DISCUSSION ON "COMPARISON OF TWO- AND THREE-PHASE MOTORS," AT MILWAUKEE, WIS., MAY 28, 1906.

A. S. McAllister: The author says that the magnetizing current in a three-phase motor is approximately 15 per cent. more than that in a two-phase motor, but that when expressed in per cent. of the full-load current the magnetizing currents of the two motors are equal. These statements are based on a study of the distribution of the primary coils, of the change in the value of the magnetizing current, and of the fluctuation in magnetism produced thereby.

I wish to call attention to the fact that these relations may be established much more simply without any reference whatever to the numerous factors which the author has taken into consideration, other than his original implied assumptions that the frames of the two motors are equal and are subjected to the same iron losses.

Although it would be possible to determine the components of the primary current necessary to supply the hysteresis loss by ascertaining the distribution of the coils, the path assumed by the flux, and then making an elaborate study of the B-H curve of the iron employed, such a laborious method is considered entirely unnecessary, and use is made of the familiar hysteresis formula:

$$W_h = h f B_m^{1.6} V$$

where h is a constant depending upon the quality of the iron. Similarly the eddy-current loss is found from the formula:

$$W_e = e f^2 d^2 B_m^2 V$$

The sum of these two quantities gives the iron loss in watts, and the current to supply these losses is found by dividing this value of watts by the impressed electromotive force.

It can easily be shown that with a closed magnetic circuit the quadrature exciting watts may be expressed by the formula:

$$W_q = q f B_m^2 \frac{V}{\mu}$$

where μ is the permeability of the iron and q is a constant, having a value of

$$q = \frac{2.5}{10^8}$$

When an air-gap is inserted in the magnetic path, the quadrature watts may be expressed by the formula:

$$W_q = q f B_m^2 \left(\frac{V}{\mu} + V_a \right)$$

where V_a is the volume of the air-gap. The exciting current is found by dividing W_q by the impressed electromotive force.

Where there are divided magnetic circuits and the magnetism is not uniform throughout the paths, it is desirable to consider each path separately, just as is true in treating the hysteresis and the eddy losses. An inspection of the formula for ex-

pressing the quadrature watts will show that if the effective value of the maximum magnetic density throughout the several volumes be used, a correct result will be obtained from a single calculation.

From the above discussed facts it will be evident that the quadrature exciting watts of an induction motor operated at a certain frequency and magnetic density depends solely on the volume of the core and the air-gaps, and is not affected by the number coils or phases or the voltage of the machine.

These remarks should not be considered as adverse criticism of the paper under discussion. On the contrary the speaker wishes to express his appreciation of the clear manner in which the matter has been presented, and of the value of the paper to a practising designer. He wishes merely to make a plea for simplicity in the treatment of electric phenomena in all cases where elaborations do not contribute to the accuracy of the results obtained.

Bradley McCormick: Mr. McAllister's method strikes me as being very good. I have employed the same method in the case of transformers, and find it works admirably; but just why I use this method instead of the other in the induction motor I can explain only by saying that it has become a matter of custom. A designer employs one method in preference to another largely through habit.

C. P. Steinmetz: I do not quite agree with the conclusion that such a considerable difference exists between the three-phase and the two-phase induction motor, in favor of the three-phase motor. This does not agree with my experience, theoretical and experimental. The exciting volt-amperes of an induction motor at constant magnetic density; that is, constant magnetic flux per pole, are the same for the three-phase as for the two-phase motor, and are slightly lower for the single-phase induction motor: the maximum output is the same for the three-phase as for the two-phase motor, and for the single-phase induction motor varies between about 35 and 45% of the maximum output of the same motor as polyphase induction motor. In other words, all polyphase induction motors have the same volt-ampere excitation, and same maximum output, while the single-phase induction motor at the same magnetic density has a slightly lower volt-ampere excitation and less than half the maximum output. The excitation of the single-phase motor is slightly lower, because one of the components of the magnetic flux is produced by transformation through the rotor, and therefore is lower by the drop of voltage in the transformation from the impressed energy phase of the stator to the magnetizing phase of the rotor.

The numerical values of reduction factors are, I believe, merely the average of the projections of the different coils as displaced in position from each other upon the main direction of the coil, or are the average cosine extending over an arc of 90°

degrees in the two-phase motor or 60 degrees in the three-phase motor. I believe, however, that when the author speaks of three-phase winding, he refers to six-phase winding. The three-phase winding, which he refers to, is a winding arranged so that each phase covers an arc of one-sixth of a period, or one-sixth of the pitch of two poles; therefore all his conclusions, while they apply to such a six-phase winding, whether delta or ring, or Y- or star-connected do not apply to the real three-phase winding, where each phase covers an arc of 120° electrically, as used in synchronous converters and such machines. The two-phase winding would better be called four-phase, since it covers an arc of 90 degrees. Otherwise, however, the paper is very interesting, in giving a discussion of the effect of arc of distribution of the winding, as varying between 60 and 90 degrees.

R. E. Hellmund: Mr. Steinmetz says that there should be hardly any difference between two-phase and three-phase motors, but it is a fact that the leakage of the two-phase motor is considerably higher than that of the three-phase motor; and therefore it is natural that it is much more difficult to design a good two-phase motor than a good three-phase motor. The reasons for the difference in the leakage are various, but it seems to me that one of the main reasons is the following: the leakage consists of two kinds, one leakage going around each particular phase, and one leakage which is going to all three phases, going around the bunch of the three phases. Now, in the three-phase motors this given leakage is, for certain kinds of windings, practically zero, (*i.e.* the chiefly used diamond winding) since the vector sum of the three-phase currents is zero and that of the two-phase currents is a certain amount. I have made a series of tests which tend to show that this is one of the main reasons for the difference in the leakages.