CHAPTER XVIII

The Use of Iron in Transformers

IRON, when used as the core of a transformer or any kind of induction coil, has two chief properties, magnetization and conduction. In that it differs from any of the other ordinary metals, which practically only have the property of conduction. When a varying current circulates near ordinary metal it induces short-circuited opposite currents in the substance of that metal, and these secondary currents react on the primary circuit in a way which is most simply described as increasing its effective or apparent resistance and diminishing its effective or apparent inductance. In this respect iron has the same properties as other metals, except that it is not so good a conductor as some of them, and hence secondary induced or so-called Foucault currents are not so strong in iron as they are in copper ; but otherwise they are just the same, in kind though not in degree.

Iron, however, has the additional property of being magnetizable. But so long as these Foucault currents last, they tend to screen it

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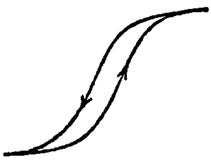
from the magnetizing effect of the primary current, since they are opposed in direction to that current. They therefore delay the magnetism, and at high frequency might protect it altogether, acting as a sort of screening skin, so that hardly any magnetic lines of force are generated inside the iron. This screening action would certainly take effect at what in wireless practice is known as "high frequency." But at audio-frequencies the Foucault currents would have time to subside, killed by the high resistance of the thin skin in which they circulate; magnetic lines of force would have time to develop, and the iron core would be magnetized and demagnetized, or reversed in magnetism, in accordance with the fluctuations of the exciting current, though with a certain amount of lag.

Of course, the Foucault currents must be kept to a minimum by subdividing the iron. It would never do to use a solid core, or a core built up of cylinders one inside the other, or of disks screwed up together so as to make a cylinder, because in either a cylinder or a disk the Foucault currents would have a free path for circulation, and the interior of the iron would hardly get magnetized at all. The core must be subdivided laterally, not longitudinally That is why it is usually built up of a bundle of thin iron wires, which, though incompletely insulated from one another (because insulation would take up valuable room), may yet be varnished, or, at any rate, slightly coated over with sufficient oxide, to prevent free electrical circulation or passage of current from wire to wire. Their longitudinal continuity is necessary for the magnetic lines of force: their lateral discontinuity is necessary for the stoppage of induced currents.

It is true that some transformer cores are made of thin sheet stampings; but the plane of these stampings is always at right-angles to the plane of the primary coil. The stampings being in the form of disks with the centre part cut away, the windings of the primary circuit are taken through the centre hollow of the disks and back round outside; so that the disks are continuous only in a direction at right-angles to the current, and are discontinuous in the direction of the current itself.

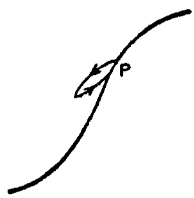
All this is probably well understood. Certainly it is understood by instrument makers.

But iron has another property, called hysteresis. This means that its rise in magnetism and its fall in magnetism are not quite similar. It rises, as it were, by one path, and it falls by another. The rise of magnetism, when plotted, follows what is called "the magnetization curve." The fall follows a similar but not identical curve ; so that the two curves, when plotted, enclose an area—an area something like this—when the magnetization and demagnetization are fairly complete.



Normal hysteresis curve.

If the magnetization and demagnetization are only partial, the two curves will still enclose an area, but more of this shape :—



Hysteresis Loop if the magnetization is momentary and slightly varied (diminished and increased again) at the point P.

Now wherever curves of this kind enclose an area, it means that work is done during the magnetization which is not got back during the demagnetization. There is loss or waste of energy. If the up-and-down paths were identical, there would be no loss. But when they differ from each other, it is like imperfect elasticity : you don't get back from the spring all you put into it. You never get more, and you may get less. The difference or the loss at each cycle is represented by the area enclosed between the two curves. The fatter this area is, the more the hysteresis. In fact, hysteresis may be considered as the name given to this area, the loss of energy per cycle.

Some kinds of iron have much less hysteresis than others ; but there is always some, and accordingly an iron core does involve some loss. But the advantages due to its extra magnetic lines of forces are so great as to overwhelm this loss and give us a balance of advantage, if the number of cycles is not too great.

The loss in commercial transformers at a frequency of fifty or a hundred per second is by no means insignificant. It results in heat, which is always the outcome of waste energy; and the transformer has to be artificially kept cool. At a frequency of a thousand a second, the loss is greater; though inasmuch as the magnetization is probably feebler, the area per cycle is likely to be less. And so for audio-frequencies, such as are used in wireless, this source of loss can easily be tolerated; and the transformer with an iron core is more efficient, much more efficient, than one with only an air core.

But when you come to a frequency of a million a second, the slightest loss per cycle is multiplied to such an extent that it cannot be tolerated. Both things, Foucault currents and hysteresis, dissipate energy; and when even a small amount is dissipated a million times a second, it naturally mounts up. Hence high-frequency transformers must not have iron cores. An air core has neither hysteresis nor Foucault currents; there is then no dissipation of energy, except the inevitable amount due to resistance in the wire: there is no supplementary loss. The effect of iron in a high-frequency core would be to confuse everything hopelessly. The iron would not get properly magnetized; it would be screened by its Foucault currents, nevertheless it would dissipate energy and tend to wipe or smear out the primary oscillations, destroying their features and making anything like clear speech impossible. There would not only be waste of energy, but there would be distortion. The resistance of the wire would be practically increased by the complicated reaction effects of the core.

It is rather surprising that these effects are not deleterious even in the case of audio-frequencies. It must have some bad effect, though it appears not to matter in practice. At the same time the cores of all transformers should be very carefully made, and these bad effects kept to a minimum, by special selection of the quality of iron and by thoroughly subdividing it in the lateral direction.

On these considerations is based the familiar fact that high-frequency coils are made without iron; though in low-frequency coils the use of iron is permitted and on the whole found advantageous, it should always be used with circumspection; and it seems to me possible

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that sets and the articulation of loud-speakers might be improved by dispensing with iron in transmitters; for instance, by using moving coils in a steady magnetic field. Permanently magnetized iron does no harm at all. All the effects spoken of are characteristic of varying magnetism under the influence of fluctuating currents.