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IRON WIRE EXPLORATION OF ALTERNATING OR CONSTANT MAGNETIC FIELDS

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Constant magnetic fields have commonly been explored with iron filings, a small compass, or search coil together with fluxmeter. Alternating fields have been explored with search coils and by other means.

The use of a bit of iron wire to find the flux lines of an alternating field may be new. The writer has found no one who has heard of such a technique. It also may be used on constant fields. It enables one to lay out continuous flux lines with speed and simplicity.

THE IRON WIRE EXPLORER

Origin of the Technique

The writer had been using a short piece of soft iron wire to give an approximate indication of the direction in space of an a-c field, at one particular location. Later, when trying out the wire in other parts of the field, it seemed that the wire was aligning itself with the field quite well, and that it might be developed as a field exploring device.

Explorer as a Straight Free Piece of Wire

The coil shown in Figure 1 has 150 turns of No. 17 wire, in 8 layers. The winding space section is 0.4 by 1.17 inches, the inside diameter of the actual winding being 5.67 inches. A piece of plate glass supports a sheet of smooth paper in the plane of symmetry.

If a short piece of soft iron wire is laid on the paper, a field set up by the coil current will cause the wire to turn and align itself with the field. However, the free wire will often not remain in location: it will tend to be drawn across the flux lines and go to the coil itself.

Thus, the wire must be held to location in some manner.

Explorer with Loop at One End

The first form given an explorer was to bend a small closed loop at one end of a short straight piece of iron wire. A pencil point was stuck down through the loop. The alternating 60-cycle field aligned the wire, and the field was thus explored. This design for the explorer demonstrated the feasibility of the technique, but there was a large error.

The source of the error can be seen by thinking of taking the free end of the wire, and deliberately moving it so that the wire is truly aligned with a short element of the flux line passing through its location. If the wire is now released (except for the looped end) the free end will swing slightly inward, toward the center of curvature of the flux line, because there is a crosswise force component of magnetic attraction acting on both ends. The result is that when the wire is stepped along and made to trace out a curve, this curve is constantly becoming shorter than the true flux line curve, and the error accumulates.

Explorer with Loop at Center

The error cited above is eliminated by letting the wire swing about its center. Both ends are now free to move. Each end tries to respond to the crosswise pull component. The effects cancel, and thus the wire is allowed to align itself with the direction of the field.

The explorer used was made from 0.014-inch round soft iron wire, bought at a hardware store. It is 0.5 inches long.

A much larger explorer is shown in Figure 1. The pencil points to it. This is merely a display demonstrator, made from a paper clip, and exhibited here because it would be large enough to show up in the photograph. Also seen is the handpiece which moves the explorer to position, and furnishes the shaft about which the explorer swings. This handpiece is made of a piece of brass, with a bent wire taped to it. The wire is No. 24 resistance wire, which like brass, is nonmagnetic. The handpiece wire is taped onto the top of the brass piece, extends horizontally out from it, and then bends vertically downward to form a shaft. The shaft goes down through the explorer loop and touches the paper.

The actual explorer was made by hand. An ample length of iron wire was tied firmly at one end. It was then pulled tight, and tightly wrapped once around a sewing needle, the needle being firmly anchored. A diameter was chosen on the tapered part of the needle, such as to give an inside loop diameter a little larger than the shaft. The excess was then cut off the wire, leaving equal lengths extending each way from the loop. The ends were pointed by rubbing them on a carborundum stone. Finally, to reduce friction with the paper, the explorer was pressed against a carborundum stone with the finger and rubbed along it to take off any roughness.

The upper part of Figure 2 shows an enlarged scale drawing of the explorer.

Trueing-up Process

The explorer was mechanically "perfected" by localized bending and manipulating of shape, until the extended arms were approximately aligned with the loop center, and also were approximately straight. But it could not be taken for granted that therefore, it would behave correctly in the field.

The field itself was then called upon to help. The explorer was placed on the coil's axis line which was drawn on the paper. With an alternating field on, it was found that when one end of the explorer was accurately over the axis line, the other end was a little to one side. This error was eliminated, and the explorer was magnetically trued-up, by bending one arm or the other until both ends rested on the axis. It was then ready for business.

Mapping the Flux Lines

The technique calls for a sharply pointed pencil, prepared to make very small, accurate dots.

A start was made by making a dot at one of the inner points shown in Figure 2. The explorer was moved by the handpiece, with field on, to where its inner end came to the starting dot. A dot was made at the other end. The explorer was moved along to start over again at the second dot, and a third dot was made at the other end -- and so on.

For inner points, this coil required only 1 or 2 alternating amperes to get positive alignment. A coil current of 1 ampere gives a flux density in the neighborhood of point A, of roughly 60 lines or maxwells per square inch.

In the weak field where outer points were secured, coil currents of up to 16 or 20 amperes were needed. Even then, the explorer's job of overcoming friction with the paper sometimes needed help, in terms of tapping the handpiece, or the paper. This coil will carry only 4 amperes continuously; but high momentary currents can be carried to secure the outermost points.

For the curves shown, somewhere around 80 points were made. This work was done in a totalized time of only 10 or 15 minutes.

All of the points fall on or very close to their curves.

Accuracy

To investigate the accuracy achieved, an independent method of exploration was set up. Two search coils were arranged in the coil's field, these being coaxial, and each having one turn. The smaller, inner search coil had one side passing through the point A of the symmetry plane, Figure 2. The outer, larger search coil's side passed through point B. The search coils were connected in series to a vacuum tube voltmeter, with their induced voltages opposed. With alternating current in the main coil to set up the field, search coil B was moved in or out axially until a null reading was secured. Points A and B would then fall on the same flux line.

Then, in using the explorer, the iron wire was started at point A, to lay out its version of a flux line. If this line passed through point B, there would be a precise check between the two methods. It is seen, Figure 2, that the agreement is very close indeed.

It is pertinent to recall that in alternating current instruments of the moving-iron type, we rely on the fact that soft iron pieces in the instrument's alternating field are expected to perform reliably, and enable the instrument to have very good accuracy. Equally, we have a right to expect that if the explorer is magnetically trued-up with high accuracy, then its alignment with the field at any one location will be achieved with high accuracy. Beyond that, if the investigator does his work with adequate precision, he can expect to get good results.

Explorers longer than the one described here could be used for flux lines of gentle curvature. Shorter explorers could be used on sharply curved lines, to preserve accuracy.

Advantages of Alternating Field Exploration

Consider those cases in which the field to be explored has the same conformation, whether direct or alternating current is used in the coil or coils setting up the field, as when air-core coils are used, and no metal pieces are present that are heavy enough to have serious eddy current effects. The field, in actual use, might be constant. But it would be better to use the iron wire explorer with the alternating field.

The first advantage gained is due to vibration. With an alternating field, vibratory forces act on the explorer, helping it to align by assisting in overcoming its friction on the paper.

The second advantage lies in its freedom from error due to residual magnetism. We can recall that in a moving-iron type ammeter, this error drops out when the ammeter measures alternating current; whereas, at least a small error may come in, if used on direct current. Likewise for the explorer.

Aside from these cases, there are cases where the field, in use, is affected by eddy currents in masses of metal. Here, the field must be explored using alternating current in the coil or coils, and the iron wire explorer will do the job.

Exploring Constant Fields

The iron wire explorer is quite able to explore constant fields. With the vibratory effect of the alternating field absent, it becomes more necessary to help alignment by tapping the handpiece; or mechanical vibration of the paper support could be used.

Also, as brought out above, there is the possibility of the explorer becoming somewhat magnetized, and bringing in residual error. This will probably be quite small, but no investigation has been made of its possible extent.

Increased Sensitivity

The simple explorer described can be greatly improved in sensitivity. The shaft-in-loop scheme would be replaced by a fine pivot bearing, such as is found in a good compass. The explorer would then respond accurately to far weaker fields.

CONCLUSION

Magnetic fields, either constant or alternating, may be explored with a short piece of iron wire made with a center bearing, it being used so that continuous flux lines are laid out. As investigated so far, the technique appears to promise high accuracy.

The extremely simple character of the exploring device, the simplicity of its use, and the fact that continuous flux lines result from the exploration, combine to recommend it, not only for application to real situations, but also for instructive experimental use in physics and electrical courses at any level where magnetic fields are studied.

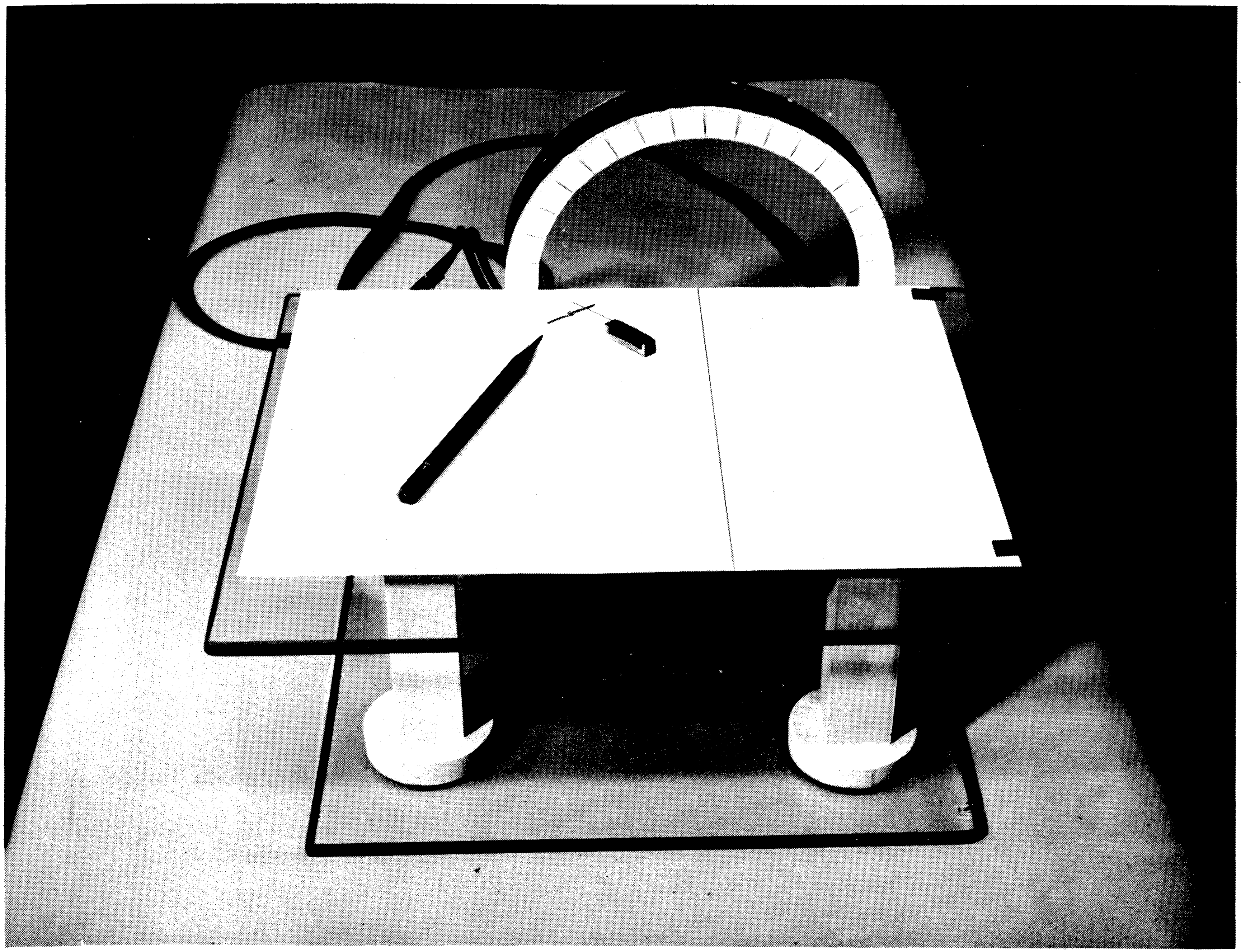

Figure 1. Coil, arranged for explorer to lay out flux lines. Pencil points to the explorer. The handpiece for locating the explorer is also shown.

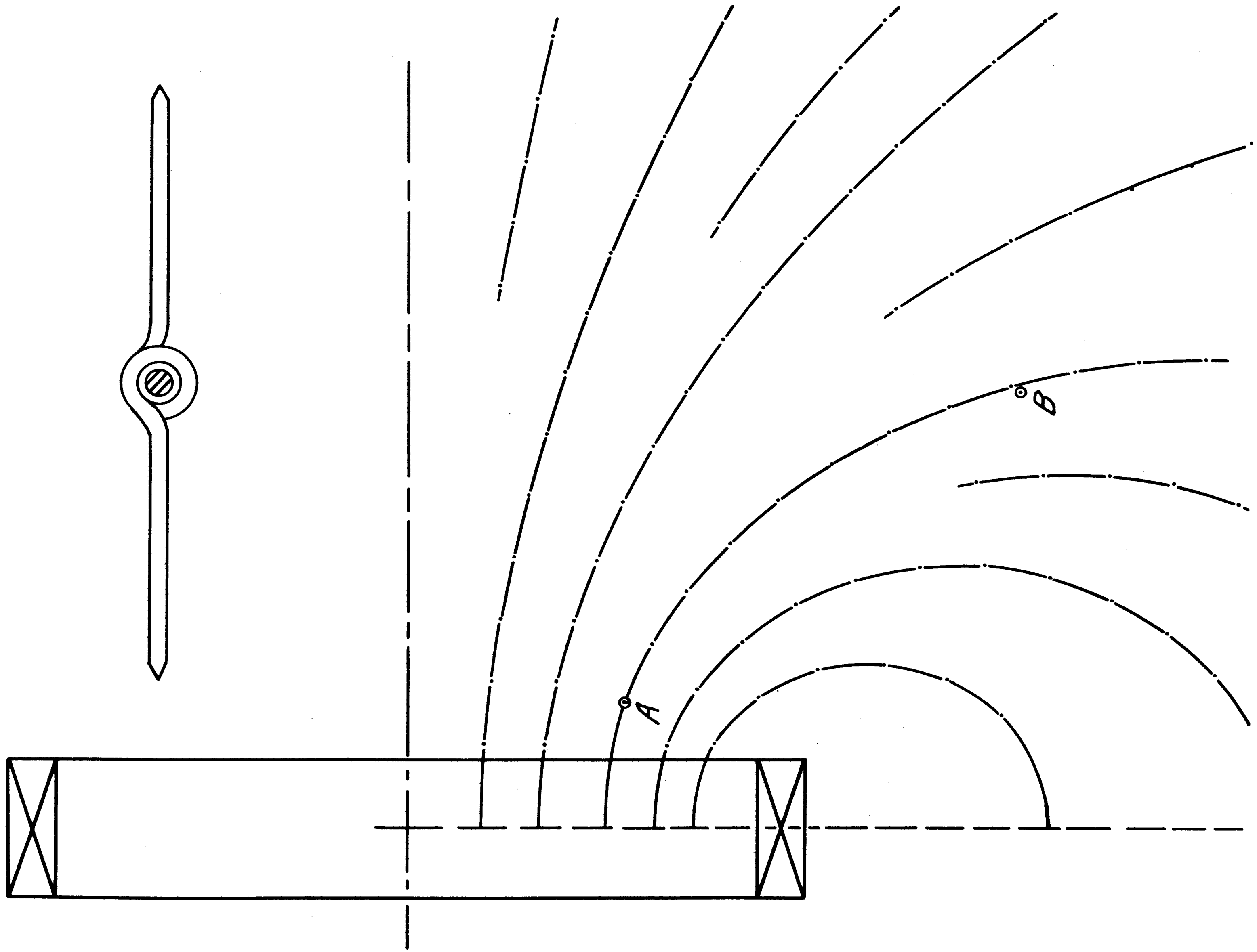

Figure 2. Coil section, and field as found by explorer.
(Above: explorer, enlarged, to scale.)