Discussion on "Direct-Current and Alternating-Current Mill Motors for Auxiliary Drives" (Wiley). Pittsburgh, Pa., April 25, 1912.

Alexander C. Lanier: Mr. Wiley's paper has brought out the principal demands made upon motors in mill and crane service and my remarks will be limited to direct-current motors suitable for such applications. Commutation is always a factor of first importance in the direct-current motor; service conditions met in mill work are much more severe than in the ordinary industrial application. During the operating cycle the load usually varies between wide limits, and momentary peaks may reach three or four times the one-hour rated load.

The commutating pole motor is particularly suitable for such conditions. I shall only mention in passing the long-recognized principle underlying commutating pole design. By providing at the point of commutation a flux closely proportional over a wide load range to the current commutated, its value in general such as to give straight-line reversal of current under the brush and its magnetizing current in series and therefore in time phase with the armature current, the commutating range of the machine is greatly extended. For motors in reversing service, with neutral setting of brushes, commutation is better provided for, in a properly designed commutating pole machine, under heavy overload conditions than in the normal non-commutating pole type at rated load. In the design of commutating pole motors of strongly drooping characteristics, slight over-compensation at normal load will add somewhat to the overload range of the motor. The short-circuit voltage per brush and per coil should also be kept within proper limits.

In commenting upon the root-mean-square method for selecting motors for a given service, with known operating cycle, and length of time during which the cycle is repeated continuously, attention is directed particularly to the utility of a table of ratings covering a wide range of time period as indicated in Mr. Wiley's paper. Besides the application in which there is practically continuous repetition of the cycle over five-hour periods, frequent cases arise in which the motor is subjected to very heavy loads of short duration, followed by long periods of light load or absolute rest. Since the temperature rise of a motor under loads of short duration is a function of the heat capacity of the machine more largely than its radiating properties, the short-time rating of the motor in such cases forms a ready basis for its selection.

M. A. Whiting: There is one point concerning which I should like to have Mr. Wiley go into a little further detail, *i. e.*, he states that the heating effect of a varying load is best expressed in terms of an equivalent continuous load with the voltage at the motor terminals reduced. I should be interested to know how great a reduction in voltage Mr. Wiley has in mind and just what conditions such a rating at reduced voltage is intended to cover. For example, it could be made to cover merely the operation of the motor during accelerating periods, during which the voltage impressed on the motor armature varies from zero to full line voltage, or it could take account of the probability of prevailing condition of low average plant voltage. Further information on this point would therefore be of interest.

The root-mean-square method, which Mr. Wiley explains and illustrates, is of course by far the best known and most widely used method for estimating the heating of a motor on a varying load, but in some cases this method introduces serious discrepancies. It is therefore of interest to consider under what conditions the discrepancies occur and in which direction they affect the result. This is not a criticism of the use of the root-mean-square method in general, but merely a consideration of its application with reference to certain cases. The accuracy of this method depends on the shape of the efficiency curve of the motor over the range of loads considered. Take for example, the curve in Fig. 7, covering a series motor with a nominal rating of 30 h.p. As the heating curve is not given, we may assume for the purpose of discussion that the continuous capacity of the motor is one-half the full load current. In using the r.m.s. method for a continuous cycle (*i.e.* for a cycle repeated continuously for, say, twenty-four hours) after determining the r.m.s. equivalent of the load we compare it with the continuous capacity of the motor for the allowable temperature rise. In doing this the assumption is made that the total *kw. losses* of the motor vary as the square of the load, or, expressed in other terms, the assumption is made that the *per cent losses* vary directly as the load. The efficiency curve assumed by the r.m.s. method therefore begins at the point of 100 per cent efficiency —zero load, and consists of a straight line extending down at an angle and intersecting the actual efficiency curve at the point corresponding to the continuous capacity of the motor (in the present case, Fig. 7 of Mr. Wiley's paper, assumed at half load as stated above). Where the actual efficiency curve follows very closely this straight line, the r.m.s. method will be very close. But in the figure under consideration the actual efficiency curve crosses this straight-line efficiency curve at a considerable angle, so that the actual losses at heavy loads are less, and at very light loads are greater than indicated by this hypothetical straight-line efficiency curve laid out in accordance with the r.m.s. assumption.

I have had occasion to work out a number of cases along this line (not, however, in connection with this paper), which show the following:

First, if the loads in a cycle are at all times below the basic value with which the comparison is made (*i.e.*, are at all times below the continuous capacity of the motor) the heating will be greater than indicated by the r.m.s. method (although, of course, still below the capacity of the motor).

Second, if the loads are all above this basic value, interspersed with periods of rest and periods during which the motor coasts without load, the heating will be less than indicated by the r.m.s. method.

Third, if the loads are partly above and partly below the basic value, the losses may be greater or less than indicated by the r.m.s. method. Where the loads vary above and below the basic value in this manner, the errors due to the r.m.s. method showing too low losses at light loads and too high losses at heavy loads, tend to compensate, so that on this kind of cycle the discrepancy will usually be much smaller than in cases 1 and 2.

Referring to the induction motor curve, Fig. 7, we note that the efficiency curve is more nearly level at overloads than is the case for the direct-current motors, Figs. 7 and 8, *i.e.* the losses for this induction motor deviate more greatly from the r.m.s. assumption, and the method is more inaccurate. In general, a motor with high iron losses and low armature and series field copper losses will vary more from the r.m.s. assumption than will a motor with large armature and series field losses and small iron losses.

To compare the relative accuracy of the r.m.s. method for open and enclosed motors we may refer to Fig. 7, and consider this efficiency curve as applying to an open motor having a continuous rating of 30 h.p. In this case the basic value assumed in using the r.m.s. method will be, as before, the continuous capacity of the motor (in this case 30 h.p.). If we draw a straight line efficiency curve on this figure, in the same manner as previously, but intersecting the actual efficiency curve at 30 h.p., these two curves lie close together over a considerable distance, and the r.m.s. method will therefore be much closer than in the case of the enclosed motor discussed above.

In practically every open motor of normal design the losses at the continuous rating of the motor are principally load copper losses, whereas with any enclosed motor, on account of the reduction in continuous output, the iron losses form a large percentage of the total losses at the continuous rating of the motor. It will in almost all cases be true, therefore, that the root-mean-square method is liable to greater inaccuracies when applied to an enclosed motor than when applied to an open motor.

R. B. Treat: There is a class of service to which the commutating-pole mill motor is not well adapted. We had an illustration on the screen of a screw-down motor and a front and back catcher table motor. This is the type of service referred to, requiring momentary high torque for very short times. The normal commutating-pole mill motor will easily stand 50 per cent over its rated load. At 100 per cent overload that motor will commence to spark. At 200 per cent overload the sparking of the brushes is worse than if there were no commutating poles present. Screw-down and catcher table service requires commutating capacity rather than heat capacity in the motor. The commutating poles should therefore be designed for the 200 or 300 per cent overload current, but such a design is not found in commutating-pole mill motors of a size necessary for screw-down or catcher tables.

It may be true that small commutating-pole mill motors (25 h.p., more or less) have been run satisfactorily in the factory with three, four or five times rated load. The design which permits this in a 25-h.p. size does not prevail in a 75- or 100-h.p. size. There is no comparison between a small motor on factory test and a large motor on screw-down or table service.

There is another feature, too. The peak current is instantaneous, mounts to its maximum value, and then drops off within a small fraction of a second. The flux set up by the windings on the commutating pole comes along a little later—after the current has subsided. It is not in synchronism with the load current. The load current is present without any commutating flux; there is sparking. The load current subsides, the commutating flux comes, and again there is sparking. For each rapid current change of great magnitude there are two sparking intervals in a commutating pole motor and only one in a non-commutating pole machine.

One sentence in the paper reads "and the recently developed type of controllers provides special protection against unnecessarily severe conditions being imposed on the motors." These controllers protect both commutating pole and non-commutating pole motors against unnecessarily severe conditions. If the controller does it, why not omit the commutating pole entirely, and have a somewhat simpler machine? The author states that the torque of an a-c. mill motor is greatly dependent upon proper adjustment of resistances, while the torque of a d-c. motor is more independent of resistance adjustment. He then goes on to state that "these inherent features" of the a-c. mill motors protect the driven machines and the driving motor. It would seem more appropriate to state that "these inherent features" of the a-c. mill motors are so troublesome as to recommend the abandonment of the a-c. mill motor, a conclusion which at least one steel mill has almost arrived at.

Gano Dunn: The Standardization Rules, and, in fact, the standardization methods in all countries, are in need of a definition of what the relation of the root-mean-square to the real capacity of an intermittently used motor is.

The methods at present in use for rating intermittent service motors, as Mr. Whiting very properly pointed out, do not take directly into account the heat-absorptive capacity of the motor, nor do they take into account many other things, and, as he has said, the accuracy of applying the r.m.s. method really depends upon the shape of the efficiency curve of the particular motor in question, not to mention the motor's absorptive capacity and several other factors which might be named.

When, in the early history of the Standardization Rules, the question was up of a simple way of determining, artificially, if you will, the efficiency of generators, the rules incorporated methods which, while not entirely accurate, were so simple that they became universally employed, such, for instance, as measuring the no-load losses and then arriving by calculation at the resistance and other losses, making a result that was partly calculated and partly measured.

Now, just this kind of thing is needed in the case of intermittent service motors. Mr. Whiting's discussion contributes a good deal in that direction. For instance, if we could adopt some standard type of efficiency curve, and assume it to apply to all intermittent service motors, and then make such modifications in the r.m.s. rule as would cause that rule to be applicable to that particular type of efficiency curve, we would have secured an approximation that would undoubtedly be sufficiently close for all purposes, and would enable us to discuss intermittent service motors more intelligently than we now do.

We ought then to add to any ratings arrived at by that method, a factor representing the absorptive capacity of the motor; so that, given what you might call the equivalent continuous load of a motor, or given its cycle in intermittent service, and stipulating that the standard or arbitrarily adopted efficiency curve for heating shall apply to calculations in connection with this motor, we would have, by applying to these results the absorptive factor, a method by which we could compare a German motor with an American motor, or with motors made in any country, and by which we could compare motors of different manufacture in this country, even if their weight and absorptive capacity, and general characteristics, were very different.

If Mr. Wiley's paper and the discussion of it can stimulate the development of a method of arriving at some arbitrary basis of comparison between intermittent service motors better than the r.m.s. method, taking into account the absorptive capacity of the motors for heat, it will have done a great service.

F. R. Fishback: Mr. Wiley has given some tables in his paper, and I get the general impression that he believes alternating current should be used for auxiliary drives. The principle argument in favor of the a-c. motor is the question of line transmission and commutator troubles, the big bugbear of all our troubles. With commutators designed to take care of the present-day loads, we can neglect the commutator question. In the table referred to, Mr. Wiley states that during a period of a year, and covering a large number of motors, no new commutators were put on, no new shafts were required and only 10 new sets of armature coils. Six of these were for 25-h.p. motors and four for 50-h.p. motors. The total repairs, according to the table, have been purely a question of armature coils. I think it is also safe to assume that in the list of motors taken, a large per cent of the motors were controlled with the manual controllers. I say this because it has not been common practise until recently to put automatic controllers on motors of 50 h.p. or under. With automatic control on all of the motors in the table above, the number of new armature coils required could have been greatly reduced, if not eliminated.

There is also the question of the electric brake that enters into the question of repairs on a motor. The d-c. brake is a much simpler one than the a-c. brake. A long-stroke plunger can be used, and this gives plenty of leeway and clearance in designing the brake. The d-c. brake consists of a steel casting, a winding and a steel plunger. The a-c. brake has a short-stroke plunger and is made up of laminated pieces, which chatter and easily get out of order.

The d-c. motor is the only right motor for auxiliary drive. The d-c. motor has the advantage over the a-c. motor of speed control and dynamic braking, and the most important advantage of all in that it will lift above its capacity until it burns out. This characteristic of the d-c. motor is most important in steel mill work where it is often cheaper to burn out an armature rather than wreck a more expensive machine or kill a man.

A. G. Ahrens: In connection with Mr. Treat's criticism of the commutating pole motor, that it is not able to stand heavy overloads of torque, I do not think Mr. Treat had in mind the mill motor. Mr. Lanier pointed out that the mill motor on ordinary loads is under-commutated, so to speak, so that on extreme overloads it is found that it commutates at its best. I have seen mill motors under a test with the special object of obtaining data as to their commutating ability, and I remember one test in which the motor was rated at 25 h.p., mill rating, which is equivalent to an armature current of 113 amperes, and under 400 amperes load, which is equivalent to over 350 per cent of normal load, that motor was sparking slightly, a condition of commutation which would have been called good on any industrial motor.

Brent Wiley: In regard to Mr. Whiting's question concerning reduced voltage, this subject has been considered from the standpoint of average conditions for motors operating with widely and rapidly fluctuating loads. This average condition is assumed to be such that the average voltage during the entire day, where 24-hour service is required, is one-half normal line voltage. For example, if the normal line voltage is 230 volts, the average voltage is figured at 115 volts for a cycle in which the motor is operating at full voltage approximately 40 per cent of the total time; and the heating of the motor is calculated on the basis of the equivalent continuous current at this reduced voltage. Operation with reduced voltage at armature terminals, due to insertion of resistance in series, for a greater percentage of time, would give equivalent results.

For a large majority of the applications for which the mill motor is particularly suitable, it is practically impossible to predetermine the exact cycle of operation, including time and load. It has been determined, however, that by averaging the data and conditions for various installations in steel mills, the actual operating period of the motor is approximately 40 per cent of the total period, and the table of ratings given has been developed on the basis of average voltage at the motor terminals equal to one-half normal line voltage.

It would be of advantage to take the motor characteristics into consideration when calculating the heating effect of a varying load for those cases where the load curve can be predetermined accurately; and further investigation of this point would be of value. It is questionable, however, if the attempt to apply such a close theoretical analysis would be of practical value for the general application of mill type motors.

Mr. Treat has questioned the ability of the commutating-pole mill motor to meet successfully the severe conditions of steel mill work.

The particular function of the commutating pole feature is to give better commutation over a wider range of operating conditions than can be obtained by the non-commutating pole motor. With the conditions to be met well established, there are no reasons why the proper commutating pole features cannot be included and better results obtained. It is true that, until a comparatively recent period, the theory of commutating pole design was not well established, and its application to motor design was therefore somewhat limited; but the unqualified success of the commutating pole railway motor is a forceful demonstration that for even severe, intermittent and widely varying load conditions, commutating poles are of great advantage.

Mr. Treat's criticism of the commutating pole motor for use in heavy-duty reversing service seems to be based on some particular design. It has come to be recognized that motors must be designed especially for this service, electrically as well as mechanically. No one conversant with conditions would apply a motor in this service having the same mechanical design as a motor suitable for, say, printing press drive. It is important to have a liberal electrical design and the use of the commutating pole permits this without going to proportions of armature that would make the machine excessively large. It is perfectly practicable to so proportion motors of the largest sizes required in this service that they will commutate the heavy overloads sparklessly, at the same time giving sparkless commutation on full load and lighter loads.

The time lag referred to between the current inrush and the building up of the flux is very much less than might be supposed, since the ampere-turns on the pole are ample to force the flux, not only through the pole, but also through the gap. As the ampere-turns required for the gap are many times those required for the iron part of the circuit, there is a very high m.m.f. forcing the rapid building up of the flux.

Results actually secured with commutating pole motors in this service show that no injurious results follow from this very slight time lag.

There are many applications of the commutating-pole mill motor being made on the mill machinery referred to by Mr. Treat, and from the preliminary tests that have been made, improved commutating conditions, as compared with those obtained with the older types of non-commutating pole motors, can be assured.

The reference which was made in my paper to improvements in control apparatus has a more significant meaning than has been brought out in the discussion. The point is that these improved conditions make it possible in many cases to increase the working capacity of the motor by the use of commutating poles. The function of series relays and series switches is to limit the accelerating and braking current to a predetermined amount. In the majority of applications, rapid acceleration and retardation are desirable—limited, however, to such values as are necessary to protect machinery and motor. With commutating pole motors these values of the current will be more dependent on the limits imposed by the machinery rather than by the motor. As the commutation limit has been raised, it means that the working capacity of the motor has been raised. It becomes more a question of heating limitations and, as stated previously, fireproof windings permit a much higher safe rise of temperature than can be obtained with the older types of motors.

Regarding the question of the relative merits of the alternating-current and the direct-current mill motors, as mentioned by Mr. Treat and Mr. Fishback, this is a very broad subject and it is not within the scope of this paper to give the various points proper discussion. There is no doubt that, for the most severe service, such as screw drives and reversing tables, the direct-current series motor has more advantageous characteristics. This is equally true of the hoist motion of cranes; but the question whether one type of motor or the other should be used should not be answered on this basis alone. With the increased attention which is being given the question of economies, there is good reason to believe that the application of the alternating-current mill motor will be made in accordance with the saving that it will insure. Much progress has been made regarding the design of an alternating-current mill motor with suitable features for this severe duty, and a careful study of the gradual applications by the designing and the field engineer will insure further progress in the successful application of this type of motor.