficult to show by the arrangement of Figure 33 that there is an attraction between the two washers. If the currents in the two washers were sufficiently large the washers would be pulled together with considerable force. The hole in either washer is immaterial since flux passes through non-ferromagnetic materials just as it does through air.

With this fundamental principle in mind, (that there is attraction between the two washers of Figure 33), let us now consider the construction and fields of the special electromagnet which will attract non-ferrous materials. The electromagnet is shown diagramatically in Figure 34. The few turns shown represent the entire winding of the electromagnet. Figure 35 is a cross section of the inner and outer laminated iron cores which extend the entire axial length of the electromagnet. Figure 36 shows the inner core and the group of copper washers which partially fill the annular space between the inner and outer cores. These copper washers occupy this space in only the face end of the magnet. The top washer shows clearly in the photograph of Figure 1. The complete electromagnet is

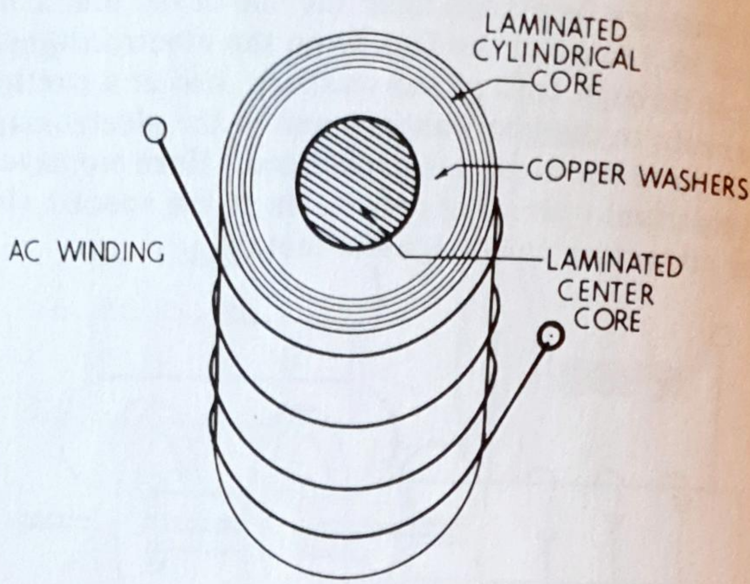

Figure 34

mounted on a supporting stand for convenience in demonstrating its unique ability to attract non-ferromagnetic metals.

We now know the construction of the electromagnet and have studied the essential magnetic theory involved in its operation.

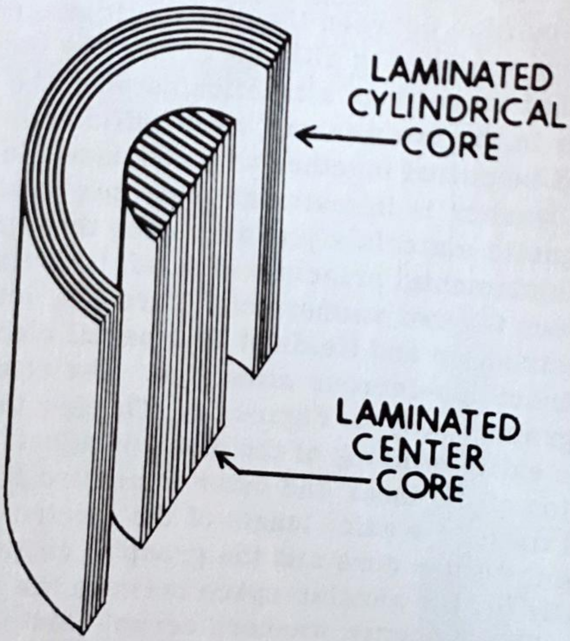

Figure 35

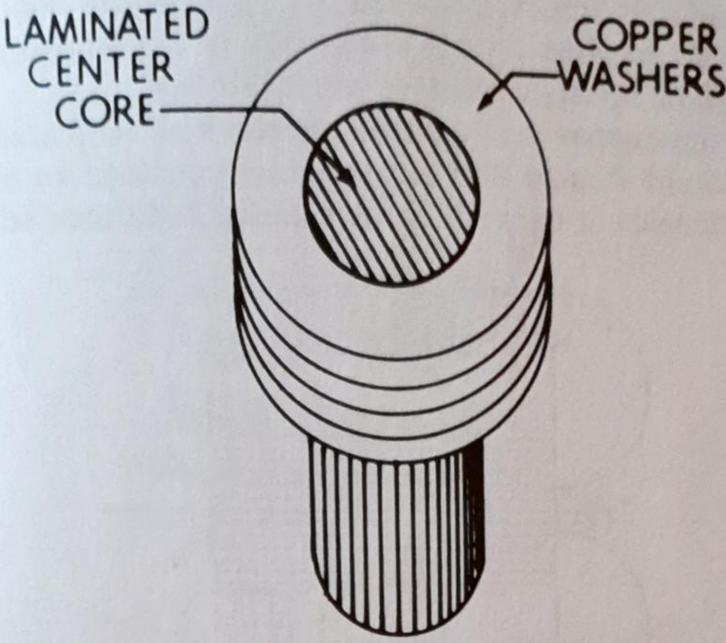

Figure 36

With this information it will not be difficult to explain its performance.

Figure 37 is a cross section of the magnet with the four copper washers removed. The circles at the top and bottom represent the winding. The dots and crosses indicate that current is directed out of the paper above and into the paper below at the instant considered. We know from the right hand rule that

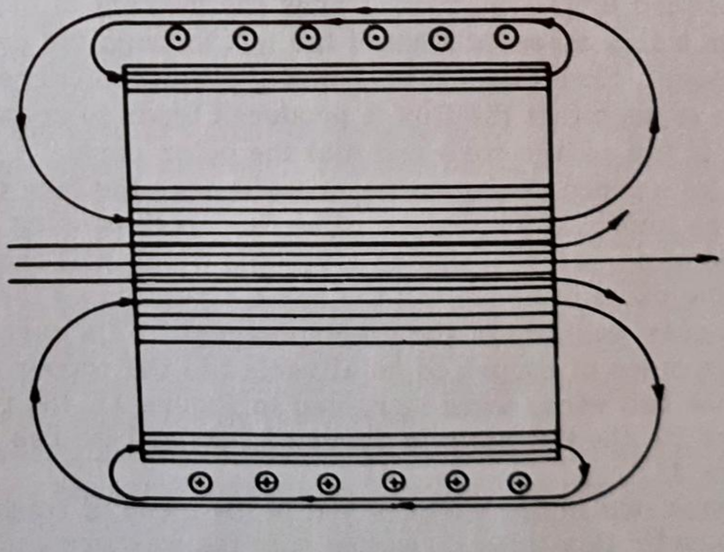

Figure 37

the flux lines are directed toward the right within the coil. We also know that practically all of the flux is concentrated in the iron because of its high relative permeability.

Now let the copper washers be replaced as indicated in the cross section of Figure 38. Again let us consider an instant when the alternating current is increasing and directed out of

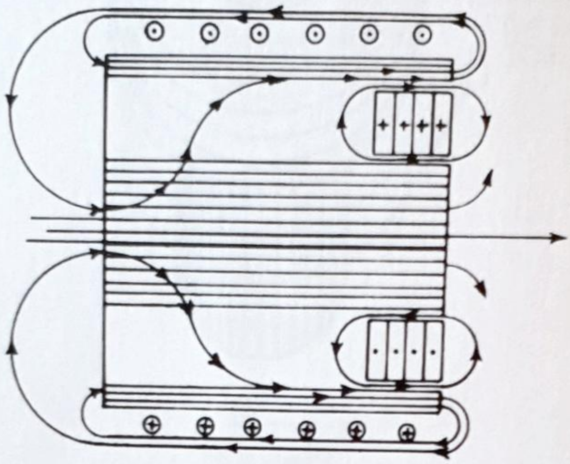

Figure 38

the paper above as indicated by the dots. Referring to the theory presented in connection with Figures 25, 26, and 27, we know that the induced currents in the copper washers will be directed in the opposite direction to those in the coil as indicated by the dots in the lower half of the washers. Lenz' law states that the current in the washers will produce a flux which will oppose the flux produced by the primary. Thus the current in the washers produces a flux directed toward the left through the center of the washers. Note that the action of the induced current in the washers is such that the flux it produces tends to crowd the flux out of the center core and into the outer core.

Now let a piece of copper be brought near the face of the magnet as shown in Figure 39. The flux lines passing through the piece of copper will induce a voltage which will cause a current in the piece of copper in the same direction as the current in the copper washers of the electromagnet. This current will cause the piece of copper to be attracted to the copper washers just as the two wires were attracted in Figure 11, the two coils in Figure 20, the two coils in Figure 21-B, and the two washers in Figure 33.

The currents in the washers and in the piece of copper produce magnetic flux lines threading both the washers and piece of copper. These flux lines tend to act as stretched rubber bands

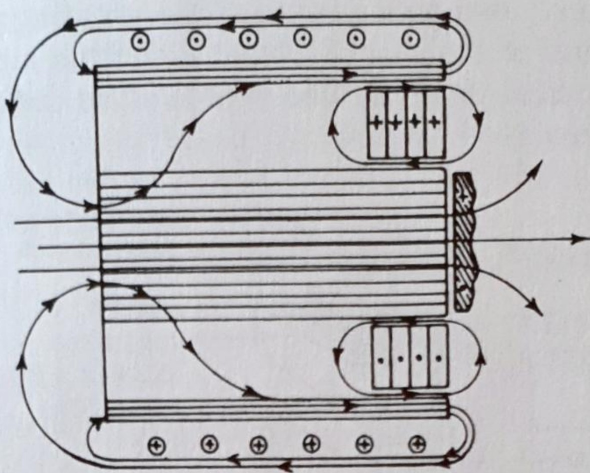

Figure 39

pulling the two parts together. The alternating current in the copper washers is sufficiently large that the copper piece is pulled forcibly against the face of the magnet. Additional conductive pieces are attracted, but with decreasing force. Each added piece will have less induced current than the preceding one and will thus be attracted less forcibly toward the copper washers. However, the electro-magnet shown is powerful enough to readily support two silver dollars or several discs of aluminum.

In this type of electromagnet there is another force involved which is of interest and importance. This force is one concerned with the effect produced by a traveling magnetic field. By this we simply mean that due to the particular construction of this electromagnet there are two magnetic flux fields produced at the end of the magnet. The first of these is the field produced by the primary coil which is a sinusoidal varying field set up by the primary current. The second is a field in the central core which lags the first field by a few degrees (less than one half cycle). The interaction of the two fields over the face of the magnet produces a magnetic field which appears to move from the outer core of the magnet in toward the central core. The traveling magnetic field is utilized in this electromagnet in a manner which produces strong centering action in the mass being attracted by the magnet.

The traveling magnetic field is produced in this electromagnet in exactly the same manner as in many commercial single-phase induction motors. These motors are called "shaded pole" motors and the principle involved is called the "shaded pole" attracted may be subject to a repulsive force from the primary field and therefore should be of a size not larger than the space within the cylindrical pole. Since the current in the primary winding is generally opposite to the current in the mass to be attracted, that mass should be of a general size and shape to lie within the cylindrical pole piece boundary and should not extend over into the influence of the primary coil.

When the circumference of the mass to be attracted is larger than the circumference of the cylindrical pole, the repulsive force exerted upon it by the primary winding increases very rapidly with an increase in its size. The non-ferrous mass is also repelled if it is approximately of the same peripheral dimensions as the inside dimension of the cylindrical core but is not closely adjacent thereto. The object to be attracted should be adapted to the field and should generally be placed fairly close to the magnet unless it is quite a bit smaller than the inside dimension of the cylindrical pole face. It is possible to make the conductive mass to be attracted "jump" a considerable distance to affix itself to the attractor by having the non-ferrous mass of considerably smaller diameter than the cylindrical core.

By experimenting with armatures of different sizes suspended at various distances from the attractor face it has been found that a region or zone of attraction exists which is conical in shape. A conductive object placed with its principal conducting path within this cone is attracted. The base of this cone

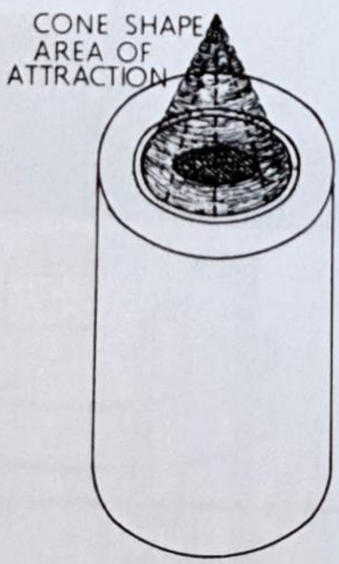

Figure 45

substantially coincides with the face of the attractor and has its vertex on the axis at a distance from the attractor as illustrated in Figure 45.

Figure 46 shows a silver half dollar suspended near the attractor face. In this figure the half dollar is suspended so as to have its plane perpendicular to the plane of the attractor face

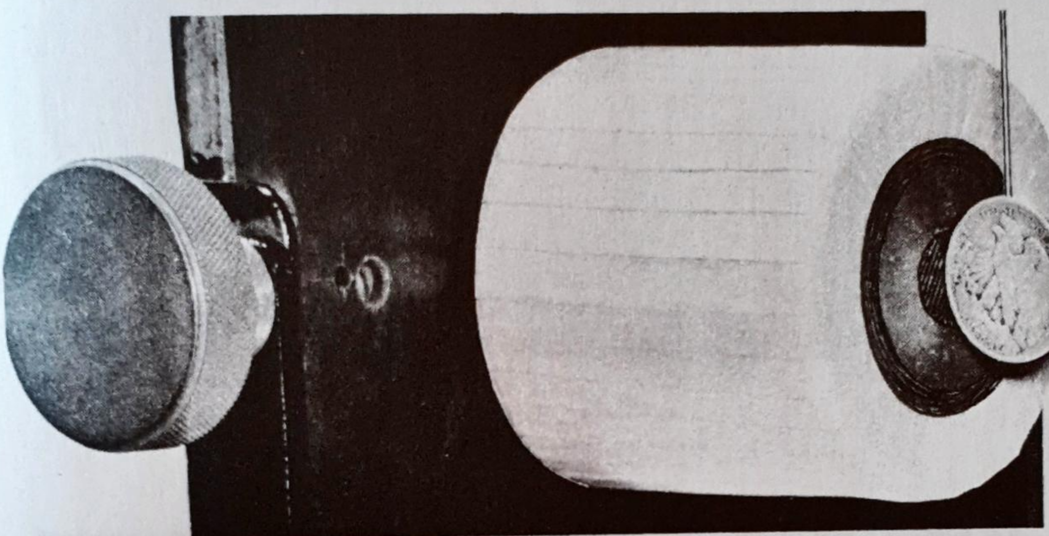

Figure 46

before the magnet is energized. But the instant current flows through the primary winding of the electromagnet the half dollar turns so that its plane is parallel with the plane of the attractor face as shown in Figure 47 and is attracted with considerable force. This result is exactly opposite to the result to be expected if the silver dollar were placed in the field of an ordinary alternating current electromagnet. If the attractor in this special electromagnet were not present to exercise its influence, the coin would then turn with its plane perpendicular to the plane of the electromagnet face.

If a non-ferrous ring, washer, or disc with a plane dimension considerably in excess of the cylindrical pole face dimension is placed near the face of this special electromagnet, then the object is out in the influence of the primary coil and, as in the case of a conventional electromagnet, the object would be repelled.