which I had used for some time, and which was given in my last year's paper. This is only a rough approximation, for, as Mr. Swinburne has pointed out, to be quite accurate, the angle should appear in the denominator as in 1 and 2. The simplest form the expression can take is given in 1. This contains nothing but the length of the air gap, the induction in it, and the angle of the pole-piece. It will be observed that it takes no notice of the diameter of the armature or of the number of poles. So far as the sparking limit is concerned, it gives a rule which may be employed in designing machines of any size and with any number of poles.

2.—THE RELATION OF v TO THE DIAMETER OF THE ARMATURE.

But besides taking care that the armature load does not approach the sparking limit, we must provide ample surface for getting rid of the heat generated in the conductors. The first thing to be settled in designing a new machine is what the amount of heat shall be; or in other words, we must fix the ratio which the energy appearing at the terminals shall bear to the total electrical energy produced. Having settled this, sufficient radiating surface must be allowed to prevent too great a rise in temperature—a point to which due consideration has already been given.

The principal factors which determine the relation of the volume to the diameter of the armature are efficiency and temperature. It will be seen that the equation (1) gives no direct information respecting the diameter for a given volume, and as long as 1, l, and Φ remain unchanged, the tendency to sparking would be the same whatever the diameter. But it is not so with the heat generated or the temperature rise, for assuming v and l to be related as shown, the smaller the diameter, the greater would be the temperature. To carry a given volume we must have, consistent with the waste of power permissible, a certain section of copper; and this copper should be disposed so that a cooling surface is provided sufficient to keep the rise in temperature within the specified limit, while the gap, being of sufficient length to prevent sparking, should have only the dimensions necessary for accommodating the conductors and allowing of proper clearance.

Through the kindness of members of the Institution and others, who have liberally supplied me with figures, I have been able to ascertain the nature of the relation between the diameter and volume existing in all the best known machines, from the smallest to the largest sizes. The figures refer to both cylinder and drum-wound armatures, and include machines with two, four, six and eight poles. Though I am not at liberty to publish the data in full, the general results are given. There is not so much agreement between the dynamos of different makers in respect to this relation as might have been expected, and for v we have all kinds of values, ranging from 200 to 1,000 times the diameter of the armature in centimetres. If full advantage of the length of the air gap were taken, and the thickest possible conductor used in each case, the diameter, to give a uniform temperature for all sizes, would be about proportional to the square root of the volume, but there are several reasons why this proportion should not obtain in practice. With this relation the ratio of the stray to the useful field would increase with the diameter, thus entailing an extravagant expenditure of energy in producing the requisite gap induction. Again, while the total field through the armature would increase simply as the diameter, the volume carried would increase as the *square* of the diameter, this being at variance with the well-established rule that the total field through the armature increases rather than diminishes relatively to the volume as the size is increased. It will be understood, of course, that precisely the same result is arrived at whether we consider the volume fixed and endeavor to find the best diameter, or consider the diameter fixed and seek for the best volume. It is simply a question of obtaining the most economical construction, having regard to cost of materials, efficiency, prevention of sparking, and temperature limit, though the figures at my disposal show estimates of the relative values of these factors to be by no means uniform.

Though the relation lacks definiteness to some extent, I find in the data of a large number of machines indications sufficiently pronounced to justify us in regarding the volume carried by the armatures of two-pole dynamos as proportional to the diameter for all sizes. In designing cylinder machines, the value of v may be taken as 400 times the diameter of the armature in centimetres, while for drum armatures the volume is obtained by multiplying the diameter by 600.* The cylinder armature has for a given volume a larger diameter, because of the influence of the interior wires. These being heaped inside to one and a half or twice the depth of the exterior winding, also being longer, a larger diameter is required for a given volume, both from efficiency and temperature considerations. Necessarily, the relations here given are not of a hard-and-fast character, and may be varied considerably. But whatever the proportion adopted, it is absolutely essential that the sparking limit already considered be not too closely approached.

In machines having four and six poles, the same average relation between the volume and diameter holds in practice for both cylinders and drums. In the calculations which follow these figures will therefore be adopted.

3. OUTPUT OF DIRECT CURRENT ARMATURES.

If we call N the total number of lines of force entering the armature from all the poles, however many, and n the number of revolutions per second, the average E.M.F. generated in each conductor is, of course, $N\,n\,10^{-8}$. If C be the total current flowing, each conductor will carry with the sections coupled in the ordinary way $\frac{C}{p}$ amperes, p being the number of poles.

The electric work due to each conductor, is $\frac{C}{p} \times \frac{N\,n}{10^8}$; and the

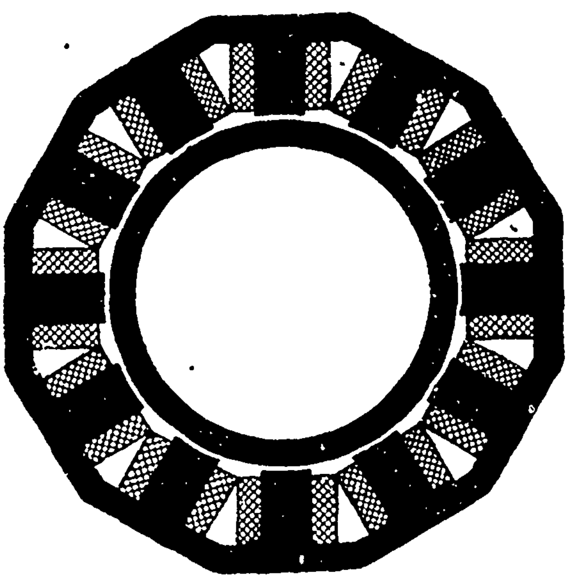

FIG. 2.

total work, $\frac{w\,C}{p} \times \frac{N\,n}{10^8}$, where w is the number of conductors, counted all round the exterior of the armature. The quantity $\frac{w\,C}{p}$ is what we have called the *volume*, and we get for the total electrical output in watts the expression,

$$W = N\,n\,v\,10^{-8} \qquad (4)$$

which is quite independent of the manner of coupling up the armature sections. It will be evident, I think, that with the same relation existing between v and d for two, four and six poles, the output of an armature of given diameter and length, running at the same speed, is quite independent of the number of poles. It matters not whether N be furnished by two poles only, or by four poles of half the angular width provided its value remains unaltered.

The volume, then, may be expressed in terms of the diameter. The quantity, N, may be expressed in terms of the diameter × length of the armature. Taking an induction of 5,000 C.G.S. units per square centimetre in the air gap—a very usual figure—and assuming that the fraction of the armature circumference covered by the pole pieces = 2.25 d, we get, calling L the length of the armature in centimetres, 11,250 $d\,L$ as the total number of lines of force entering the core. Call this, in round

* In my last paper the number given was .7. This I now amend as above.—W. B. E.