DYNAMO DESIGN.*

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(Continued from April number.)

THE MAGNETIC CIRCUIT.

We now come to the consideration of the magnetic circuit which produces the fields to be cut by the armature conductors. There are a great many different types of magnetic circuits. Dynamos are classified by the forms and arrangements of these. They can only be utilized for dynamos by conductors cutting through gaps in them. The rest of the circuit is, therefore, only of use as it provides the fields. Electric current circulating in a continuous direction, in coils which surround the material of the magnetic circuit, is necessary to produce and maintain the magnetic flux. The excitation is proportional to the product of two terms, the current and the number of times it encircles the flux or to NC. Only the current involves energy, so that we are able to reduce the energy waste by increasing N.

As they are inter-related we may consider together the questions: How do we adjust the proportions of the magnetic circuit? what excitation will be needed for it? and how shall this be provided?

They are, in fact, the discussion of the equation

$$N\,C = \frac{10}{4\pi \times 2.54}\,\phi\,\frac{l_1}{S_1\,\mu_1} + \frac{l_2}{S_2\,\mu_2} + \frac{l_3}{S_3\,\mu_4} + \&c.$$

where l_1, l_2, l_3, etc., are the average lengths of the magnetic paths in the different parts of the magnet circuits.

s_1, s_2, s_3, etc., the corresponding areas of cross section.

μ_1, μ_2, μ_3, etc., the corresponding permeabilities.

ϕ the magnetic flux forced through the circuit by the ampere turns NC.

In this equation we have to fix the quantities ϕ and for each part of the circuit the term $\frac{l}{S\mu}$. To fix ϕ we have already the intensity of the field $\mathfrak{B}_a$, its width, which is taken as the length of the pole face, and its depth is calculated from the ratio of polar arc and the circumference of the armature; so that we have the area of the pole face, which is taken as the cross section of the field S and therefore $\phi = S\,\mathfrak{B}_a$ is determined.

We will now consider the terms $\frac{l}{S\,\mu}$ for (1) the air gaps, (2) the armature core, (3) the pole pieces, (4) the magnet limbs, and (5) the yoke or connecting pieces.

For the air gaps, we have already settled S, μ is unity, and l is the distance between armature core and the pole face, which is made up of depth of winding and clearance. The depth of winding has already been settled. The clearance varies with the diameter, in practice, between 1-32 and 7-16 of an inch. The larger distances are for slotted armatures, being found necessary to prevent sparking; it should be as small as possible, but there should be safety assured, for the surface of the armature, from touching the pole face. The smallness of μ makes this the most important term in the calculation. The main reason for making S large or $\mathfrak{B}_a$ small is now apparent.

Let us now deal with the armature core. In the first place, it has to be well laminated, for the reason that iron is a good electrical conductor; so that if the core were made of solid iron, this, cutting the magnetic lines which pass through it, would have the same effect as though conductors on the surfaces were short-circuited, which would waste power if it did nothing worse. The current that would flow in it would be in the same direction as in the conductors; the lamination, therefore, is to effect discontinuity in this direction. If the lamination is too thick, there will still be formed circuits in it sufficient to cause serious loss. The range of practice seems to be between 10 and 80 mils in thickness. Special insulation is not required between the plates; the coating of oxide formed by heating the iron is sufficient.

The radial depth of the core is fixed so that, after allowing for air space in the lamination, the total cross-section is sufficient to keep the value of $\mathfrak{B}_a$ in it well within the limits of saturation. In bipolar machines the total flux has two paths to take about the centre. In multipolar machines, for each magnetic circuit, it has but one path in the armature. The S for the armature is now fixed, since we know the length and have corrected it for lamination already. We must determine μ from tables giving the relation between $\mathfrak{B}_a$ $(=\frac{\phi}{S})$ and μ. l is the average length of magnetic path through the armature core, and may be estimated. The hysteresis losses in the core are proportional to the number of magnetic reversals and to the 1.6th power of the intensity of magnetization; for this reason $\mathfrak{B}_a$ should be lower as the speed increases, to keep down the heat and the heat losses.

The quantities, l, s and μ are readily estimated for the pole pieces—the pole face has already been fixed. The general design of the pole should be such as to prevent the unequal distribution of the field. They are often made of cast iron, especially in smaller sizes, when the intensity of the magnetic flux carried by them is not great, and therefore the permeability is large.

The magnet limbs, on the other hand, should be of the best annealed wrought iron, for the cross-section, as it affects the cost of winding, as well as the weight of metal, should be a minimum. It should also be as nearly circular as possible, as this has the least circumference for a given area. The limbs are usually run pretty well up to saturation, so that $\mathfrak{B}_a$, and therefore $S = \frac{\phi}{\mathfrak{B}_a}$ can now be fixed. For the present, the value of l will have to be estimated. This may be done from comparing similar machines. It is decided later, when we find the space required for winding. μ is fixed by $\mathfrak{B}_a$. If the dynamo is to have field regulation for electro-motive force or speed over any considerable range, then the value of $\mathfrak{B}_a$ chosen should correspond with the field needed for maximum pressure or minimum speed, so as to keep the field below saturation.

The cross-section of the yoke or other connecting pieces between the limbs should, at least, be as great as the latter, if of the same kind of iron. It is better to have it somewhat larger, so as to bring $\mathfrak{B}_a$ and μ down. If of cast iron, the value of S, being decided by $S = \frac{\phi}{\mathfrak{B}_a}$, *would be considerably larger, as the* permissible $\mathfrak{B}_a$ would be much smaller. It is again the length of the average path of the magnetic lines (not the length of the yoke over all).

We now have all the data for calculating the ampere turns NC necessary to produce the field for the armature conductors to cut. We should find, however, that if we took this value and designed the fields according to the cross-sections, etc., above obtained, and provided windings and current accordingly, that the useful flux that we should actually obtain would perhaps be only ½ or ⅔, perhaps, even less, of the amount calculated upon.

The explanation is this. air is a magnetic conductor not a good one, but still it has conductance, and magnetic lines, instead of passing around, and keeping within the bounds of the circuit, run out from the exciting coils, in more or less wide paths through the air, constituting magnetic leakage. The part of the total flux that does not go through the armature is considerable.

If we were to take a practical example of the magnetic circuit, and calculate the ampere turns, or the magnetomotive force necessary for each part of it, we should see that by far the greatest term would be that for the air gaps; so that if we consider the magnetomotive force about the magnetic circuit in the same way that we do electro-motive-force about the electric circuit, we see that the drop is proportional to the resistances. The air gap is to the magnetic circuit in very much the same relation that the space between plates suspended in acidulated water is to an electric circuit. The reluctance of the air gap is greater than that of the rest of the circuit, and, therefore, the greatest drop of magnetomotive force takes place over it. Wherever we have *difference of magnetic potential in a magnetic conductor, we shall* find magnetic lines. The pole pieces have great difference of magnetic potential. There are, we may say, two magnetic conductors between them, the air gaps and armature core as one, and the remaining possible paths as the other. Most of the lines will follow the former path, but only in proportion to its magnetic conductivity as compared with the other. In the same way there will be leakage between the limbs, and between the pole pieces and the yoke; there will be very little between the ends of the yoke. In all cases given the machine the magnetic conductivity of the air spaces is perfectly definite and can be ascertained, and, therefore, the proportion of the lines in a given case that leak through the air and those which are used in the armature can be ascertained.

As all the lines (or nearly all of them) will have to pass through