

DISCUSSION ON "METHODS OF VARYING THE SPEED OF
ALTERNATING-CURRENT MOTORS. (MAIER) NEW YORK,
DECEMBER 8, 1911.

H. W. Buck: There is a popular idea that alternating-current motors can be used only where constant speed is allowable, and that where variable speed is required it is necessary to convert the alternating current into direct current and obtain in this way the flexible speed variation through direct-current motors.

Recent developments in this country and abroad in variable speed alternating-current motors, which have not as yet been extensively applied commercially, afford means for many industrial purposes of variable speed control almost as flexible as that obtainable with direct-current machinery.

The variable speed alternating-current motor is a very important field for development work and a paper like this of Mr. Maier which points out the direction in which the development is taking place, is of great value.

Mr. Maier's paper is an excellent resume of the art as it stands to-day and should be suggestive and instructive to those interested in this branch of electrical engineering.

R. N. Dickinson: I ask Mr. Buck if the developments he speaks of are in multiphase machines or single-phase machines?

H. W. Buck: In both.

W. N. Smith: I will ask a question which perhaps Mr. Maier or some of the manufacturers represented here can answer. Take the case of a large outfit of motors to drive machine tools in shops such as you have in a locomotive repair shop, or in one of the larger industrial plants. Which of the systems mentioned in the paper this evening have actually been tried on a commercial scale at the present time, and found satisfactory? Possibly some information, showing what has been actually accomplished in practice, would be worth hearing.

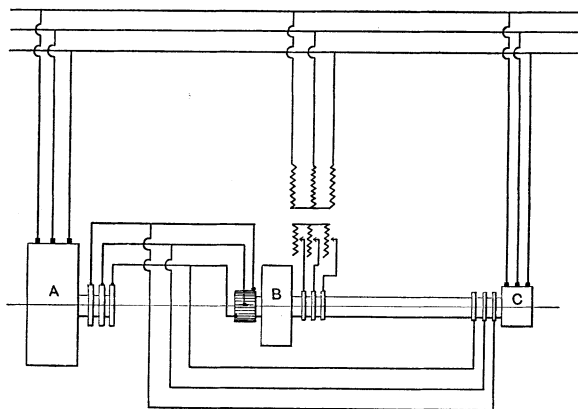
G. A. Maier: At the present time in this country there is only one type of adjustable speed motor which is used, that is the multi-speed motor, which is used to a limited extent. In Europe they have used the adjustable speed single- and three-phase commutated motors but I do not think there has been much use made of those motors in this country up to the present time. The slip ring motor is used in some cases where the torque is constant and continuous, such as wheel laths or boring mills doing certain classes of work where the load is always on; the load must be constant and continuous. For general machine tool work, the alternating-current motor has not been used to any considerable extent in this country.

C. J. Fechheimer: An account of a system other than described by the author of this paper for obtaining adjustable speeds appeared in the *Electrotechnische Zeitschrift* of October 19, 1911. This is the system which has been brought out by A. Heyland and R. Ruedenberg. It is somewhat comparable to the Scher-

buis and Kraemer systems and the accompanying sketch shows the scheme of connections.

The large polyphase induction motor *A* is to have its speed adjusted to suit the requirements. The stator of this motor is connected to the line and its slip rings are connected to the commutator of a machine having an armature similar to that of a synchronous converter. The slip rings of this converter, or more properly, frequency changer, are connected to the secondary of the transformer, the primary of which is connected to the line.

On the same shaft with this machine is a small induction motor *C* with primaries connected to the line and secondary connected in parallel with the slip rings of the large induction motor. The speed is adjusted by changing the number of turns in the secondary of the transformer, which changes the voltage between slip rings of the frequency changer *B*, which in turn alters the pres-



sure between the brushes on the commutator end of this machine. As is well known, a change in voltage between the slip rings of an induction motor will change its speed. The speed of the frequency changer is set by means of the small induction motor *C*.

It is very interesting to note that the frequency changer *B* has no windings on its stator except those which are used to neutralize the unbalanced higher harmonics of armature reaction and thus assist commutation.

Now when we consider whether it is advisable to use a polyphase commutator motor to secure adjustable or variable speed, we must remember that in America it is essential to design apparatus which is practically fool-proof. In other words, after the machine is installed, it is necessary for it to do the work intended for it and not require much attention.

Judging from the great length of time that has been required to successfully design direct current machines and secure satis-

factory commutation, we may expect an equal or greater length of time to be able to predict satisfactorily the commutation in alternating-current commutator motors. It is in fact doubtful whether polyphase commutator motors can be designed in large sizes without sparking, so that the question arises: will any variable speed systems which involve the use of alternating-current commutator motors for large outputs be acceptable on the American market?

It has occurred to me that we might use a system which, while costly, would be absolutely certain of results. This system is outlined in Mr. Maier's paper and we suggest a modification of it—one which I have thought of employing a number of times. When there is a direct-current source of supply it consists of an inverted synchronous converter or motor-generator set. The speed is varied by changing the field strength of the converter or direct-current motor. The speed of the induction or synchronous motor changes with the speed of the converter or motor-generator. Or, if the source of supply be alternating, two synchronous converters may be used, one to change from alternating to direct and the other from direct to alternating. By using a split pole converter for the first machine and changing the field excitation of the second, or by having reactance coils in series with the first machine and varying the field strengths of both converters, the frequency may be altered as desired with corresponding changes in the speed of the main induction or synchronous motor.

These systems would be especially applicable to cases to which direct current cannot be directly applied, such as for large capacities and high speeds for which direct current motors cannot be built. We could then use synchronous or induction motors, and have their speeds varied as indicated above.

B. G. Lamme: The question was asked in this discussion, to what extent adjustable speed or variable speed alternating-current motors have been used in machine tool drive. Mr. Maier has replied to this question by stating that multi-speed motors without commutators have been used to a limited extent.

I can cite one case where commutator type alternating-current motors have been used for adjustable speed, not in machine tool work, but in print work where print rolls had to be driven at various speeds between zero and full speed. The motors used in this case were somewhat different from any described in the paper of the evening, although based upon the same principles.

In a single phase commutator type motor it is obvious that if the field winding be connected in shunt with the armature, the operation of the motor will be very poor, because the shunt field current, and therefore the field flux, will lag practically 90 deg. behind the armature current, whereas, for good operation the armature current and the field magnetism should be practically in phase. This condition can be obtained by connecting

the field winding to a supply circuit which has practically a 90 deg. phase relation to the circuit which supplies the armature. This is illustrated in Fig. 1. With this arrangement the field current, or field flux, is still 90 deg. behind the exciting e.m.f., but as this latter is practically 90 deg. out of phase with the armature e.m.f., the field or exciting flux will thus be practically in phase with the armature current and the machine becomes the equivalent of an ordinary shunt machine. Such a motor can be connected either across a two-phase circuit or can be connected to a three-phase circuit by certain arrangements of the windings which give the equivalent of a two-phase condition.

With this arrangement the speed can be controlled just as with a shunt-wound direct current machine, either by field control or by control of the armature voltage. In the direct-current shunt machine, field control is obtained by insertion of resistance in the field circuit. In this alternating-current motor, field control is obtained by insertion of reactance in the field circuit, instead of resistance. As the field current already lags practical'y 90 deg. behind its supply e.m.f., the addition of reactance in series does not modify the phase relations materially. Added reactance thus causes weaker fields and increase in speed.

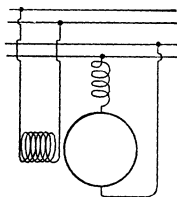


FIG. 1

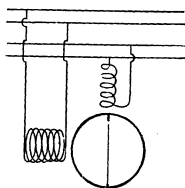


FIG. 2

The speed of such a motor can also be varied by means of resistance in the armature, the same as a direct-current machine, to give variable speed; or can be regulated by means of adjustable voltage supplied to the armature terminals from a transformer with taps. This will give practically constant speed characteristics for any given adjustment. The arrangement thus becomes the equivalent of a direct-current shunt motor with an adjustable supply voltage.

An equivalent arrangement to this was also built and tested, in which the armature was not connected directly across the line but was closed on itself and was supplied with current from a transformer winding on the primary or field core. This arrangement is shown in Fig. 2.

Several motors of the first described type were put into commercial operation. One of these motors was of 20 h.p. normal capacity and another of 30 h.p., both for 25 cycles. Both were controlled by adjustable armature voltage from transformers. The speed was adjustable from practically zero to 1000 rev. per min. The 20-h.p. motor was in operation for about 18 months and

was apparently a very satisfactory machine. The 30-h.p. motor was operated for a much shorter period and was not nearly as satisfactory. Later both motors were taken out of service, partly because the system of operation of the plant was modified. The equipments were expensive, due partly to the cost of the regulating transformer, but they could be operated successfully in the hands of careful men. However, the apparatus was rather delicate in its characteristics compared with direct-current machines with equivalent characteristics.

In going over this paper hurriedly, I find several points which are open to discussion. On the last two pages of the paper where reference is made to the Kraemer and Scherbius systems, certain features of these systems are not brought out fully. Both of these are forms of the so-called cascade connection in which the secondary of an induction motor feeds current to another motor. Here the secondary motor is of the commutator type. The feature of this arrangement which makes the commutator motors operative in general, lies in the low frequency delivered by the secondary of the induction motor to the commutator motor. At synchronism of the induction motor, the frequency of the secondary is zero. If the speed is within 10 per cent of synchronism, for instance, the secondary frequency will be 10 per cent of the primary frequency; that is, with 60 cycles in the primary the secondary frequency would be six cycles. At a speed of 30 per cent from synchronism, the secondary frequency will be 30 per cent, or 18 cycles, with a 60-cycle supply circuit. These low frequencies are particularly advantageous in the design of commutator type alternating current motors whether of the single-phase or three-phase type. However, the further the speed departs from synchronism the more difficult becomes the design and operating conditions. In consequence, such systems are usually built to operate within a certain limited per cent of synchronous speed, this per cent depending upon the frequency of the supply circuit. These conditions apply to the arrangement shown in Figs. 34 and 36. However, in the scheme shown in Fig. 35, the current from the secondary of the induction motor is fed to the collector rings of a synchronous converter and direct current from this synchronous converter is fed to a direct current motor, which thus absorbs the extra power of the secondary to the main motor.

A little consideration will show that the synchronous converter should be of the same capacity as the motor to be regulated, if operated at the primary frequency. It is therefore necessarily a large and expensive machine, relatively speaking. The lower frequency and the lower speed at which it is normally operated will be of indirect advantage in somewhat reducing the cost and size of this synchronous converter.

Furthermore, the direct-current motor operated from this synchronous converter cannot be of very economical proportions for it must be designed for operation over quite a wide range

of voltage due to the fact that the synchronous converter will give different voltages with different speeds, and the direct-current motor must be adapted for operation at these voltages.

Therefore, considering this scheme as a whole, it appears to me that equivalent results would be obtained if the synchronous converter were connected directly to the supply circuit, so that its direct-current side supplies current to a direct-current motor which drives the load. The synchronous converter could be of the synchronous booster type for varying the direct-current voltage delivered by it. The size and capacity of the synchronous booster would be dependent upon the range of voltage, and speed variation desired, like the direct-current motor in Fig. 35. Therefore, in this arrangement the synchronous converter would correspond in capacity to the synchronous converter shown in Fig. 35, while the direct-current driving motor would correspond in capacity to the induction motor, and the synchronous booster would correspond in capacity to the direct-current motor in the same figure. The scheme, as a whole, appears to me to be simpler than that shown and no more expensive. With either of these schemes the permissible range of speed could be fairly wide.

C. P. Steinmetz: While the alternating-current motor has the reputation of being a constant speed motor, you see from the paper that in recent years a very large amount of work has been done in developing not only one but quite a number of types of variable speed alternating current motors, although the work is so recent that these motors have thus far come into industrial practice only to a limited extent, and there is no doubt that many further developments are still possible and desirable. There is one feature which impresses itself very forcibly, and that is, that in most of these variable speed alternating-current motors, the variable speed is connected with the use of the commutator. A commutator is not necessarily objectionable. We know that the direct current motor has a commutator and can be extremely successful. But, on the other hand, as the great advantage of the alternating-current motor has always been claimed its great simplicity, due to the absence of commutator or similar device. When we wish to get variable speed, in most cases we have to accept the commutator—the same complication which is inherent in the direct current motor whether variable speed or constant speed.

In order to see how far we have advanced, and what further work may still be done, it is desirable to make a classification of the problem. The Standardization Rules divide the motors in two types: constant speed and variable speed motors. Of the variable speed motors, three classes again are distinguished: multispeed motors, which have several steps of constant speed, hence, which can by adjustment be operated as constant speed motors not only at one but at two or more speeds; second, varying speed motors, in which the speed varies with the load

as a rule decreasing with increase of load. Typical thereof is the direct-current series motor; third, adjustable speed motors, in which the speed can be adjusted to any desired value within a certain range, but when once adjusted the motor remains at this speed irrespective of the load, or approximately so. Typical of this class is the direct-current shunt motor with field control, where, by varying the field rheostat, you can set the speed at any desired value, and at that value it remains approximately from no load to over load.

Alternating-current motors of these three types can be produced as follows: Multi-speed motors are in industrial use to a considerable extent as induction motors without commutators—either by changing the number of poles, by some switchover device, or by concatenation of two motors, or by combining the two concatenated motors in one structure as an internally concatenated motor, or by a combination of several of these methods whereby we can then gain a considerable number of speed steps.

The varying speed motor also exists as a motor without commutator. It is the induction motor with slip rings and external rheostat. In this motor with increasing load the speed decreases. It has a characteristic in its speed torque relation similar to the direct current series motor, except that the speed is limited to a definite maximum speed, the speed of synchronism. But the limiting feature of this motor is that when the speed falls off, the efficiency also falls off. That is, at fractional speed you get correspondingly fractional efficiencies. The varying speed alternating current motor which is free from this dropping off of efficiency with dropping off of speed, is the commutator motor of the series type, or of the repulsion type, or of the combination type, the series-repulsion type, but, as stated, this is not as simple because it has a commutator.

The third type of variable speed motor is the adjustable speed motor, a motor which can be run at any constant value of speed, within a certain range. This motor does not yet exist in the commutatorless type, but it does exist in an almost infinite variety of commutator types of motor. Many of these are mentioned in the paper, but there exists no adjustable speed alternating current motor yet, which does not have a commutator, and this field is still open for development. It is this class of motor, which after all, would be the most useful, because very often in the industry we desire to be able to vary the motor speed over a moderate range as in cotton mills, to adjust it to the materials and the atmospheric conditions, so as to operate the mill at maximum efficiency. This means the ability of varying the speed, say, ten or twenty per cent, up or down, and still at any speed to have constancy independent of the load. In the absence of this motor there have been developed adjustable speed commutator motors which are in industrial use, are eminently satisfactory, but have not yet the simplicity of the plain induction motor.

In concluding, I may say, so far as my experience goes with the variable speed alternating-current motors, there are in use to a large extent: the induction motor with external rheostat as varying speed motor in hoisting work, in three-phase railroading, etc.; then there is in extensive use the multi-speed motor of the changed-pole type, and also to some extent, of the concatenated type; then there is in use the varying speed motor of the commutator type, as series and repulsion motor, and finally there is in use the adjustable speed motor of the so-called induction-repulsion type, especially in small units for general service.

C. O. Mailloux: It is remarkable what a transformation of feeling electrical engineers have undergone, in the last few years, in regard to the commutator. For a time, the commutator was charged with all the crimes in the electrical calendar; it was considered a great objection in connection with electrical machinery, in general. It was the fashion, among the partisans of the poly-phase induction motor, to allege, as one of its most meritorious features, the entire *absence* of a commutator. It was very pleasing to me, at the last electrical Congress, at Turin, in the discussion on electric railways, before Section 5, where I had the honor to preside, to find evidence of a return to a spirit of greater toleration with respect to the commutator. The partisans of alternating-current systems of traction, at that Congress, were not as rabid as formerly, on the subject of "commutators". The reason is that, in Europe, just now, the single-phase system of electric traction is in vogue; and that system, as we know, involves the use of a commutator-motor. That, of course, makes some difference. It is sufficient to change the opinion of many men who, some years ago, thought that a commutator-motor was not fit for traction purposes at all. Thus the "evil" of former days is fast becoming a "virtue." The old French proverb says: "*Chassez le naturel, et il revient au galop.*" (The nearest English equivalent is: "what is bred in the bone cannot be beaten out of the flesh"). Perhaps the commutator is much more "natural" than some people have been willing to admit. In dealing with the problems of speed-regulation, with alternating-current motors of any phase and type, we are obliged to come to the commutator, in order to increase the range of speeds obtainable, and to realize the fullest possibilities. It is the most "natural" thing to do, and it should have been done long ago. It is now being done because it cannot be put off any longer, presumably. Whatever may be the reason, the result will be to make the induction motor much more "fit" than it was or would ever be otherwise, for many applications, old as well as new, in competition with the direct-current motor.

Those of us who obtained their first practical experience with commutator machines, in the days when there were no others, were reconciled to commutator-motors. We were not afraid of them; and we knew that they could be made to do good work under any and all circumstances. For many purposes the com-

mutator-motor did much better work than the commutatorless motor, even before the advent of the commutating pole, or the so-called "inter-pole" motor. Today, with the auxiliary or commutating pole, we are getting commutation which is absolutely satisfactory, if not absolutely faultless, in the case of direct-current motors of good design. The problem will not be quite as simple, however, with alternating-current motors. There are many difficulties here, due to electromagnetic phenomena and reactions which are not "in phase" with each other, and it is necessary to resort to compensating devices of various kinds to secure a line of commutation that is "stable"—which may not shift back and forth, describing an angle, during each period—and which "stays put" at least a portion of the time, same as in the direct-current motor. It is gratifying to find that considerable progress has been made in the adaptation of the commutator to polyphase motors, in the last few years. In that respect, the Europeans appear to be in the lead. During my recent trip abroad, I had occasion to learn something of the latest improvements made there in multi-speed, adjustable speed, and variable speed motors; and I was surprised at some of the results which are being obtained with alternating-current commutator motors. M. Latour, who is mentioned in the paper as the inventor of a method of speed-regulation involving the use of a commutator motor, has recently brought out some new methods of regulation which are of the greatest interest and merit. He kindly explained some of his methods to me and also gave me some results of practical tests and operation. I was astonished at the wonderful range of speed obtained, with motors of all sizes, with very satisfactory commutation, and with good power factor and efficiency. His results have not been excelled, and I doubt if they have been equalled, in this country. They are hard to match, even in Europe, and his methods have been adopted and are being used by several manufacturers, and they are being imitated by others there. M. Latour is one of the few alternating-current specialists who never had *commutatorphobia*. It was he who first made a success of the single-phase commutator motor of the compensating type. (Even the German Patent Office had, ultimately, to give him the priority over all others). His recent work with polyphase commutator motors, evincing great originality, and producing valuable industrial results shows what can be done to make the commutator appear, even here, as a blessing in disguise. It is high time that the rest of the alternating-current designers and specialists should realize that the commutator not only need not, but that it should not, be banished from their "repertoire." With proper appreciation and treatment, its role may become as important and as useful here as in the case of the direct-current motors.

Gus A. Maier: It seems that in the discussion of the paper, the commutator of the motor is what practically everyone objects to. It is not considered desirable to go back to direct-current

practice and use the commutator. We are agreed on that point, but there seems to be no way of getting away from it at the present time. The Europeans have done a large amount of work on the commutator motor and use it in many places. As far as I can learn, the commutation is fairly good, although I understand that the European standards of commutation are not as high as the American practise.

There is one point which has not been brought out which the advocates of the alternating-current motor can still hold on to, and that is, the voltage on the commutator is very low, compared to the line potential. It will probably run in the neighborhood of from 50 to 100 volts, and then with some sparking on the commutator, even if the commutator becomes black, it does not seem to affect the commutation or operation of the motor in any way. The Europeans are running these motors in various places, cotton mills, hoisting outfits, lathes, and using Scherbius sets in rolling mills, and Scherbius and Kraemer systems are giving very good results. I think it is up to the American engineers to follow closely the European developments and make improvements wherever possible, and I have no doubt the future will show some rapid progress in that direction.
