duty of *each* field coil is then to develop sufficient ampere-turns to establish—

1. The full value of the flux for the length of one pole, once across the air gap, and in one set of armature teeth; and

2. One half the full value of the flux along one half the length of the single path in the armature core and yoke.

Each field coil may then be regarded as establishing the flux over one half of the complete circuit, as indicated by the thick line in Fig. 9.

Owing to magnetic flux leaking from pole to pole without entering the armature, as discussed later, the effective value of the flux in the poles is considerably greater than in the armature. Actually the flux in the pole increases as the yoke is approached, and the flux density varies appreciably. The yoke also has to carry both the useful flux and the leakage flux. On no-load the effective flux in the pole, Φ_p will for a modern machine be about 15 to 20 per cent greater than the useful flux, Φ; the total flux carried by the yoke paths, Φ_y, will be from 20 to 25 per cent greater than Φ. If then the area carrying the flux is denoted by A_p for the poles, A_g for the air gap, A_t for the armature teeth, and A_c and A_y for *each* path in the armature core and yoke, respectively, as in Fig. 9, the corresponding values of the flux density, for a useful flux Φ, are $B_p = \Phi_p/A_p$, $B_g = \Phi/A_g$, $B_t = \Phi/A_t$, $B_c = \Phi/2A_c$ and $B_y = \Phi_y/2A_y$.

The m.m.f. required per unit length for the various parts of the circuit is then at once obtained by reference to magnetization curves, as given in Figs. 6 and 8; normally, for the air gap, the value is calculated as already indicated, i.e., $= 0{\cdot}796 \times 10^6\, B_g$ AT/m. The value of the ampere-turns required for each portion of the magnetic circuit is then calculated by multiplying the length of the magnetic line in that portion by the corresponding value of the ampere-turns per unit length. Thus, denoting the value of the ampere-turns per unit length for the various parts by H_p, H_g, H_t, H_c, and H_y respectively, and the corresponding lengths, by l_p, l_g, l_t, l_c, and l_y, the total value of the m.m.f. developed by each field coil is then

$$F_f = H_p \times l_p + H_g \times l_g + H_t \times l_t + H_c \times l_c + H_y \times l_y \quad \text{ampere-turns per pole} \qquad (37)$$

The method of obtaining the values of the various sectional areas and lengths of the magnetic lines is discussed later. For the moment we will work out an example for which the various dimensions—areas and lengths—have the values given below, the useful flux being 0·08 Wb per pole, the mean pole flux being 0·092 Wb and the total yoke flux 0·096 Wb. The calculations are given in tabular form.

The values of the densities, and the dimensions generally, in this table are fairly typical of a machine of medium size. The factor

The total reluctance of the air gap for a slotted armature is then

$$R_g = K_g \times \frac{l_g}{\mu_o K_f \tau_p L} \quad . \quad . \quad . \quad (43)$$

In this expression, $l_g/\mu_o\tau_p L$ is the reluctance that would obtain for a smooth core machine having a uniform air gap l_g over the whole pole-pitch; K_f takes account of the fact that a definite or salient pole is used, and allows for fringing at the pole tips and bevel of the shoes; K_f is numerically equal to the ratio of the average density over the whole pole-pitch to the maximum density under the centre of the shoe; K_g takes account of the fact that the armature is slotted, and allows also for the effect of the ventilating ducts.

An approximate value for K_f is obtained, for a machine with normal proportions and degree of saturation, by taking, simply, K_f = pole arc/pole-pitch. For precise calculations, the actual value of the coefficient should be determined.

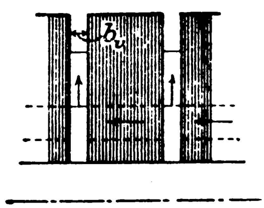

FIG. 18. VENTILATION DUCTS

Air-gap Ampere-turns. There is no need in practice to work out the actual reluctance of the air gap, the air gap correction coefficient K_g being used as a simple "correcting" factor to the calculation based on a smooth-core machine. Thus

$$F_g{}^* = K_g \times B_g l_g/\mu_o$$
$$= 0{\cdot}796\, K_g B_g l_g \times 10^6 \quad . \quad . \quad . \quad (44)$$

with m.k.s. units for B_g and l_g.

Active Iron Length. The armature core of a d.c. machine is built up of a number of plates, or laminations, lightly insulated from each other by paper, varnish or some other suitable material. These steps are taken to reduce eddy currents to reasonable proportions. Further, to keep down the temperature of the active parts, it is necessary to ventilate the core, and this usually is effected by subdividing the core into packets of 5 to 7 cm in width, separated at intervals by distance pieces called "vent spacers" so as to leave a ventilating duct through which air can pass. These ducts are radial, as indicated in Fig. 18, and are from 8 mm to 10 mm in width.

Of the total gross core length, then, a certain proportion is taken up by the ventilating ducts, and of the other part only a portion is iron, the remainder being the insulation on the core plates and an amount due to the springiness and irregularities in the thickness of the core plates. It is usual to define the space factor of the iron in

* $F_g = 0{\cdot}796\, K_g B_g' l_g'$ with B_g' in gauss and l_g' in cm (cf. page 18).
In these expressions B_g and B_g' denote the maximum flux density in the air gap, for a smooth-core armature.

Where greater accuracy is required, the real flux density should be calculated at the top, bottom and mid-section of the tooth and the effective value of the ampere-turns per cm determined by the aid of Simpson's rule. The use of Fig. 20 in this connexion has already been given.

It is only at very high values of the flux density that the slots, etc., carry an appreciable portion of the flux, and for values of B_{appt} not exceeding 1·9* it is generally negligible, and B_{real} may be taken as equal to B_{appt}. By having the teeth highly saturated, however, not only is it possible to obtain a relatively large output from a machine, but in addition certain undesirable effects of armature reaction are minimized, as discussed in Chapter IV.

The effective value of B_{real} with large machines is from 2·05 to 2·15, or even 2·2, for ordinary iron.

When calculations for highly-saturated teeth are based on Simpson's rule it is necessary to work out the value of k_s at the top, bottom and mid-tooth position.

Armature Core. The sectional area of the core, below the slots, has to suffice to carry one half of the total useful flux per pole. Fig. 23 gives a developed view indicating the manner in which the

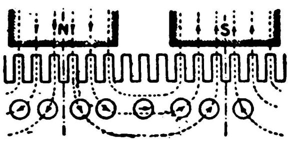

FIG. 23. THE FLUX DISTRIBUTION IN THE ARMATURE

flux is distributed, and it is evident that the flux density in the core is far from being uniform. A precise calculation of the ampere-turns required to establish the flux is then not to be expected; fortunately, the reluctance is normally so very small that an approximate value is sufficient.

An approximate, and sufficiently exact, method is to base calculations upon the maximum value of the flux density, which will occur at AB in Fig. 9, p. 21, and to take the total length of the path as being the value of the pole-pitch measured at the mean diameter as indicated by the heavy dotted line in Fig. 9.

Thus, if D_t = the diameter at the root of the teeth, and d_c = the core depth below slots, the length of the magnetic line may be taken

$$= \frac{\pi (D_t - d_c)}{2p}$$

and the value corresponding to each pole being one half of this amount, becomes

$$l_c = \frac{\pi (D_t - d_c)}{4p} \quad . \quad . \quad . \quad . \quad (53)$$

* 1·9 for ordinary iron, and 1·7 for Stalloy.