machines vary up to 35 300 kVA in one unit, and operate at pressures up to 13 200 volts.

It is clear that makers who have to compete for orders for machinery of this class are placed at a disadvantage if they are unable to offer standard machines with the higher temperature limits.

It has already been pointed out that, in designing machines to meet specifications calling for low temperature guarantees to be obtained by thermometer measurements on external surfaces, manufacturers had to consider their safety in view of the high temperatures known to exist in the interior. Reliance had therefore to be placed on the makers in this respect, and it may be taken for granted that no manufacturer would advocate a departure from existing practice except with the knowledge that no risks would be incurred.

It is encouraging to note that some engineers in this country are disposed to accept higher temperature limits than existing standards, but it is of great importance from the point of view of standardization that it should be generally recognized and accepted that higher temperatures may be adopted without reducing the margin of safety.

The author wishes to express his thanks to the Metropolitan-Vickers Electrical Company, Limited, for affording facilities for carrying out the tests, and to Mr. Churcher of the Research Department for the interest and care taken in making the tests.

Discussion before The Institution, 27 January, 1921.

Mr. C. H. Merz: It is in large machines particularly that the adoption of any increase in the allowable temperature would show a benefit, and it should result in reducing the cost, a point of very great importance at the present time. It will not only cheapen the cost of the machine; it will also allow us to obtain, under all conditions, the maximum output. In other words, we should be better able to know how we stood if we were to work more definitely and continuously by the maximum recorded temperature on the switchboard. I think that, after reading this paper, with its very clear evidence of the advantages of working on definite total temperatures, as distinct from somewhat artificial temperature-rises, few of us will hesitate, wherever possible, to have such temperature detectors installed in alternators, and to test them in practice in the way the author suggests. I am sure that it will result in a very great step forward in the manufacture of large turbo-alternators. There are one or two questions upon which I should like the author to give more information. I presume that if we run the machines at a higher copper temperature the question arises whether there are any other parts of the machine that will suffer. The author refers to the question of distortion of the mechanical parts. Is there any question of the iron in the magnetic circuit suffering deterioration, and, if so, what is the limit in this case? Then there is the question of the insulation used between the laminations. Have we to consider the specification from that point of view or is it, in the author's opinion, entirely beyond the region of danger? I think that, apart altogether from this special way of dealing with the question of temperature, the electrical industry should permit higher temperatures. I do not know that those of us who have been concerned with high-speed turbo-alternators of recent years would in general, without going into statistics, be inclined to support the idea that there has been any great reduction in the number of failures, but I think we should agree that there has been a great reduction in the number of failures which could be clearly attributed to excessive temperature. If there has not been a reduction in the number of failures with turbo-alternators, say, during the last five years as compared with the previous five or ten years, I think it will probably be found to be due to the much harder conditions which the machines are called upon to fulfil in general, such as running at very much higher speeds for given output, and so on, in which case no doubt everything is stressed to a much greater amount. As systems have grown in size, the short-circuit and shock conditions which the windings of large turbo-alternators have had to meet have been very greatly increased. I think that there is a fairly simple way of dealing with this question of temperature in buying machinery at the present time. We are most of us accustomed, in inviting tenders for turbo-alternators, to allow the manufacturer to fill in the steam consumption he is prepared to guarantee, and I do not see why, for a machine of given size, he should not in the same way be allowed to state the temperature at which he proposes to run the machine. If any of us accept or allow too high temperatures, at any rate we shall have the satisfaction of knowing that we are helping to advance the knowledge of the subject.

Mr. R. Orsettich: The paper raises a serious question for designers and manufacturers of large units. I agree with the author in every respect when he states that the copper temperature is very different from the temperature one measures by ordinary means of surface temperature measurements, and that the correct way to arrive at the approximate temperature is by installing temperature detectors, but I disagree with him emphatically when he implies that, as we are exceeding the temperature which we thought we should get, we should go further and use much higher temperatures. I think that the tests which the author has made, and of which he gives interesting curves, have no real connection with the conditions under which the coils work inside the machine. They are not representative, because they refer only to one question, namely, to bending stresses. The coils in the machine, however, have to stand all manner of conditions, and the tests only cover one of them. Take the question of expansion. If one calculates the linear expansion of a coil in a machine, one will find that with a temperature difference of about 100 degrees C. there will be an expansion of about 3 mm. in a length of core of 2 metres, which is a very large figure. The insulation will probably expand to only one-third of that amount. The core will also expand, but again at a different rate, and a certain amount of rubbing and perishing will be going on all the time. In addition, the copper core of the coil will tend to press against the insulation at the two ends which, being bent, are opposing its expansion. I do not think it would be possible to take account of these facts in any tests. Then there is the question of moisture. Machines generally work with air which is usually cleaned, or sometimes even cooled, by means of a water spray. The dampness of the air plays a very great part in the life of the insulation, and the condensation of ordinary air is also very important, and so are also the continual alternations of heat due to variations of load. If air which is hotter than the machine is admitted, say after the machine has been standing over the week-end, the machine will be entirely coated by moisture on the inside, and most stations to-day use all manner of dampers at the air inlet and outlet to avoid this, some even going so far as to provide a number of heating elements inside the air duct to maintain a reasonably even temperature under all conditions, whether the machine is working or not. This is a very important point. Some experiments were made at our laboratory, and it was found that the insulation of the coil after being kept for six months at a temperature of 150° C. had become more hygroscopic and could absorb as much as 10 per cent of its own weight of moisture. Again, in a machine taken out of service after a year or two, the coils are always covered with dirt and grit in spite of the use of the best cleaners. If the grit contains any metallic substance the life of the insulation will be considerably shortened as compared with that of a machine tested under pure-air conditions. The presence of dirt also causes a reduction of the radiation of the heat and, as a result, after three or four years the temperature is very much higher than before. That must be taken into account, as machines which might have a temperature of only 100° C. in the copper when new would have a very much higher temperature later on. If we start with 160° C. we shall probably have a temperature of 200° C., or even higher, after a few years. Vibration is also always present and plays an important part in reducing the life of the insulation. Our knowledge of what happens under these conditions is very restricted, and I think it would be very rash to adopt a policy concerning which there is not sufficient experience available.

Mr. F. H. Clough : In the past I think we have had machines working at much higher internal temperatures than we were aware of, particularly in the stator windings. These high internal temperatures were in a great measure due to eddy currents in the large conductors of turbo-generators, but in modern machines this difficulty has been largely overcome. I agree with the author that it is desirable to work to temperatures as high as possible, as in many cases the alternative to high temperatures in turbo-alternators is high mechanical stresses and, if the insulating materials employed are capable of standing high temperatures, it is obviously wise to take advantage of this, and so reduce the mechanical stresses. The most congested part of the design of the modern turbo-alternator is the rotor and, as the voltages in the rotor winding are quite low, I am inclined to agree with the author that we should adopt the temperatures he advocates, but I think that it is not advisable to go to quite such high temperatures in the stator. Stator windings are subjected to high voltages, and it is a little doubtful whether mica insulation which has been subjected to high temperatures is capable of withstanding high voltages as readily as it does when the binding material has not been affected by high temperatures. The currents in the rotor and stator are approximately proportional to one another and, therefore, if the machine is operated at the maximum current and temperature in the rotor winding consistent with safety, the stator winding under such conditions should be designed with a rather lower temperature. This should be quite feasible, as the mechanical stresses in stator windings are not very difficult to provide against, and it is very largely a question of proper elimination of eddy currents. The majority of manufacturers are inserting temperature detecting devices in their machines, and I hope that shortly, with the assistance of the operating engineers in the country, the information gained from the use of these detectors will enable us to estimate with considerable certainty what temperatures are safe in the interior of large machines.

Mr. J. Shepherd : I think the reason we are so accustomed to buying machines rated on temperature-rises by thermometer is that it has been practically impossible, until recently, to be sure what the internal and maximum temperatures are. Of course, the thermo-couple in small sizes and applied between windings is of comparatively recent introduction, and one cannot always be sure it reads correctly. Also, it is not always certain that it is placed at the hottest spot or, if it is near the hottest spot, that it is giving the highest temperature of the copper. It has been used in America to some extent, and Mr. Newbury is one of the most experienced users, but in a recent paper * he expresses considerable doubts as to the true and accurate readings of thermo-couples placed either at the bottom of the stator slot or at the top between the winding and the wedge. The question of ultimate temperatures must be considered, because higher temperatures may mean a considerable saving in plant. But I do not think that we can afford to sacrifice the running safety of the machine by suddenly accepting very high temperatures; and, further, a temperature of 160° C. may become 170° C. or 200° C. when the air ducts are choked. I do not think the author's experiments represent what is really happening to the insulation of the machine. There are far more factors involved than the bending of the insulation and treating it as a bar. There is the risk of the joints breaking down, and this of course is greater with increase of temperature. The vibration difficulty is not mentioned at all, and the temperature increment of the copper over that of the insulation and iron has not been considered at all in the experiments. If, however, we can restrict the insulation to its legitimate uses, viz. to insulate and to conduct the heat away, and then bind the insulation tightly against the metal in a similar way to the insulation between the sectors of a commutator, we can undoubtedly

* F. D. Newbury: "Some Practical Experience with Embedded Temperature Detectors," *Journal of the American Institute of Electrical Engineers*, 1920 vol. 39, p. 549.

run at higher temperatures than at present, because then we should have restricted the function of the insulation and relieved it of mechanical and vibration stresses. I see no reason why, if we can only hold the laminated bars together in a better way than by means of the insulation, a temperature of 150° C. could not be contemplated with safety when the insulated bars are supported in continuous winding slots, and soldered joints are replaced by welded or riveted ones.

Dr. S. P. Smith: The author points out that the standards which have been recommended in Report No. 72 of the B.E.S.A. are not those commonly used. That is unfortunate and is a state of affairs that should not be allowed to continue. It would be very desirable, in the interests of both manufacturers and users, if some agreement were reached, and rules to which all must work were developed and kept up to date. With regard to the question of detectors I am inclined to agree with the author's suggestions, because we have no better means at present of obtaining the temperatures inside the slots. Our troubles at present in connection with the design of turbo-alternators arise largely from ignorance. The measuring of surface temperatures is of very little use in informing us what is going on inside the slots. It is true that the temperature detector outside the insulation does not give us, strictly speaking, the temperature of the copper, but it certainly gives more useful results than the mercury thermometer gives. There are, I know, objections to its use from the manufacturer's point of view; it has to be applied with great care; also, unless several are used, they may not be of much value. It is necessary to choose, as judiciously as possible, a certain number of points at which to place thermo-couples; and, in addition, in a station there must be a registering instrument with a multiple-contact switch, which should be read at regular intervals and the results recorded. Though such a method has defects, it tells us something definite about the distribution of the temperature along the core. The author mentions the well-known axial and radial ventilation methods, and nowadays these have to be combined in large units. By means of temperature detectors, we could get more information as to the superiority of one method over the other. In addition, we should be able to check our calculations and the work in the shops. From Field's curves we can calculate fairly well what the increased copper losses will be for any proposed arrangement, but to predict the copper losses accurately we must know the temperature at which the copper will have to work. Further, until we know the temperature inside the core we cannot say whether the insulation between the plates is being subjected to too high a temperature or not. Thus, it is not safe to increase the present limits until we know what the existing temperatures are. There are, of course, many views as to what should be the final temperature. Mr. Orsettich mentioned the expansion of copper when heated, and it seems to me that that alone is a sufficient argument in favour of using temperature detectors. There is another point which is very important to all designers. The limiting factor in many designs, especially with large machines, is the amount of air that can be forced through the machine. The skill of the designer is exercised in getting this limited quantity of air through the machine in the most efficient manner, and in reducing the losses as much as possible in order to get the largest possible output from a given weight of material. In this connection also, the temperature detector would be of considerable assistance. Therefore I think we ought to make a practice, as far as possible, of introducing these detectors and recording the results for the information of all concerned. The method of finding the mean temperature-rise by means of resistance increase is well known, but the form given in the B.E.S.A. Report No. 72 entails the use of a table, and is not as simple as it should be for those who have often occasion to find the average temperature of rotor windings. For their assistance I should like to submit this formula:—

$$t_2 = \frac{R_2}{R_1}(234 \cdot 5 + t_1) - 234 \cdot 5 \text{ °C.}$$

or, on the Fahrenheit scale,

$$t_2 = \frac{R_2}{R_1}(390 + t_1) - 390 \text{ °F.}$$

The resistance R_1 is measured at temperature t_1; R_2 is the resistance when hot; and t_2 is the mean final temperature of the winding. The average temperature-rise is, of course, t_2 minus the temperature of the cooling air. For any particular machine installed in a station a graph of the above equation should obviously be plotted, so that the temperature of the rotor winding can be recorded from day to day.

Mr. A. R. Everest: The question of thinking in terms of higher temperature values can be considered under three heads. First, we have the higher temperature values due to the adoption of new methods of measurement. The International Electrotechnical Commission pointed out years ago that the expectation of life of a machine depended upon the highest temperatures to which its insulating materials are subjected, and that it would be desirable to measure the maximum temperature occurring within the machine. Since that time, temperature-detecting devices which may be embedded within the machine have been developed in a practical way, and the only remaining point in this connection is the establishment of the due value of increased temperature which should be recognized for this method as compared with the more familiar temperature limits applying to the same machines when measured by the older methods. The determination of these proper limits is now under active consideration by the British Committee. The application of this method is particularly desirable for the stators of turbo-alternators, since otherwise only surface measurements are available, temperature measurements by resistance of the windings immediately the load is taken off being impracticable for the stator of a turbo-alternator on account of the disturbance created by the residual magnetism of the field while the machine continues to run. It is evident, therefore, that these new methods of measurement constitute one necessity for thinking in terms of higher temperatures. As a second consideration we have the modern employment of materials actually intended to operate at higher temperatures, i.e. the extended employment of mica insulations. The use of embedded temperature detectors is not practicable in the rotor windings of a turbo-alternator; the temperature of these parts should be determined by the increase of resistance, employing for these measurements suitable special brush-gear on the slip-rings. We have, therefore, also to become familiar with the higher temperatures associated with the use of these modern insulations. The third consideration is the proposal made at various times that, when employing material such as mica, the actual temperature limits occurring in good modern machines might be safely increased. It is my impression that the author's argument for the recognition of higher temperatures applies principally to the first and second considerations mentioned above, rather than to proposals for actually increasing the operating temperatures beyond the limits found to-day in a good machine. Regarding the reference to the tests upon the mica-insulated machine at Niagara, I think we must be careful not to draw erroneous conclusions. The operating voltage of this generator (2 200 volts) is only one-third to one-fourth of that which would be considered proper to-day for the thickness of mica-paper insulation which was actually provided, and the fact that the machine continued to operate at this abnormally low voltage after the insulation had been subjected to the damaging effects of the high temperatures which the investigation disclosed is no proof that the modern machine with thickness of insulation duly proportioned for its working voltage could safely operate at the same temperatures. Incidentally, it is of interest to know that when these tests were made at Niagara there were in an adjacent power house 11 generators of another make which contained no mica insulation, but were designed to operate at low temperatures. These generators had been in service for 12 or 13 years without a single failure, beyond one due to an operator's mistake. In connection with this question of high temperature limits on turbo-alternators it is of interest to note the opinion recently expressed by Mr. P. Torchio, chief engineer to the New York Edison system. A few years ago Mr. Torchio was supporting the arguments in favour of increasing the limit of temperature permitted on mica insulation, but in a paper * before the American Institute last summer dealing with the failures of large turbo-generators he said : " Too great range of operating temperatures is bound to cause generator failures. Mica insulation in hydro-electric generators operated at steady load will last indefinitely at high temperatures, while under similar conditions mica insulation in steam turbo-generators operated intermittently will fail."

(*Communicated*) : When a machine is equipped with suitable embedded temperature detectors it is easy to arrange that the internal temperature of the machine shall be continuously indicated by an instrument on the switchboard. This practice is very common in the United States. It is sometimes suggested that the chief advantage of such an arrangement is that it permits operation at outputs limited only by the maximum temperature, thus utilizing increased output capacity at times when the temperature of the cooling air is very low. This argument is somewhat difficult to follow. The output of a turbo-generator set is physically limited by the capacity of the steam turbine. If this is large enough to supply the full output from the generator in very cold weather without exceeding assigned temperature limits, it appears that during the chief part of the year, when the cooling air is initially warmer, the set will be obliged to work at less than the available capacity of the steam turbine. If the set is designed to utilize the full capacity of the steam turbine with a moderate temperature-rise on the generator, the limitations of the turbine will prevent advantage being taken of increased generator output, which might appear possible in cold weather. But the switchboard temperature-indicating device performs another very useful function. If the ventilating air is not properly filtered and commences to clog the air-ducts, the temperature indicator at once gives warning of an increased temperature.

Mr. A. B. Field : The qualities upon which we place most importance are, I think, reliability and efficiency, and of these reliability is generally the more important. I think it has not always been recognized in this country that in limiting the manufacturer too closely in the matter of temperature the purchaser is actually getting a machine less reliable, and very frequently less efficient, than that with which the manufacturer would otherwise supply him. I refer at the moment particularly to rotor temperatures. At the present time, in this country, the great bulk of the demand for turbo-generators can be met by machines running at a speed of 3 000 r.p.m., as 50-period units are offered at this speed up to about 14 000 kW normal rating, or 20 000 kVA maximum rating. Now for this speed a solid forging is rightly used for the rotor, and simplicity and soundness of mechanical design are of the first importance. Methods of construction now available, using all mica insulation, allow us to use a simple rotor without ventilation provided a reasonable temperature-rise by resistance be accepted; whereas insistence upon a temperature which would have been suitable for the older methods of insulating merely encourages the designer to indulge in undesirable rotor-ventilating schemes and forces him to distort the magnetic and electric proportions of the design. We should, on the contrary, try to obtain the greatest possible mechanical soundness and operating reliability in these machines, together with high efficiency, rather than certain results on paper. The general idea of specifying temperature limits by thermometer measurements was carried over, some 12 or 15 years ago, from the smaller machines and machines of other types to the case of large turbo-generators, but, although American manufacturers continued to supply turbo-generators on this selling basis, they quickly discovered the neighbourhood of the actual internal operating temperatures corresponding to thermometer temperature-rises of 40 and 50 degrees C., and they gradually evolved insulating methods to suit both the rotor and the stator. Such methods are now in use in this country and, as they are not hedged in by patents, purchasers should insist upon their use. It is useless to ignore this

* *Journal of the American Institute of Electrical Engineers*, 1920, vol. 39, p. 548.

position, and merely to think that we have recently found improved means of internal temperature measurement for which but a small extra allowance, as compared with the figures given by thermometer, need be made.

Mr. H. W. Taylor: The question of the internal temperatures of turbo-alternators came prominently to the attention of designers a few years ago. It arose in the natural course of development as larger ratings were built. There is no doubt that some machines built at that time attained on load internal temperatures corresponding to the highest figures quoted by the author, but nevertheless they are still giving satisfactory service. The question arises as to whether such high temperatures can continue to be tolerated by manufacturers in their designs for the still larger machines which are now being built and proposed. The vital parts of an electrical machine consist of a heterogeneous assemblage of unmechanical details, such as thin steel laminations, copper bars of comparatively small cross-section, and insulation consisting of an assemblage of mica flakes. The problem of moulding these components into a satisfactory complete turbo-alternator design presents considerable mechanical difficulties, and it is probable that excessive temperature variations between different parts of the structure tend to increase these difficulties. While agreeing that the present standardized temperature limits are unnecessarily low, I do not think it will be necessary, with the refinements in the details of the design which are continually being made, to recognize the highest temperatures which the author has proposed. In any event it can be definitely stated that large machines are being built to-day which are cooler than the smaller machines of a few years ago.

(*Communicated*): I think the author should have devoted a short portion of the paper to explaining with what difficulties designers have to contend in building machines of the present ratings to comply with narrow temperature limits. Fig. A shows the relative proportions, without any attempt at the inclusion of full mechancial details, of the largest machine which was being produced by one large firm in or about 1907 and of the largest machine which is being manufactured at the present time. The ratings are in the ratio of 1 : 15. The diameter of the rotating part has been increased nearly 40 per cent and has attained a limit from the point of view of mechanical stresses. The length of the machine has increased practically three times, and the difficulty of carrying the cooling medium on the outside of the machine to the innermost portions and again to the outside of the machine will be appreciated. The increased rating has, however, not only been obtained by increases in the mechanical dimensions, but also by the use of heavier copper loading in both stator and rotor, the relative dimensions of which are again shown in Fig. A. If the heat to be carried

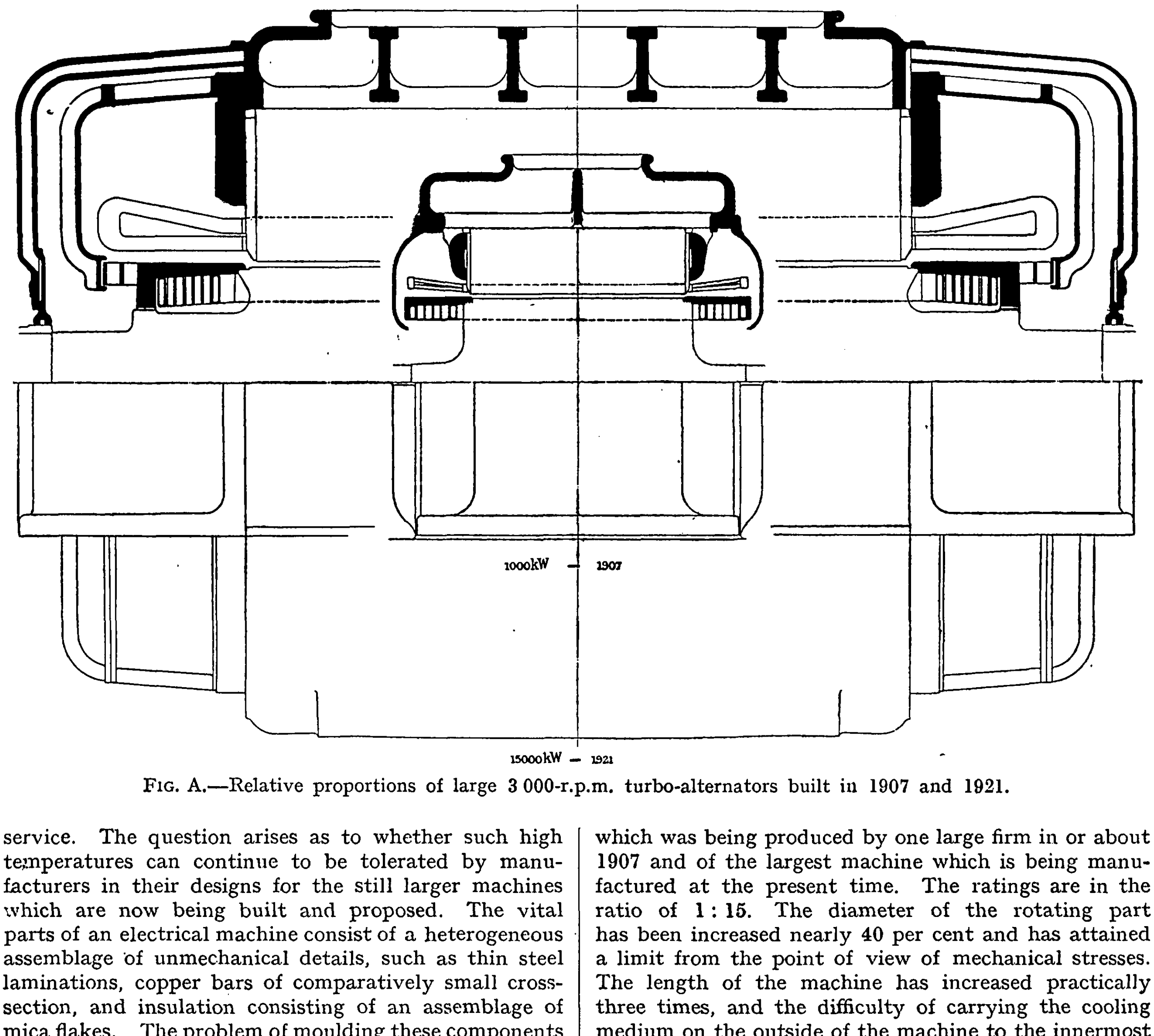

FIG. A.—Relative proportions of large 3 000-r.p.m. turbo-alternators built in 1907 and 1921.

away from them be taken as proportional to the volume of winding used it will be further appreciated that not only has the cooling medium to travel over greater distance, but it has to be provided in larger quantities to carry away with it an increased quantity of heat.

Mr. H. M. Dowsett (*communicated*) : The author has raised the question of temperature limits in connection with its application to large turbo-alternators, but this subject may be discussed with advantage in its relation to other classes of machines covered by the Reports of the British Engineering Standards Association. Take the case of the high-frequency alternator which is to-day a commercial proposition up to units of 200 kW. As it is a resonance machine its possible output is limited solely by its internal losses, which of course increase as the copper and iron temperatures increase and, suitable insulation being provided, it is the limitation of these losses which in this case should determine the permissible maximum temperature. It must be remembered that the smaller the section of the conductor and its insulation the larger will be the possible number of poles and the higher the frequency, so that to impose a low temperature limit may prevent the designer from obtaining as high a frequency from a given size of machine as he otherwise might do. The small direct-current high-tension machine is another case which may be quoted. Its rotor usually runs at high speed, and it has many turns per slot, heavy slot insulation, solid end insulation and poor ventilation. In any case the heat conduction is poor, and the temperature of the windings tends to be high, but this should not increase the risk of failure if a systematic use is made of the vacuum impregnating process for thoroughly insulating the windings at every point with one of the many forms of fluid bakelite now obtainable, which on solidifying is able to stand the working temperature without flowing. Finally I would refer to machines built for service in the tropics. They have to work under conditions of moist heat and of heavy condensation which is very conducive to chemical change, and only those insulating materials should be used which after prolonged exposure to such conditions show no chemical reaction whatever. In this instance one would not advocate an increase in the existing temperature limits, but one would like to see an addition to the standardization rules to the effect that no absorbent material of any kind should be employed for such machines, and that plenty of clearance should be allowed between live parts in order to maintain a good value of insulation resistance.

Professor M. Walker (*communicated*) : The data given by the author relating to the effect of high temperatures on insulated stator conductors are exactly what the electrical designer and the user of electrical machinery want. We know that mica insulation will resist the long application of high temperatures, but we have no quantitative measurements showing the effect of long application upon the mechanical properties of the coil. The figures that he gives are very reassuring to users of electrical machinery, many of whom know that the temperature inside the copper in their machines is considerably over 100° C. As stated in the paper, the formula by which the curves in Fig. 4 were obtained is not really applicable to the case of stator bars. A calculation of the temperature distribution inside a stator conductor, when there is heat conduction both along the conductor and through the walls of the tube, affords an interesting problem ; the solution is comparatively simple, and I give it for the benefit of electrical engineering students.

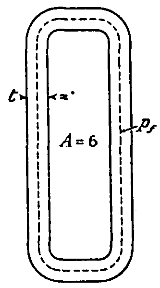

FIG. B.

Let t = thickness of the insulation in cm. (see Fig. B).
A = sectional area of copper.
p_f = periphery (mean) of insulating tube.
$s = (0 \cdot 0012/t) \times (p_f/A)$ = watts per cubic cm. conducted through the walls per degree C. rise in temperature of copper above iron.
$\rho = (1 \cdot 6 \times 10^{-6} \times T)/235 = aT$.
T = temperature of copper + 235° C.
i = current density (allowing for eddy currents).
T_i = temperature of iron + 235° C.

Then at a distance x from the centre of the machine

$$\int ai^2 T dx - \int s(T - T_i) dx = -3 \cdot 5 \frac{dT}{dx}$$

That is to say, the negative temperature gradient multiplied by the heat conductivity of copper is equal to the difference between all the heat generated, $\int ai^2 T dx$, and all the heat dissipated through the tube, $\int s(T - T_i) dx$.

Integrating, we get $3 \cdot 5 \frac{d^2T}{dx^2} - (s - ai^2)T + sT_i = 0$

and $T = C_1 \cosh \beta x + C_2$

when $C_2 = sT_i/(s - ai^2)$, and C_1 depends upon the length of machine and the external temperature of the copper, and β^2 is $(s - ai^2)/3 \cdot 5$.

Particular case : When $x = 88 \cdot 6$ cm. let

$$T = (70° + 235°) \text{ C.} = 305° \text{ C.}$$

and let $T_i = (60° + 235°)$ C. = 295° C.

Let $t = 0 \cdot 3$ cm. and $p_f/A = 2 \cdot 3$, then $s = 0 \cdot 0092$.

Take the virtual current density at 500 amperes per square centimetre, equivalent to a density of 350, and $K_d = 2$. Then

$i^2 = 250\,000$, $ai^2 = 0 \cdot 0017$, $(s - ai^2) = 0 \cdot 0075$, $\beta^2 = (s - ai^2)/3 \cdot 5 = 0 \cdot 00215$, $\therefore$ $\beta = 0 \cdot 0463$, and

$$\frac{sT_i}{(s - ai^2)} = \frac{0 \cdot 0092}{0 \cdot 0075} \times 295 = 362° \text{ C.}$$

Filling in values for $x = 88 \cdot 6$, we get

$$305 - 362 = C_1 \cosh 0 \cdot 0463 \times 88 \cdot 6 = C_1 \cosh 4 \cdot 1.$$

Now $\cosh 4 \cdot 1 = 30 \cdot 178$, therefore $C_1 = - 1 \cdot 9$, and $T = 362 - 1 \cdot 9 \cosh 0 \cdot 0463x$.

Taking the particular case in which the stator has a total length of iron equal to 177·2 cm. (about 70 in.), in which the temperature of the teeth is 60° C., that of the copper outside the slots is 70° C., and in which the other values are as above, the expression for T takes the form

$$T = 362 - 1 \cdot 9 \cosh 0 \cdot 0463x.$$

The full-line curve in Fig. C shows the temperature distribution under these conditions. It will be seen that the effect of heat conduction along 35 inches of conductor only reduces the temperature in the centre of the machine by about 2 degrees C.

If, however, we apply the formula to a machine having a total iron length of 32 inches and an insulating tube 4 mm. thick, we find that the conduction of heat along the copper towards the end-connectors reduces the temperature in the centre by 35 degrees C. below the figure that would be attained if there were no heat conduction along the conductor.

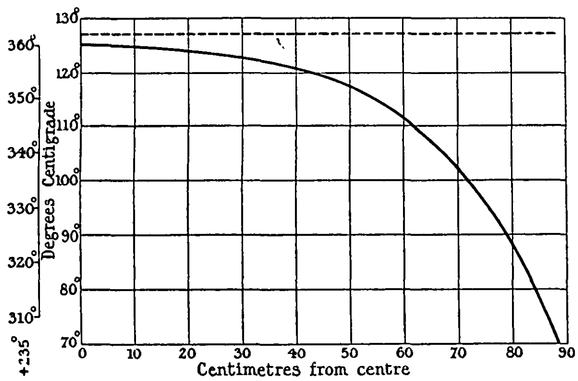

Fig. C.

It is very desirable that thermo-couples, or other temperature-measuring appliances, should be placed in turbo-generators so as to enable the operator to determine accurately at any time the value of the maximum temperature of the stator copper. For some reasons it is undesirable to place the thermo-couple directly adjacent to the copper, even though a conductor close to the neutral point is chosen, because it may be desirable to insulate the neutral point, and in that case a third harmonic might cause considerable difference of potential between the junction and earth. I suggest that a better plan is to place the thermo-junction at a point half-way through the thickness of the insulating tube when the insulation of one of the stator coils is being made up; it will then register approximately half the temperature difference between the copper and the iron. It may be more exactly calibrated if necessary by placing a thermo-couple next to the copper, the latter couple being cut out ultimately. It would then be easy to arrange the scale of the temperature-indicating instrument so that it reads the actual temperature of the copper. While I agree that the data in the paper sufficiently establish the fact that machines can be operated at high temperatures without suffering injury, I do not agree that one should deliberately aim at temperatures as high as 150° C. in the case of stators. In considering the amount of copper to use in designing the stator conductors, one must have regard to the fact that the greater the amount of copper the greater the amount of eddy-current loss. The eddy currents that we must have in view are not only those that arise from the field due to the magnetomotive force of the current in the slot, but also those arising from the cross field and the longitudinal field due to the saturation of the teeth. These cross fields and longitudinal fields are exceedingly strong in many modern machines and, unless very great care is taken in the lamination and crossing-over of the conductors within the slots, the eddy-current losses arising from them may be greater than the normal copper losses. With very careful lamination and crossing-over, however, it is possible to increase the copper in a stator slot so as to make the total cross-section considerably greater than it is in many modern machines, and to reduce the copper losses at full load by many kilowatts. In a case that I recently worked out I found it possible to reduce the copper losses in a 20 000-kW machine by 40 kW, while the total cost of material and labour did not exceed £600. If the interest on this is taken at 10 per cent, the cost to the consumer need not exceed £60 per annum, whereas the saving of 40 kW is worth several times that amount. At the same time, the internal temperature would be so much reduced that the fibrous materials, some of which still enter to a certain extent into the composition of the insulation, would be very much better preserved. Reliability is, of course, the first consideration, and we must only consider first cost in conjunction with efficiency.

Mr. G. A. Juhlin (*in reply*): The views of Mr. Merz on the question of higher temperature limits are of very great interest and value, and it is gratifying to note that he is in general agreement with the suggestions made in regard to increasing the temperature limits, as well as to operating machines on final temperature rather than temperature-rise. With regard to the question as to whether increasing the copper temperature would cause difficulties with any other parts of the machine, I would say that there would be little or no increase in the temperature of the laminations of the machine; and, as we are operating to-day at temperatures far removed from the limits for the insulation used between the laminations, we should be entirely beyond the region of danger. Mr. Merz raises a very important question in connection with the number of failures of turbo-alternators, and in this connection I would refer to Fig. D on which are shown the total kVA output installed and running since 1911, as well as the number of machines. In addition to this the total kVA of breakdowns and the number of breakdowns have been shown for both stators and rotors, together with these failures given as a percentage of the total kVA of plant running at the time of the breakdowns. It has not been possible to obtain accurate records of the breakdowns further back than 1917, but it is of interest to note the reduction which has taken place in the number of failures from that date. It should also be pointed out, in connection with the number of failures, that many of these are very minor ones, especially those in connection with rotors, and in no case is a breakdown recorded on a modern type of rotor, most of the machines being very old. There is no case on record where the insulation breakdown can be attributed to damage of insulation due to overheating. As pointed out by Mr. Merz, the increase in speeds for a given output and the growth of the systems on which machines operate to-day have an important bearing on the question of failures.

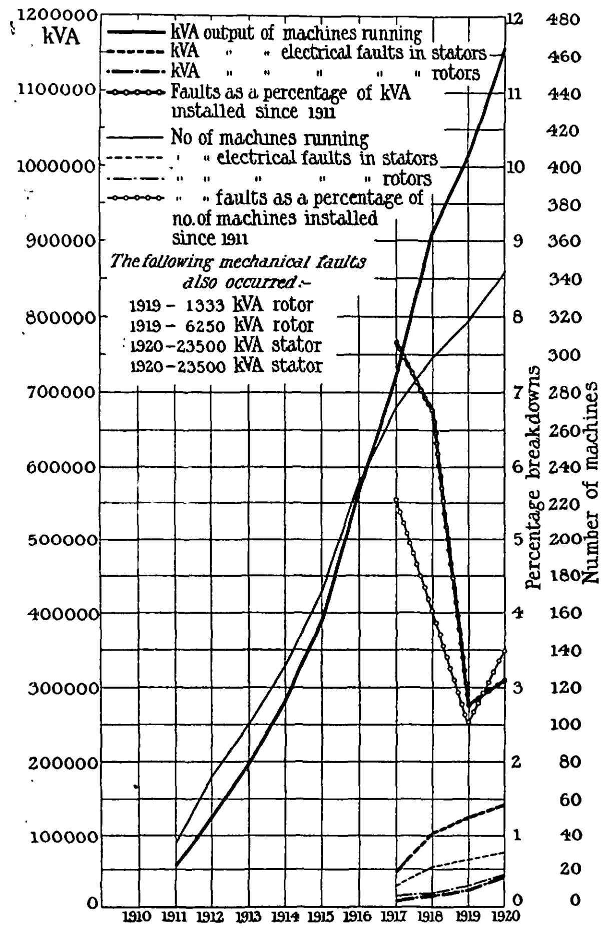

FIG. D.—Number and output of turbo-alternators in service.

I think the broad-minded view taken, when he suggests that manufacturers should be allowed to state the temperature at which a particular machine should be run, must commend itself to all concerned.

I agree with Mr. Clough that the rotor is the most congested part, and higher limits may be adopted for this portion of the machine than for the stator. I do not think that the temperature suggested in the paper is the highest to which rotor insulation may safely be subjected.

I cannot quite follow Mr. Orsettich when he states that it is implied in the paper that we should increase the temperatures because we are exceeding the temperatures we thought we should get. What I suggest is, that we should recognize the fact that machines have been operating with satisfactory results for many years at higher internal temperatures than are now accepted. Manufacturers have known this to be a fact for many years, and I think it is to the advantage of the industry as a whole that it should be known to all concerned. It is probable that opinion in America is divided on the question of maximum temperature-rise, but I would suggest the possibility of this being due to the fact that different types of insulation may be in use, and that different engineers have had varying experience depending on the class of insulation employed in their machines. I hardly think that the argument put forward by Mr. Orsettich, that the station staffs do not use the detectors, should be taken as evidence against the installation of embedded temperature detectors. Such a state of affairs would indicate indifferent operation methods, and does not seem to be general in America. I quite agree with Mr. Orsettich that insulation is subjected during operation to other stresses than bending. I think bending stresses are the most important, and the bending tests were chosen because they indicated as well as any other test the condition of the insulation. With reference to expansion, there are many machines having longer cores than 2 metres which have been in operation for several years at copper temperatures as high as, if not higher than, 100° C. with perfectly satisfactory results. I quite agree with the provision of dampers as a protection against the possibility of moisture condensing on the windings due to changes in temperature of the atmosphere. It has been the standard practice of the company with which I am associated to install such dampers, but I would suggest that this precaution is necessary at whatever temperature the machine is operating. I am of the opinion that machines operating at a high temperature will be less affected if operating with a wet filter than those at low temperatures. The figures giving the percentage moisture absorbed by insulation after heating at 150° C. are interesting, but would have been more valuable if the type of insulation had been stated. I think Mr. Orsettich provides a very good argument for the embedded temperature detector when he states that after a few years' operation the temperature may increase due to accumulations of dirt. Such increases in temperature cannot, as a rule, be detected by the thermometer measurements on the external surfaces, but will be indicated by embedded detectors. I think it follows that if we eliminate the necessity for making allowances for increases in temperature due to such causes, it is possible to operate at higher temperatures because of the knowledge that our maximum limit will not be exceeded.

Mr. Shepherd seems to have some doubts as to the accuracy of the thermo-couple. It is our practice to provide several couples placed in similar positions in the slots in order to provide against possible errors in any of the couples. With regard to the question of the accuracy of the readings of thermo-couples placed either at the bottom of the slot or at the top between the coil and wedge, this point has been recognized, and increased hot-spot corrections have been adopted by the American Standards Committee for couples so placed. Whether all these corrections are sufficient is open to some doubt. I entirely agree with the view that we cannot afford to sacrifice the running safety of machinery, but I do not think this would be the case in adopting the temperature limits suggested; and in connection with the possibilities of the temperature limits being exceeded due to ventilating ducts becoming choked, this would be taken care of by the fact that we are measuring the internal temperatures, and should therefore be able to record any increase due to reduced ventilation. With regard to the question of joints, Mr. Shepherd has some doubts as to these being satisfactory, but I think it should be borne in mind that the temperature of the joints will, of course, be very much lower than the limits suggested for the centre of the machine, due to the fact that the end windings are well ventilated. It is our standard practice to-day to make mechanical joints and, in addition to this, a sweated sleeve, so that I do not think any fear need be entertained on this point. I am pleased to know that Mr. Shepherd is in general agreement with the necessity for increasing the temperature limits.

Dr. Smith has very clearly set forth some of the difficulties confronting the designer of high-speed turbo-alternators of large outputs, and I am glad to know that he is generally in agreement with the use of embedded temperature detectors. I think the formulæ given for the calculation of temperature-increase from the resistance method are very useful, as they obviate the use of any specially prepared tables.

Mr. Everest raises a very important point when dealing with the question of actual methods employed for the determination of temperatures. If new methods are adopted, clearly the limits should be changed so as to conform with these new methods. With reference to the point raised in connection with the thickness of the insulation on the Niagara machines, it may be true that the insulation thickness on these machines is greater than would be employed for a similar voltage to-day, but it should not be overlooked that the type of insulation is also different from that we are now employing, so that I think the conclusions drawn from these tests are not erroneous. In any case these tests are not the only evidence in support of the contention that mica insulation will withstand considerably higher limits than have been considered safe up to the present. Mr. Everest quotes the opinion recently expressed by Mr. Torchio, Chief Engineer of the New York Edison system. Opinion from such a quarter is undoubtedly of great value, but I think it is easy to lay too much stress on it, as we have no information as to the actual class of insulation referred to. Mr. Everest expresses some doubt as to the feasibility of the suggestion of taking advantage of operating turbo-alternators on the ultimate temperature and thereby taking advantage of a lower cooling-air temperature, because of the physical limitation of the steam turbine. It is not uncommon, however, to find specifications where overload capacity is called for on the turbine, and in such cases it would certainly be possible to take advantage of low cooling temperature.

The question of mechanical soundness and reliability of the turbo rotor raised by Mr. Field is, in my opinion, of extreme importance, and I agree with him that this point is in many cases of greater importance than the question of temperature. Simplicity of the rotor construction is undoubtedly of primary importance, and, as rightly pointed out, increased temperature limits enable us to simplify the rotor construction considerably.

I agree with Mr. Taylor as to the difficulties confronting the manufacturer in constructing the large turbo-alternator, but I think these difficulties have been overcome successfully. While one agrees that there may be no absolute necessity to increase the temperature limits, it does not, to my mind, follow that we should not take advantage of the higher limits if this can be done with safety, which I believe to be the case. I quite agree with Mr. Taylor's statement that large machines are being built to-day with lower temperatures than in the case of the smaller machines of a few years ago.

With regard to the point raised by Mr. Dowsett in connection with high-frequency machines, it is probable that other limitations than the insulation will determine the temperature-rise of such machines. Referring to machines built for the tropics, I think that the question of ultimate temperature instead of temperature-rise is of more interest, as this eliminates the question of the air temperature, and I do not think it would be necessary to adopt, for the ultimate temperature, limits lower than those in machines built for operation in this country. The question of the use of non-hygroscopic material in damp and humid climates has of course received the closest consideration of manufacturers of electrical machinery, and this class of material is employed as far as possible.

The formulæ given by Professor Walker are of great interest, and will be useful for obtaining approximate figures for the temperature gradient in the axial direction. The suggestion to place the thermo-couples half-way through the thickness of the insulation tube is very interesting, but it is of course necessary to select the bars next to the neutral point, as the value of the insulation would be reduced to one-half if the couples were placed half-way, because the thermo-couples would be earthed. Even with this scheme, however, it would be necessary to estimate the temperature-drop between the point of the couple and the copper itself, so that it is doubtful whether any real advantage would be gained. I quite agreee with Professor Walker that close attention must be given to the question of eddy currents when increasing the depth of the copper, and in some cases it is necessary to consider the stray losses due to the saturation of the teeth. Most designers have probably from time to time investigated this point and, in the cases of some large machines which were investigated from this point of view, the losses due to the stray flux caused by saturation were found to be comparatively small. Professor Walker emphasizes the fact that reliability must be the first consideration, and I think this is a point with which all engineers heartily agree.

NORTH-WESTERN CENTRE, AT MANCHESTER, 25 JANUARY, 1921.

Dr. S. F. Barclay: The author has not made quite clear the relationship that his proposals bear to present-day practice. He says in one part of the paper that he proposes to run machines with a higher temperature-rise than is at present permitted. On the other hand, however, he rightly points out that actual "hot spot" temperatures exceed considerably the rise specified by thermometer. On page 284, in connection with some calculations, he refers to a hot-spot temperature-rise of 78 degrees C. above the cooling air for a 6 600-volt machine, and of 98 degrees C. for a 10 000-volt machine. He points out that although these figures may appear to be high, if the temperatures of existing machines were measured they would probably be found to be in their neighbourhood, if not higher. Most people will be inclined to agree with the author in his opinion with regard to the actual temperatures of machines built and passed to the conventional specification of a 40 degree C. rise measured by thermometer, but how does he reconcile this opinion with his proposal to increase the temperature-rise to 75 degrees C. (actual temperature)? Clearly he is recommending the adoption of a specification that will ensure hot-spot temperatures being lower than he considers they are at present, a state of affairs that is not consistent with the substance of the paper. Another point to which reference should be made is the author's proposal to measure the temperature of the rotor winding by the resistance method. In consequence of the good cooling of the part of the rotor winding that is embedded in the rotor, and the relatively poor cooling of the part of the winding that is enclosed by the end coils, the hot-spot temperature of the rotor must be considerably greater than the average temperature. Clearly then, so far as the insulation is concerned—and it is from that point only that the author considers the case—the temperature-rise that is suitable for the stator where the hot-spot temperature can be taken fairly accurately is excessive for the rotor with which the hot-spot temperature is an unknown quantity. The author might be disposed to consider that the difference between the average and the maximum temperatures of the rotor should not be very great with a well-designed machine, but he has to remember that if his proposal were adopted it would be applicable to badly designed as well as to well-designed machines. For this reason I would express the considered opinion that an ultimate limit of temperature of 160° C. for the rotor as determined by the resistance method is excessive. In several parts of the paper the author refers to the importance of economy in first cost and in operation, but he has not considered what appears to me to be the most important quality of all, i.e. reliability of operation. In my opinion, for generating plant, reliability should have the first consideration from all concerned, and to impair this first essential for any small gain in first cost or efficiency is an unsound policy. An unduly high percentage of failures with turbo-alternators continues to take place from unknown causes, and it might quite well be that relative movement due to large temperature variations may account for some of these failures. Before higher temperatures are adopted it is important that the matter should be considered from other standpoints than merely that of the suitability of the insulation to withstand high temperatures.

Mr. J. A. Kuyser: The author states at the commencement of the paper that the B.E.S.A. Rules allow higher limits than the old practice of guarantee by thermometer. There is a certain amount of misunderstanding on this point, and I should like to bring forward some arguments to show that the B.E.S.A. Rules mean, on the contrary, lower limits and larger machines than the old guarantee of 40 degrees C. as measured by thermometer. This will be best brought out by a comparison between a machine designed on the old basis and one designed to the B.E.S.A. Rules. If we take a 1 000-kW machine designed on the old basis this would have a temperature-rise on the outside of the stator iron of 40 degrees C. by thermometer, and the same on the stator end-windings. It is practically impossible to measure the rotor temperature, and for a normal design this would be approximately 75° C. if measured by the resistance method. If this same machine is operated at the specified overload of 25 per cent the temperatures would be as follows: Stator iron 45° C., stator end-winding 60° C., and rotor, by resistance, 90° C. Now the machine rated to the B.E.S.A. Rules must have a maximum continuous rating corresponding to the 25 per cent overload on the machine designed on the old basis, or 1 250 kW, and the temperatures specified in the Rules are: Stator iron 75° C., stator end-winding by thermometer 50° C., and 55° C. by resistance, rotor winding by resistance 75° C. In the machine rated to the B.E.S.A. Rules we must therefore operate at a considerably lower temperature in the rotor winding (75° C. against 90° C.) also in the stator windings (50° C. against 60° C.) and this will result in a larger and more expensive machine. The price of the latter machine will therefore be approximately 10 per cent higher than that of the former. A further point is whether for this extra outlay extra value is obtained, and in this respect I will show that instead of more value a lower efficiency and poorer performance will generally be obtained. The stator iron, according to the B.E.S.A. Rules, can be operated at a much higher temperature-rise than the corresponding machines based on the 40 degrees C. rise, namely 75° C. instead of 45° C. (for overload conditions). To obtain the largest B.E.S.A. rating out of a certain machine, and for a given cost, the designer will therefore take advantage of the extra allowed on the stator iron and increase the core density to the maximum possible. This can be done by using a larger rotor diameter for a certain stator diameter. The larger rotor will be necessary to find room for the extra rotor copper. A further reduction may be made in the length of the air gap to reduce the rotor heating. In general, everything would be sacrificed to reduce the temperature of the rotor winding, because that is as a rule the most dangerous guarantee in the whole contract. All these changes will result in a poor design compared with the machine designed on the old basis, in which the designer has practically a free hand except for the stator iron temperature. The machine will have a high flux and few ampere-turns, whereas a turbo-alternator should be designed for a minimum flux and maximum ampere-turns. The iron losses and the windage losses will be high, due to the larger rotor diameter. The total temperature in the stator, and the hot-spot temperature, will be higher and the efficiency will be reduced. All these disadvantages can be eliminated to a large extent by specifying the more reasonable temperature limits recommended in the paper, particularly for the rotor which is at present insulated by means of fire-proof materials only. By specifying the higher limits, operating engineers will obtain better designed machines having higher efficiencies at a lower cost.

Mr. A. E. Clayton: It seems to me that one result of this paper will be that purchasers of turbo-alternators will be quite convinced that any rating on the basis of temperature-rise by thermometer is absolutely hopeless. When we read on page 284 that a 10 000-volt machine has an actual temperature-rise of 98 degrees C. instead of 40 degrees C. as measured by thermometer, it is obvious that any rating based on temperature measurement by thermometer is of little use. With regard to the measurement of the actual temperature of the winding, the author is apparently in favour of the use of thermo-couples. I should be very glad if he would give us in rather more detail the reasons why he has not adopted the method of increase in resistance. I remember reading some few months ago of an installation in France where temperature indicators of the resistance type had been installed in hydro-electric plant for supplying energy to a single-phase railway. I should like the author to tell us why he has adopted the thermo-couple. Of course a thermo-couple enables one to obtain the temperature in a particular spot very accurately, but it seems to me that the resistance method is rather less delicate and more suited to actual operating conditions. It seems to me also that in the case of a rotor the author has only allowed a difference of 10 degrees C. between the temperature of the hottest part and the temperature measured by increase of resistance. I think he has come to the conclusion that 160° C. is a safe temperature at which to run mica insulation. If he were to take a temperature of 150° C. by resistance for the rotor I should imagine that it would correspond to a maximum temperature of well over 200° C. in many cases, the actual figure depending partly upon the type of ventilation, i.e. whether axial or radial.

Mr. G. F. Sills: The author showed slides of a number of coils which have been tested. There appear to be four conductors per slot. Presumably these conductors are not in parallel and, if so, there is presumably mica between each individual conductor. I raise this point because in a number of instances in the past, although the slot insulation surrounding the conductors has been mica, the insulation between the conductors forming the coil has not always been of the same material, and in view of the high temperature suggested it would be necessary to have nothing but mica. I should like to know what effect the high temperatures have on the core, particularly if paper insulation is used between the laminations, bearing in mind, of course, that the temperature is lower on the main body of the core. Have the Americans found any core trouble due to the expansion of the core bolts when using these high temperatures? Perhaps the author will also tell us what insulation was used between the stator laminations on some of the machines he mentions. References are made in the paper to a test carried out on water-wheel generator coils. I should say that these coils, at any rate so far as the rotor is concerned, would be working under more favourable conditions than the rotor of a turbo-generator. One speaker has calculated that by using an extra high temperature on a 20 000-kW machine one could show a net gain of about £250 a year. I rather think that when the capital cost of a complete 20 000-kW set and its auxiliaries is taken into consideration a saving of £250 a year would have no influence with a buyer if it would in any way affect the reliability of the set. With reference to the author's remarks on foreign competition it should be possible to put forward higher-temperature machines for export work where it has been found from experience that foreign competitors are doing the same, supplying the lower-temperature machines to the home market, until the engineers in this country are willing to use higher-temperature machines. With the extra-high-temperature machine it might be necessary to have a larger air-filter, which would occupy more space, and with building prices as they are to-day this may offset the reduction in price of the higher-rated turbo-generator.

Mr. B. G. Churcher: Voltage was applied during the bending tests, and it was found that electrical breakdown occurred just after mechanical failure. In regard to the question of thermo-couples, it is necessary to measure the cold-junction temperature whether one employs the deflection method or by a potentiometer. With the latter method one does not, of course, balance the voltage of the thermo-couple against a cell but against a slide-wire which is calibrated with the cell. Mr. Clayton mentioned the use of the resistance thermometer. I think it will be found that the argument of robustness will not work out in practice, because with thermo-couples one can use a fairly thick wire which is sufficiently strong to stand ordinary shop usage, whereas with the resistance thermometer one finds that in order to get sufficient resistance in the arm of the bridge which forms the resistance element, and to make the element reasonably small, one has to use very fine wire. I think it will be found that the resistance thermometer will be no better than an ordinary mercury thermometer as far as robustness and accessibility are concerned. That is where the advantage of the thermo-couple comes in. On page 285 the statement is made that surface temperatures can be measured accurately by means of a thermometer. That does not seem to be quite correct. Thermometers are primarily intended for measuring the temperature of liquids or gases and are calibrated by being immersed in a liquid up to the level of the reading. The emergent mercury column has to be corrected for when they are used under other conditions. For commercial testing the correction may be negligible, but, in measuring surface temperatures, if the thermometer be placed against the surface it will measure the temperature of the air just outside the surface plus a certain amount of radiation from the surface. The author points out that pads introduce abnormal conditions because the cooling conditions are altered where the temperature is being measured. I have measured the temperature-rise of a commutator by the two methods, that is to say by putting a thermo-couple and a thermometer on to the commutator at the same time. The reading by thermometer was 56 and by the thermo-couple 71, thus indicating that the thermometer method was in error by 21 per cent. It is simply due to the fact that the thermometer reads the temperature of the pad, not the temperature of the commutator, and the temperature of the pad was nothing like that of the commutator owing to the poor thermal conductivity of any material that can be used for a pad. I think that in surface temperature measurements where any sort of pretension is made to accuracy, one cannot use a thermometer, especially when there is an air blast. In the latter case, I do not think such a method could be considered for a moment. The only way to get surface temperatures accurately, especially where there is an air blast, is to use thermo-couples and sweat them on to the surface. This will give perfectly satisfactory results.

Mr. T. Baxendale: Last year we opened up a generator rotor, insulated with press-spahn, which had been in use for 7 years. The insulation was practically as good as when first put in and, so far as can be seen, will last at least another 10 years. This set runs with an average temperature of 120° F. on the rotor, so that there is something to be said for low temperatures on rotors. I should like to ask the author if he has considered what effect wet-air filters will have on machines with high temperatures. With air filtered through cloth the insulation resistances will, in general, be high, but with wet filters the insulation resistance drops very quickly. Dr. Barclay mentioned the expansion of the copper. Although the conductors may be held by the mica there is always the possibility that the insulation may give at the joints between the end connections and slot windings, due to expansion, especially if insulated with ordinary Empire cloth (which so far has been the general custom). Insulation made of fibrous material will quickly carbonize at high temperatures. In drying out a machine we find that if the temperature rises much above 180° F. the varnish comes up in small bubbles, which raises a point as to what quality of varnish should be used for the temperatures suggested by the author. With regard to rotors running at high temperatures, we have one, mica insulated, running continuously at nearly 100° C., which up to the present has not given any trouble due to deterioration of insulation. I would suggest that makers extend the mica insulation of the slot winding a little further from the core, as any dirt collecting at this point is apt to earth the winding, especially if any moisture comes over from the wet-air filters. The author mentions the hot spots in a machine. The thermo-couples we had on a large machine showed a temperature of 117° C. on the stator winding. The makers of the generator expressed some doubt as to the accuracy of the temperature, but after reading the paper I am inclined to think that the temperature shown was about correct. On this machine the average temperature of the winding by the resistance method was 55° C. During the manufacture of one of the smaller units, rather more than 10 years ago, it was arranged with the makers that resistance test-coils should be fixed in the stator slot windings which are mica insulated. These on test showed that the temperature varied from 69° C. on the outer ends of the slot windings to 81° C. in the centre. The set is still in constant use.

[**Mr. A. B. Field** and **Professor Miles Walker** also took part in the discussion. The substance of their remarks will be found on pages 296 and 298 respectively, in connection with the discussion before the Institution.]

Mr. G. A. Juhlin (*in reply*): Dr. Barclay seems to have misunderstood the limits advocated in the paper. The limit suggested is 160° C. final temperature and not 75 degrees C. temperature-rise as mentioned by him. Dr. Barclay expresses the opinion that 160° C. temperature limit is too high for the rotor because of the difference between the temperature as measured by resistance and the hot-spot temperatures, particularly in a badly designed machine. It hardly seems logical to settle the limits on the basis of a badly designed machine. Surely the correct way would be to weed out such bad designs and not to penalize the industry on account of these. I do not think one can agree with Dr. Barclay that an unduly high percentage of failures due to unknown causes occur to turbo-alternators, as our experience is that the percentage of breakdowns has shown a general decrease.

Mr. Kuyser is perfectly correct in his statements regarding the actual internal temperatures of machines rated at 40 degrees C. temperature-rise by thermometer, as compared with the B.E.S.A. limits, but if we consider the observable temperatures in each case, those of the B.E.S.A.-rated machine will of course be higher than the 40 degrees C. by thermometer. I agree with Mr. Kuyser's analysis of the machines designed for different temperature ratings, as well as his statements in connection with efficiency and performance generally, of the machine designed for a higher temperature limit.

Mr. Clayton's question as to why the thermo-couple has been advocated in preference to the resistance thermometer has been answered by Mr. Churcher's contribution to the discussion, with which I agree. I think Mr. Clayton considerably over-estimates the difference between the temperature as measured by resistance, and the hot-spot temperatures in the rotor, as there should not be anything like this figure in a well-ventilated machine.

In reply to Mr. Sills, I would say that nothing but mica insulation is used between turns, as well as to earth. The question of the influence of temperature on the insulation between laminations has been dealt with in reply to other speakers. With regard to the question of tests carried out on water-wheel generator coils, these coils were only chosen because they were available for tests, and the question of the insulation used between turns has no bearing on the general results of the mica insulation. It is of course quite possible to supply high-temperature machines for export work where such temperatures are acceptable, but it entails considerably more work for the manufacturer to carry several different lines of designs, and does not tend to efficient production. In reference to the question of air filters, I should say that these would be smaller, rather than larger, for the higher-temperature-limit machine.

Mr. Churcher's remarks are of interest and show clearly the varying results which may be obtained by thermometer measurements, and there is no doubt that considerable care has to be exercised to obtain correct readings by means of thermometers.

Mr. Baxendale desires to know what effect wet-air filters will have on high-temperature machines. I am of the opinion that there will be very little difference in this respect with varying temperature, but any difference would be in favour of the higher-temperature machines. The information given regarding machines running continuously at nearly 100° C. is of considerable interest, and one would venture to predict that no trouble need be anticipated at this temperature. I do not think there would be much doubt that the temperature of 117° C. obtained by means of thermo-couples on the machine referred to by Mr. Baxendale is correct, as this temperature was obtained on the bare copper at considerably above normal load, and could therefore be considered to be a very satisfactory result.

South Midland Centre, at Birmingham, 2 February, 1921.

Dr. G. Kapp: The author in his opening remarks disclaims any intention of suggesting a general rating up of existing sizes of alternators on account of temperature-rise, but the logic of his experimental evidence points that way. To my mind the most important matter is to obtain, not cheaper machines, but safer machines, and that involves an exact knowledge of the heating conditions. The method of temperature test by thermometer is stated in the paper to be the easiest and simplest, but I cannot agree with this statement. It appears to be easy, but in reality it is not so, and is very misleading. During the run a thermometer cannot even give the real surface temperature, as it is blown upon by the ventilating air, and it is a common experience to find that, after the machine has been stopped, the thermometers show a sensibly higher temperature, at any rate in machines which can be stopped quickly. A true hot-spot temperature cannot be recorded by thermometer, for the simple reason that the hot spot is inside the material and is therefore not accessible to the thermometer. We have to guess it more or less from the difference between the readings of the thermometers placed on the surface of the body near the point where the hot spot is presumed to be, and those of the outside thermometers. The latter are exposed to local draughts and show great variations, so that a temperature chart shows an uneven line and to use this curve for the determination of the time-constant becomes mere guess-work. What really matters is not the temperature-rise, but the actual temperature at the hot spot, and to get this we must have a temperature detector which can be placed actually at the hot spot or at a point where the temperature is actually the same as at the hot spot. As it is obviously impracticable to place the detector in metallic contact with the bar in the slot, we must place it so as to insulate it from the bar. The conception of a hot spot implies that no heat must flow past it, for if there were a flow of heat there would necessarily be a hotter spot somewhere else, in our case in the bar itself. The author has recognized this essential condition and illustrated it in Fig. 5. The ideal condition is attained by placing the detector at the point C, for this point is in what may be termed thermic equilibrium. Point D is not quite as good, but still acceptable, but point B is quite useless as it involves an evaluation of the temperature-drop between points A and B. Detectors based on the principle of increase of resistance with temperature are rather bulky in comparison with thermo-couples and, as such a couple can be accommodated at the ideal point C, it would seem that the thermo-couple is the right instrument to use. But here we come to a difficulty; if we attempt to make it direct-reading we introduce an error due to what is known as the "Peltier effect." A potentiometric method is therefore more exact, but this requires some manipulation and an exact knowledge of the thermoelectric coefficient. Copper-eureka with about 44 microvolts per degree C. is a very suitable combination, but this figure is not a rigid constant, so that a coefficient would have to be supplied with each machine according to the particular couple used. It is also necessary to know the temperature of the cold junction, and therefore at least one thermometric observation is required in addition to a calculation. There is a simple method to avoid the calculation and obtain the exact hot-spot temperature direct. All we need is to use for the outside circuit the same metals as are embedded in the hot spot and connect the two circuits in opposition with a galvanometer in circuit. The so-called cold junction may then be immersed in liquid which is heated by a spiral, and whose temperature is observed. If the temperature of the liquid under the influence of the heating spiral has attained that of the hot spot, the galvanometer will read zero and the thermometer will indicate the hot-spot temperature. One beaker, heating spiral and thermometer can, by an arrangement of switches, be used for the determination of any number of hot-spot temperatures. Can the author tell us if the readings of thermometers are influenced by eddy currents from stray fields being produced in the mercury? I have not observed such an effect, but my experience is limited; on theoretical grounds, however, such an effect should exist.

Major A. M. Taylor: I am very interested in the results of the tests given on pages 289, 290 and 291, but I feel that it is necessary for engineers to go very carefully in this matter of temperature. One thing is quite certain—that if there is any tendency for the alternators to break down under present conditions, due to temperature, that tendency would be increased by raising the temperature—it certainly could not be altered. The tests appear at first sight to give ground for the proposed increase in temperature, but it must be remembered that the author was able to examine in detail the condition of the insulation when opened up after the end of the test, and no doubt he is far better aware than the users of the machine can possibly be of all the little points and weaknesses which might develop into trouble, and which can hardly be conveyed to the engineering public through the medium of a paper. The most conclusive way of backing up his opinions would be for his firm, and other firms, to give guarantees for a number of years with alternators constructed to work at certain temperatures measured by temperature detectors. The second point to which I should like to refer is the question of the detector method versus the resistance method. The latter has, it appears to me, been condemned off-hand because it only measures the average temperature of the complete circuit. This no doubt is a very serious disadvantage, but on the other hand, from the calculations given on page 284, in connection with Fig. 5, it would appear that between points A and B there is a difference of temperature of 28 degrees C. with insulation for 6 600 volts, and of 48 degrees C. with insulation for 10 000 volts. This difference of temperature is only a matter of calculation and is a factor as to which there may be considerable uncertainty, the temperature detector only being of service as far as the point B. Looking into the question of the error introduced by measuring the average increase of resistance over the whole circuit as compared with the desired "hot-spot" increase of resistance I have arrived at the conclusion that, if one knew what proportion of the length of the circuit the hot spot covered, and if one could measure the increase of resistance over the whole circuit due to the combined action of the normal part and the hot-spot, and also could measure independently the rise of resistance of the complete circuit when the hot spot was not active (as, for example, when the stator was cool), one could from these two measurements obtain the actual temperature of the hot spot. It may be argued against this that it would not be sufficient merely to take the length of the core along the axis and find the proportion of the copper bars lying in that to the total length including the end connections; but if the core could be assumed to be at a uniform temperature along this length this course is feasible. If, on the other hand, the core is not at a uniform temperature along its length, it would be practicable to introduce indicators in the form of a tinned sheet-iron lamina inserted every 6 inches or so, which would give a clue to any one part of the core being at a higher temperature than any other (working along the axial length). I believe it to be possible, by taking a cooling curve with the machine kept running, but without any excitation on the field (and if necessary with a small counter excitation, so as to prevent any electromotive force being generated in the stator winding), to obtain a curve which at its highest points will tend to read high, due to its including the rise of resistance of the hot-spot part, whereas at its lowest point it would tend to be nearly a correct measure of the rate of cooling when there was no hot spot, due to conduction along the windings. If, when the machine has reached its lowest temperature, a comparatively short run were to be taken on a rising temperature curve—preferably obtained on full load for a very short period, but, alternatively, by passing a direct current through the stator winding, sufficient to give the same I^2R losses as the full-load alternating current—and the heating curve were to be deduced under these conditions (initial and final temperatures), and if, finally, we were, in the case of the alternative test, to run the generator on short-circuit and with the excitation arranged to give only just the necessary voltage to obtain full-load current, measuring the initial and final temperatures also under this condition (the latter test being carried out merely to correct the direct-current test) a correction could then be made on to the direct-current curve to allow for alternating current, and the starting curve obtained. Having thus obtained the initial portion of the heating curve by one of the two methods indicated, this may now be inverted and taken as the initial portion of the cooling curve, and we thus get the true cooling curve when there is no hot spot. Having thus obtained the difference between the part of the cooling curve for that part of the machine which does not include the hot spot, and for the included hot spot, it is possible, knowing the proportion of the length of the hot spot to the total length of circuit as stated above, to get at the true hot-spot temperature in the way I have indicated above and to plot a third cooling curve, which should at its peak give the highest temperature reached by the copper itself in the hot-spot portion of the circuit. The whole of the above depends, as already stated, upon being able to estimate approximately the length of the hot-spot portion of the circuit, and from the curve given in Fig. 2 it appears to be a not very difficult matter to make a fair estimate, where radial ventilation is employed, of the length of this portion of the circuit, which could be checked by the tinned laminæ, if these had been inserted during construction.

Mr. A. T. Bartlett: The author has set forth very clearly and fully the case for the adoption of temperatures higher than those already agreed upon by the British Engineering Standards Association for turbo-alternators. It is most difficult in experiments of this class to imitate even approximately the working conditions which obtain in practice. For instance, in the experiments on the strength of mica tubes shown diagrammatically in Fig. 7, the tests were made on a composite cantilever consisting of a mica tube with a more or less solid copper centre. It seems to me that it is almost impossible from the results obtained to draw any useful conclusion, as the strength of the copper will be comparable with, if not greater than, the strength of the mica tube. I suggest that had a finely stranded and therefore weaker bar been used the experiment would have given much more satisfactory results. Then, again, we cannot draw definite conclusions from experiments even when they are prolonged for 7 000 hours. Experiments which I have carried out show that, even with the B.E.S.A. specification for materials, class A and class B are already on the high side. In my opinion, therefore, we should fix a maximum temperature of, say, 110° C., and if this proves satisfactory we might adopt a higher temperature in the future. As regards the use of temperature detectors, in my opinion this is the only correct method of running plant. For instance, in the case of a power house, if one is starting up a set cold and the steam end is capable of doing considerable overload, can there be any reason why this machine should not be run at a heavy overload for a short time, readings being taken on the temperature detector so that the safe temperature is not exceeded? Reference has been made to methods of ascertaining temperatures which need balancing in order to get the temperature readings. In my opinion this is wrong; all such detectors should be of the inspectional type, as the average power-house attendant has already enough to do without work of this kind. With the inspectional instrument there can be no excuse for any neglect of definite instructions as to the temperatures at which to run various machines.

Dr. M. Kahn: Many engineers still specify for large turbo-alternators a temperature-rise of 40 degrees C. measured by thermometer, a specification which goes back to the early days of electrical engineering. High-voltage machines were then practically unknown and a 100-kW set was considered a large unit. On small low-tension machines the temperature is nearly uniform all over the armature after a 6 hours' full-load run, and the thermometer measurements give a fairly accurate idea of the temperature-rise. The large turbo-alternators which we build to-day differ from those early machines in size, construction, insulation, in method of ventilation, in short in every respect, and it is obvious that the experience on which the rating and testing of these small units was based does not now apply. The author has given a very comprehensive treatise on the main points on which the rating and testing of the modern large units should be based. Temperature measurements by thermometer on these machines are deceptive, and the only possible and correct way to ascertain the temperature-rise is by measurements by temperature detectors. For these a temperature-rise must be allowed which has been found safe for the mica insulation which is now universally applied on large turbo-alternators. The temperature limit stipulated in the B.E.S.A. Report No. 72 is 120° C. for large high-tension machines, and this is certainly on the safe side. A machine insulated with mica and asbestos only and working with a temperature-rise of 80 degrees C. corresponding to this 120° C. limit is safer than a motor insulated with cotton insulation and a temperature-rise of 40 degrees C. For cotton insulation this temperature-rise is nearer the safety limit than that of 80 degrees C. is for mica. The *sine qua non* for this is, of course, that cotton is not used except on the surface of the end winding which is directly exposed to the incoming cooling air, where, in consequence, high temperatures cannot possibly occur. On page 291 the author mentions coils with cotton insulation between turns. The insulation between turns causes trouble more often than the insulation to earth, and only mica insulation should be employed between turns and to earth throughout the coil. I favour a gradual development rather than an immediate increase of the temperature limits. All firms building these large units, and many operating engineers, are alive to the question, and data and experience are continuously accumulated. The question is not an urgent one, as it is quite possible to produce the sizes at present required within the limits of a total working temperature of 120° C. Manufacturers and the operating engineers who have to rely on these units for a large percentage of their load have no interest to run any risk. If we consider what the breakdown of a 20 000- or 30 000-kW set means in a power station and for the manufacturer, this is self evident. The accumulation of experience will naturally tend to lead in course of time to development up to a safe limit. A point which may conceivably determine the temperatures which can be allowed has not been mentioned by the author. I refer to the question of heat expansion of long coils on large turbo-alternators. These coils may be 10 ft. and more in length. With a temperature-rise of 160 degrees C. the expansion of the copper conductors is over $\frac{1}{4}$ inch and, as the mica tube will not expand anything like as much, the copper conductors in the tubes may get loose in course of time and the tubes may be damaged by wear due to vibration of the loose conductors. There are two points in the paper with which I do not agree. One is Figs. 2 and 3; I believe the author has not been quite fair to machines with axial ventilation. The temperature-rise of the iron depends on the temperature at which the cooling air leaves the machine, the specific loss per unit of cooling surface, and the air velocity. These three factors are practically the same for machines with axial and radial ventilation, except that the temperature-rise of the cooling air, given equal amounts for both types, may be rather less for machines with axial ventilation, and this is rather a point in favour of this type. The maximum temperature of both types will therefore be more or less the same, the balance being if anything in favour of the machine with axial ventilation. The only difference is that the maximum temperatures on machines with axial ventilation occur at one end, and on machines with radial ventilation in the centre. The other point is the author's rather optimistic views as to rotor windings. The temperature-rise on the rotor is often quite as high as in the stator, and the enormous stresses to which the rotor insulation of large turbo-alternators is subjected, together with the hammering effect of vibration in case of out-of-balance, and the effect of short-circuits, make the problem of rotor insulation of first importance. The mica insulation between turns and to earth has, however, proved very efficient, and asbestos bakelite is also satisfactory if used for distance pieces.

Mr. R. Orsettich: I entirely agree with the author in his plea for the adoption of temperature detectors in all large turbo-generators or any other large machines of the totally-enclosed type, because only in this manner shall we be able to obtain an approximate idea of the real temperatures existing in the coils of such machines under full-load conditions. I am so convinced of this that I arranged some time ago that all machines from 5 000 kW upwards made by my company should be fitted with temperature detectors. Dealing with the higher limit of temperature proposed in the paper, and the suggestion that such higher limits should be adopted because they are already in use in America and also because they will enable us to produce larger and cheaper machines, I should like to say that opinion in America is very much divided on this question and that some of the leading makers are against it. Mr. Reist stated in a recent paper before the American Institute of Electrical Engineers that in the design of a turbo-generator it is important that the limits of temperature adopted should not exceed those laid down for class A materials in the Standardization Rules of the Institute, also that the increase of cost of a machine designed for a low temperature is very small compared with that of a machine designed for a high temperature. Mr. W. J. Foster, in a discussion on another paper on turbo-generators before the American Institute of Electrical Engineers, in November 1919, stated that it had been his experience to design turbo-generators for temperatures of 105° C., and that this also was the case with practically all the 60-period generators which had been built by the General Electric Company up to that date. Mr. Torchio, the chief engineer of the New York Edison Company, assured me that in the light of recent experience he would refuse to discuss a tender embodying special guarantees for higher temperatures, as he was certain that the principle of increasing the temperature was based on a misunderstanding and not on actual experience. In a paper which he read at the June Convention of the American Institute of Electrical Engineers he gave details of 55 breakdowns of turbo-generators of sizes ranging from 5 to 30 000 kW. Of these breakdowns 33 were due to armature failures, of which 17 were caused by high temperatures. My recent visit to the United States did not confirm the generally accepted belief that generators in that country are loaded on the basis of temperature as recorded by detectors. The detectors are installed, but usually on the wall opposite the switchboard and not on the switchboard itself. They are not read by the station staff when the machine is being loaded, and most managers confirmed that this was not their practice.

Mr. W. J. Line: Although the title of the paper is "Temperature Limits of Large Alternators," only the questions of the heating of the copper and its insulation are considered. It seems desirable to consider also the heating of the iron due to the various losses occurring in it. If iron temperatures are excessive, damage to the insulation paper or varnish between the laminations may result, thus destroying its utility. Undue expansion due to heat may also cause undue axial expansion of the assembled core, resulting possibly in excessive stress and stretching of the core clamping parts, or compression of the core laminations and insulation, in either case causing slackness of core and vibration at lower temperatures and further destroying the insulation of laminations. Even if iron temperatures are moderate and lower than those of the copper, the temperature of the iron due to its own losses tends to cause higher temperature in the copper windings which are embedded in it than would otherwise be the case. The particular design of slot insulation considered in the paper is that in which composite insulation, consisting mainly of mica, with some support of less dielectric strength, is wrapped or wound round the bars, which are then pushed into the slots. Other forms which have been used in alternators are, first, micanite tubes; these are pushed into the slots and the bars then inserted; secondly, micanite or other troughs, the two outer edges of which are turned down over the conductor and secured tightly by wedges, in the case of slots partially closed at outer ends. A form of resistance construction introduced a good many years ago by a leading firm and still, I believe, in successful operation, is electrically and mechanically practically the same. It consists of troughs in a heavy cast-iron box, lined with micanite troughs, the top edges of which are turned down and suitably secured over the "brick" resistance. The latter is made up of folds of resistance material (with heat-absorbing plates and insulation between the folds) laid in the troughs in blocks or "bricks," and forced up from the ends. The heat produced in the resistance is dissipated through the mica to the iron. Temperatures up to 240° C. have been commonly used on this and have given little trouble, the only result being carbonization of the shellac or binding material in the micanite. The insulation remains satisfactory if undisturbed, but if removed is very brittle and breaks up. It is not suggested that machines should be worked at anything approaching such a high temperature, as the margin of safety on large and expensive machines, where breakdowns and interruptions are serious, must be above suspicion, whereas on resistances which are relatively small a narrower margin may be justified. But experience on these resistances tends to show that somewhat higher temperatures than have so far been commonly employed might be adopted without undue risk on machines with good mica insulation. It appears to follow from the mechanical tests described by the author that breakdowns under high voltage may be expected at the point where mechanical breakdown may occur, i.e. where the insulated conductor leaves the slot. I believe it is a fact that breakdowns occur more frequently at this point than elsewhere, but is this due to the bending of the insulated conductor where it emerges from the slot? In connection with the results published in the *Electrician* some years ago of dielectric and other tests by Professor E. Wilson and Messrs. W. H. Wilson and T. Mitchell on samples of mica, it is suggested that, as the density of the dielectric force at the ends of the slots in which high-tension coils are embedded is considerably increased, the ends of such slots should be rounded off. The suggestion seems worthy of consideration, if it is practicable in ordinary manufacture. In the section entitled "Heat Flow through Insulation" the author gives a dissipation figure of 0·7 watt per square inch. I should like to know the numerical limits of such a figure under varying conditions. In my own experience on many kinds of apparatus I have found the following figures :—

Description	Temperature-rise		Watts per sq. in.
	deg. F.	deg. C.	
Solenoid coils in free air—small to large, black varnished ..	*75	*41·7	0·7—0·4
Solenoid coils in iron covers (some air space)	*75	*41·7	0·5—0·25
Large coils in iron covers, filled with bitumen	85	47·2	0·46
" Brick " resistance, as already described	216	120	4·0
" Brick " resistance, as already described	432	240	8·5

* These are on surface. Increase of resistance 20 per cent, corresponding to 85 degrees F. average internal rise.

considered, since the dissipation of heat is the chief factor. The table showing the breakdown voltage of various classes of mica wraps after heating for 7 000 hours is very interesting. I notice that the temperature during this test was maintained at 190° C. It would be interesting to know if any tests were carried out to ascertain the mechanical strength of the material, in addition to the dielectric strength, after the temperature test was completed. I quite agree with the author that it is hardly possible to come to any definite decision with regard to the maximum temperature to which mica, as an insulator, may be subjected. It would appear that the temperature limit would depend upon the binding agent, in this case shellac. There is no doubt room for considerable research in this direction, since machines with a high temperature rating are cheaper to produce from a manufacturing point of view. The latter is very necessary if we are to prevent further orders for machines going abroad.

Mr. C. Sylvester (*communicated*) : I am interested in the author's remarks concerning temperature measurements, and I agree that the use of felt pads for determining the stator temperature is likely to result in false readings. As a general rule these pads, which hold the thermometers, are tied to the ends of the stator winding and after the test they are removed and the readings taken as being the maximum temperature-rise of the machine or windings. I cannot see how this can be, because I have seen these pads loosely tied to the ends of the coils in such a manner that in all probability, when the machine is running, they are not actually touching the coils at all. In this case the temperature indicated on the thermometers would be merely that of the forced draught, after allowing for a slight error due to the heat dissipated by the end shields. I consider the embedded temperature detector (the thermocouple) is very reliable for obtaining temperatures at any given point but, as the author points out, considerable care has to be taken in locating these, or serious trouble may result. When in America last year I visited some of the large electrical engineering works, and I found that the use of the thermo-couple was greatly resorted to. I should like the author to express his opinion as to whether, in the majority of cases, the present systems of air cooling are all that is to be desired. My reason for asking this is because I consider there is room for considerable improvement in the lay-out of some plants. I know of a large power house in the Midland counties where the air filters are situated in the basement in close proximity to the small steam turbines which operate the circulating-water impellors. Moreover, the main steam-range pipes also run along the wall, in addition to a large 2-ft. pipe through which the steam passes when the air pumps fail and the turbine exhausts to atmosphere. It is hardly necessary to say that when the turbine is running on atmosphere the temperature in the basement is unbearable, and this air has to pass through the alternator for cooling purposes. This points to the fact that, in connection with the temperature limits of large alternators, the air-cooling system should be adequately

Mr. G. A. Juhlin (*in reply*) : I entirely agree with Dr. Kapp in his remarks as to the difficulties in obtaining thermometer measurements where thermometers are exposed to strong air blasts, and in such cases it is of course necessary to shield the thermometers carefully. Dr. Kapp makes an interesting suggestion with regard to temperature measurements by thermo-couples, and this would seem to be perfectly feasible, although some difficulties may be experienced where a large number of couples have to be read quickly. For general power-station work, however, the suggestion is certainly worthy of attention.

Major Taylor considers that the most conclusive way for a firm to back its opinion with regard to temperature would be to give guarantees for a number of machines with alternators constructed to work on certain temperatures measured by temperature detectors. It is extremely difficult for manufacturers to give prolonged guarantees of machinery, and I think it should not be overlooked that purchasers of electrical plant in the past have had guarantees covering only, say, 12 months, but at the same time no manufacturer would shirk his responsibilities if conclusive proof could be given of a breakdown having been caused by excessive temperature ; and it should not be overlooked that, in the past, the question of internal temperature-rise has been very largely a matter for conjecture, so that the purchaser's risk would certainly be greater under such conditions than where internal temperatures were known. I am afraid considerable difficulty would be met with in carrying out the suggestion of obtaining heating and cooling curves, as large alternators cannot be tested except on commercial load, and the time taken in shutting down is so long that the temperatures would be more or less uniform by the time the machine came to rest. It is, of course, a fact that the temperature of the embedded portion of the windings is not by any means constant over the whole length, but varies from point to point.

Mr. Bartlett is doubtful as to the value of the experiments on the strength of mica tubes shown diagrammatically in Fig. 7. There are, of course, difficulties in obtaining absolute measurements, but, as the same size of copper was used for the coils before and after heating, the question of the strength of copper would be eliminated, and any change in the strength of the insulated bar would be due to a change in the insulating material. It is doubtful whether a stranded conductor would give any better results. Mr. Bartlett suggests a limit of 110° C. as the maximum. I do not think, however, that engineers with experience of modern insulation would agree that this is a satisfactory limit. Experience extending over a considerable number of years has shown that such a limit is altogether too low, and it would certainly be a retrograde step to adopt it. Mr. Bartlett's suggestion would indicate unfortunate experience with insulation, and could hardly be considered typical of high-class mica insulation. I agree with the statement that detectors should be of the simplest type without any special arrangements.

With reference to Dr. Kahn's remarks that cotton insulation between turns is mentioned on page 291, it should be noted that it is stated the samples for the test referred to were taken from a standard water-wheel machine, which is not of the same class of machine as a turbo-alternator, but is more in the line of an ordinary low-speed machine. These coils were taken because they were available for the test; in addition to this, an excellent comparison between the cotton insulation and the mica insulation was obtained. Nothing but mica insulation is used for turbo-alternator work. One can hardly agree with Dr. Kahn that the need of data and experience is not urgent. I am of the opinion that no time should be lost in securing all the information that can possibly be obtained, in view of the demand for large high-speed machines. The question as to the possibility of producing units of the sizes required within a temperature limit of 120° C. may be justified, but it can only be done at greatly increased cost. Dr. Kahn seems to be of the opinion that Figs. 2 and 3 do not give a fair indication of the temperature distribution of the axially ventilated machine. As these figures are only intended to be diagrammatic, I do not think any definite conclusion in this respect could be arrived at from them, but in general I think one may say that the uni-directional axial ventilation system would certainly show higher hot-spot temperatures than the ordinary radial ventilation, other conditions being the same. With reference to the question of rotor insulation, I do not think it would be satisfactory to allow any machine to run under conditions which would give rise to a hammering action, because this would destroy any type of insulation independent of the question of temperature. Dr. Kahn must have misunderstood the reference to the rotor temperatures. I agree that the temperature of the rotor is often as high as that of the stator, and this part is, in general, able to withstand higher temperatures than the stator.

Mr. Line suggests that the heating of the iron should be considered. This question has been raised by previous speakers, and no fear need be entertained for the safety of the armature laminations when operating at the temperature limit suggested. Mr. Line referred to the normal limits of the loading watts per square inch under varying conditions. It is not possible to give information on this point in a general way, as full consideration would have to be given to the conditions of ventilation for each individual case. It is not possible to express a definite opinion on the present systems of air cooling, as they vary very greatly in different stations, and one could not therefore express a general opinion. I think, however, that the closed air circuit with air coolers will find general favour, as against the present system of using filters, since it obviates some of the greatest difficulties experienced at the present time in the way of filtering the air and keeping it free from loose moisture.

North Midland Centre, at Leeds, 8 February, 1921.

Mr. W. M. Selvey: In listening to the author, I at first had an uneasy feeling that he was breaking the news to us that, whereas for a number of years we had been taking temperatures by thermometer and thinking these temperatures were correct, we had actually been having in the hottest spot temperatures approaching those which he proposes to standardize. If that is the correct view, he is justified in bringing forward his plea for the adoption of higher temperature limits. In the early days the load grew more rapidly than machines could be built, and I think that is the case to-day, and will be for at any rate the next five years or so. The earlier experiences of electrical power were based on a load in which diversity, as we know it to-day, had not proved its full benefit in levelling up the load. There were times of very great fluctuation, and one of the conditions in the early specifications for turbines was a type of governing which should operate with very wide fluctuations without any appreciable change of speed and maintain a constant voltage. That resulted in turbines being erected with very sensitive forms of governors. The only way to meet the specification was that the overload, or the load which could be given by the turbine, should be very large compared with its normal rating. The reason for that may easily be seen; if a governor has to open very suddenly, it must open widely. The consequence was that in our early turbines, particularly those for which Messrs. Parsons were responsible, we could always give 50 or perhaps 100 per cent overload according to the conditions at the steam end; the generators were wound, as we thought then, in very generous and ample proportions. Judging by thermometer tests the rotors and stators were remarkably cool. Therefore a machine which was put in to work from 3 000 to 3 500 kW almost immediately got rated up, because the load was growing so fast. The consequence was that those machines had no sooner been put on load than their everyday load was not 3 500 but 5 000 kW. The question of heat dissipation operates in a reverse direction on economy of material. It is economy of material to adopt a higher speed if the heat losses are the same. Therefore one has to get rid of a great deal more heat from the same mass of material, or conversely the same amount of heat from a smaller amount of material. This is done by forcing air through the machine at a high pressure. The earlier machines took perhaps $\frac{1}{8}$ inch pressure to force the air through them. A modern machine takes up to 2 inches, and I have even heard of a projected design of a larger machine which might require 6 inches' pressure. There are many reasons why we should adopt these large machines at 3 000 r.p.m. if we can trust the insulation. The author mentions the possibility of an entirely inorganic mineral form of insulation. He has not so far entirely eliminated the organic part, because I think he still proposes to use some organic binding material, but at any rate it is getting very much less. The drawback to this is that a good electrical insulator is also a good heat insulator. Therefore in adopting the mineral or silicate form of insulation we adopt a type whch tends to keep up the temperature of the metal which it encloses. We have to reconstruct our point of view, therefore, and we must now endeavour to make the temperature of the hottest spot the standard, because that is all that really matters. The way to do this is to employ an embedded temperature detector at the hot spot. This idea is not new, but I doubt if it is possible to make this measurement accurately without interfering in some way with the general solidity of the generator as a whole. The question of a standard voltage is going to be serious if we are to have, as we have been led to believe, stations at the seaside with 30- or 40-mile transmissions. We should allow the designer to select any voltage he likes, because in any case it would be transformed. It would be not less than 33 000 and probably 66 000. But to-day we are facing the problem of 11 000- versus 6 000-volt machines. Pressures of 10 000 and 11 000 volts have been employed without any transformer, and have proved very satisfactory. The author says that in this case we must run the machines at still higher temperatures, because with pure mica insulation there will be a larger temperature gradient. Also, the more insulation we use, the less will be the amount of available copper, and therefore the copper losses will be higher. If that be so, there may be a difference of the order of 5 to 10 per cent in the output per pound of 6 000- and 11 000-volt machines.

Mr. F. Creedy: I am very interested in the author's application of Professor Miles Walker's method of calculating temperature-rises. I have tried from time to time to make use of this method but, no doubt due to the causes he mentions, i.e. the variations in the tightness of packing of insulation and other factors, I have never been able to get results closely in accordance with test. I am chiefly referring to low-speed machines. This method seems to me to give the hot-spot temperatures not only in turbo-alternators but in machines of all kinds. I should be very glad if the author would say to what extent that is practically possible and how closely calculation agrees with test results. Referring to the stresses on the rotor of a turbo-generator in the case of short-circuit, I should have thought they were equal, as action and reaction are equal and opposite. The author does not explain the precise methods of bracing adopted, but no doubt they are the same as in the case of the stator. I should like to know whether there is any method of limiting these stresses by the use of choking coils or similar apparatus to cut down the short-circuit current. Instead of providing for such very heavy stresses one would think that it would be desirable to diminish the stresses if possible.

Mr. R. D. Spurr: The best of the author's designs can be wrecked by careless handling or assembling under bad conditions. I have in mind large stators which are assembled on site, or else are handled on the railway. The handling of a 15 000-kW stator weighing 45 tons entails heavy work. Although armature winders are very careful, they are sometimes expected to make a good job under very adverse conditions. I believe a large machine wound recently under very bad conditions has since broken down. Another probable cause of failure is the air filter, of which there are two types, wet and dry. I do not think we have yet arrived at the final development of wet filters. I believe the practice of blast-furnace engineers in the United States is to refrigerate the air after it passes the wet filter, in order to dry it. If we passed the air from a wet-air filter over refrigerator pipes there would be no necessity to run machines at a higher load in the winter than in the summer.

Mr. J. D. Bailie: Nearly 25 years ago we used asbestos insulation on direct-current generators of 150-kW rating at 500 volts, and these machines are still in use. I am not quite clear whether the high temperatures referred to in the author's tests were maintained continuously over the long period of time named. If they were, I think it would have been of great interest if more or less similar experiments had been carried out with the current applied for 12 hours and cut off for 12 hours alternately over the whole period of the test, the object being to ascertain the effect of the resulting alternate expansion and contraction of the conductors. Referring to the method of anchoring the end windings of large machines by wide metal rings, I think the object was to provide a rigid support. Would not the tendency of these rings, however, when the windings are subjected to the high temperatures contemplated, be to prevent their longitudinal expansion and so stress the windings against the rings? A point in favour of the higher temperatures proposed, which does not appear to have been referred to so far, unless indirectly by the author, is that they would enable a reduction to be effected in the diameter of the rotor. This, in turn, would be favourable to the adoption of a higher speed of rotation by reducing the peripheral speed of the rotor. I believe there has been a tendency of late to run rotors at higher peripheral speeds than desirable, i.e. up to something like 450 ft. per second. The firm with which I am connected was perhaps the first to criticize wet-air filters adversely. We carried out many experiments on them, and found that they passed moisture. We now make a practice of testing the air for moisture by a method which seems to be fairly satisfactory. I am in favour of the closed-circuit air coolers which are, I believe, now being adopted extensively. I should like the author to tell us which type he prefers. Mr. Selvey referred to the advantages of 11 000 volts over 6 000 volts as the generating voltage. There are many machines now generating at 11 000 volts—for example, in the stations of the Sheffield Corporation and the Yorkshire Electric Power Company—and I think they have given very little trouble. Some 15 years ago we installed two 1 500-kW turbo-alternators generating at 11 000 volts, and they are still running satisfactorily. Where the requirements are in favour of 11 000 volts—for example, when the supply is for what may be termed local use, rather than for long-distance transmission when a step-up transformer would be used—there seems to be no very sound objection to it as the generating voltage. I am entirely in agreement with the author in his advocacy of the ultimate temperature being specified rather than the rise in temperature.

Mr. G. A. Juhlin (*in reply*): With reference to Mr. Selvey's remarks, I do not think there is any doubt that machines have actually been operating in the past with hot-spot temperatures approaching those suggested in the paper. In connection with the question of providing an entirely inorganic mineral form of insulation, while it was found possible to produce mica wraps without the use of any paper, and with shellac only as bonding material, it should be pointed out that such insulation is not at the present time commercial, as there are many difficulties connected with its production, and the cost would be prohibitive. The value of the tests, in this connection, lies in the fact that they show the importance of obtaining a high percentage of mica in the wrap. I should like to correct what appears to be a misunderstanding regarding high-voltage machines. The suggestion is not to run high-voltage machines at temperatures still higher than is the case at lower voltages. In discussing the increased temperature-drop, I wished to emphasize the fact that the surface temperatures did not indicate hot-spot temperatures unless all factors were taken into consideration. There is no difficulty in producing 11 000-volt machines.

In reply to Mr. Creedy, I would say that it is exceedingly difficult to obtain test results sufficiently accurate to make a comparison with calculations owing to the many variables which are encountered; and, in general, the calculation of internal hot spots can only be regarded as approximate.

With regard to the question of wet-air filters, raised by Mr. Spurr and Mr. Baillie, a satisfactory solution of this difficulty has been found in a closed air circuit which obviates all possibility of loose moisture in the machine.

The other points raised by Mr. Baillie have been dealt with already in reply to other speakers.

North-Eastern Centre, at Newcastle, 14 February, 1921.

Mr. E. Fawssett: The paper contains some valuable experimental results, and I find myself in almost entire agreement with the author's conclusions. He says that the sources of heat are well known, and enumerates them. But with the increasing duty expected from materials in general at the present day there is an increasing risk that some small unexpected cause of heating may be magnified into a serious trouble. One or two recent accidents of this sort, although no doubt mechanical in origin, and perhaps even "bad luck" (if one can justify such a term in such important design), developed before becoming apparent as electrical trouble causing intense local heat. If one loads a machine according to the readings of an embedded temperature detector one is too apt to assume that it really indicates the temperature of the hot spot; yet it is safe to say in such a case as above referred to no such warning was given. Hence, I think the conservative limits asked for with embedded detectors are understandable, even if not quite justified. When the author states that "temperatures of bare surfaces can be obtained with accuracy by the thermometer method" I should suggest he has omitted the word "not." He goes on to point out the difficulties so far as any part of a turbo-alternator is concerned, but even then he lets the thermometer method down too gently: there is virtue in an understated case. He mentions the application of the resistance method to turbo-alternator rotor windings, and I venture to supplement his remarks by means of a diagram (see Fig. E) showing how a Harris ohmmeter can be used to give a continuous indication of temperature while the machine is on load. This method has been applied commercially in this district. As at present installed the instrument is momentarily sensitive to changes in the field current, and it is proposed to correct this by inserting a mutual inductance in the circuit, as shown in the diagram, if thought advisable. Continuous indication of actual temperature of both rotor and stator is most valuable to the operating engineer at all times, but especially to enable him to deal with short-time overloads with the minimum of running plant. All machines should be run to a total temperature and not a temperature-rise, and with continuously indicating instruments installed this should be a much easier matter than hitherto; indeed, such instruments should be the most important instruments on the machine panel. While a machine can be operated to a maximum temperature I do not see how a guarantee can be framed on that alone, unless it is merely a guide to safe temperature and not a criterion of performance on a given load; for that, surely, temperature-rise must be taken as the basis. I agree with the author in preferring thermo-couple methods for general practical work. The problem of the cold junction can be attacked in several ways; if the instrument is close to the machine and both couple wires are taken to it, the Darling compensator is possibly the best solution; if the instrument is remote (as is usually the case) it is not convenient to run the couple wires so far, and a "steady junction" (not necessarily "cold") is provided near the machine with an all-copper pilot to the instrument. The temperature of the earth, even at a depth of 6 feet, is subject to a considerable seasonal change, and the reference junction is best placed in a small oil bath maintained at a constant temperature by a thermostatically-controlled immersion

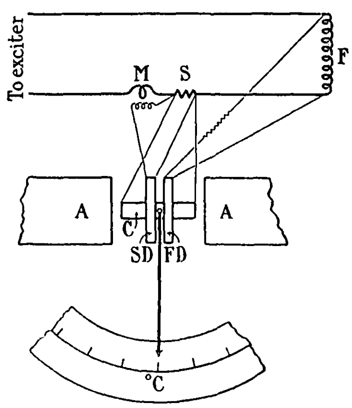

FIG. E.—Method of connecting the Harris ohmmeter to give continuous indication of temperature.

F = alternator field.
S = shunt.
M = mutual inductance.
C = ohmmeter control coil.
SD = standard deflecting coil.
FD = field deflecting coil.
A = poles of permanent magnet.

heater. We adopted a temperature of 40° C. for this as being always higher than the engine-room temperature, and being attained with a very small watt loss and wear on the thermostat contacts.

Mr. T. Carter: Of all the problems that beset the designer of electrical machinery, that of the pre-determination of temperature-rises is perhaps the most difficult, and the author has thrown light on some of the obscure points in connection with this particular problem. I think it should not be too lightly assumed that "the difference between the internal and external temperature is comparatively small in the case of low-speed machines." No doubt the particular reference is to large low-speed alternators, but the statement reads rather as a general one, and it ought to be clearly pointed out that the difference between the internal and external temperature in the case, say, of the field coils of ordinary small dynamos and motors may be really very excessive. It seems to me that the reason that very few specifications are based on Report No. 72 of the B.E.S.A. is that the provisions are not understood. Particularly is that the case with regard to overloads: it is not recognized that the Report simply does not permit overloads, and yet it is common to find a demand that machines shall be in all respects in accordance with the Report and shall have in addition an overload capacity of 25 per cent for two hours, and so on. The definition at the beginning of the section of the paper entitled "Heat Flow through Insulation" is incorrect. A cubic inch is a perfectly indefinite quantity, as it might be either long and thin, or short and flat, or, as is intended, a cube the sides of which are one inch in length. It is not even sufficient to say, instead, "a one-inch cube" because it is not stated how the flow shall enter and leave the cube, and it seems to me that the only really correct way to deal with the point (and the same applies to other definitions in many places, even in standard textbooks) is to talk of the flow through a piece of material one inch long and one square inch in cross-section. The author rightly points out in more than one place how often the hands of a designer are tied by the inclusion in specifications of limiting conditions as regards, say, current densities or temperatures to be ascertained in definitely stated ways. All that should be asked is that a machine shall be supplied that will work, and will be generally in accordance with what is recognized as good practice, of which the manufacturer ought to know more than the consultant, so far, at least, as ultimate details are concerned in regard to the smaller matters about the machine. The result of the practice of putting all these clauses in specifications is that the manufacturer's staff too often have to read page after page of verbiage in order to discover if there are, after all, somewhere in the specification perhaps one or two words that matter. I should like further information in regard to one point mentioned in the paper, i.e. the limit of temperature-rise for fibrous insulation, which is 55 degrees C. measured by resistance, or 50 degrees C. measured by thermometer. I have never regarded this as a sufficient difference. A rise of 50 degrees C. measured by thermometer nearly always represents something much more than 55 degrees C. by resistance, and the two methods, which are intended to be equivalent, seem to me to be really very widely different in what they allow. If the rise by resistance corresponding to 50 degrees C. by thermometer is not too high, then the figure of 55 degrees C. is too low; if the figure of 55 degrees C. by resistance is correct, then that of 50 degrees C. by thermometer is too high. In the section headed "Conclusions" the author instances the cheapening and the increase in efficiency and the saving in space, and so on, that will be secured if his suggestions are adopted. It would be interesting and useful to have some quantitative statement on this point, and I hope that he will give some figures in his reply. The whole matter seems to be one, first of all of finding out the facts of the case, as the author has tried to do, and then of educating the consultants and general buyers of machinery up to the point of understanding that it will be to their advantage to buy on the terms laid down in the paper. Low temperatures are called for at present in order to provide a margin of safety, because people are not sure of how far it is safe to go and, unless the real meaning of the indications of temperature-rise by present methods is known, safety will naturally always be aimed at.

Even then, as the author points out, the results may not be satisfactory. Some engineers are already willing to take advantage of the possibilities of the method given in the paper, but others have yet to realize what it is all about, and if the author can convert some of these to his views, he will have done a very useful piece of work. The state of ignorance of some of the people who are in a position to place orders for large quantities of machinery is appalling. The principle of the paper is sound, but we must be very sure that the method of measurement of temperature-rises is equally sound, because if we are to work closer to the limits of safety it is more and more essential to know exactly what is going on in those parts of the machine that we cannot see. I think it is also clear that the usefulness of the general principle depends on whether the general design of the machine is good, so that there shall be equal use made of all the material, and not just a few hot spots carefully measured while the rest of the machine is too cool. It is, I imagine, no part of the function of a designer to give away information, and the paper necessarily gives only an outline of a very wide subject, but it is none the less useful on that account.

Mr. J. N. Waite: The subject of this paper is one that has required publicity for some years. From Mr. Fawssett's remarks it will be patent that the subject has been under consideration by the engineers of the North-East Coast group of power companies for a long period, and the conclusions arrived at are, in principle, identical with those of the author. The data given will be of material assistance in formulating schemes to enable the operating staff to run their generating plant at its full capacity. It is obvious that the capacity of air-cooled generators will vary with the air temperatures, and the fallacy of settling capacity on a fixed load basis is so apparent that it seems scarcely necessary to point it out. As stated by the author, the practice up to the present has been to specify a definite temperature-rise for a given kVA output, the temperature-rise to be measured by thermometer. It must be remembered that an interval of at least 30 minutes must elapse after taking off the load and taking temperature measurements by thermometer. Also, as pointed out, these measurements are surface insulation measurements and their relation to the actual copper temperature will depend on the temperature gradient across the insulation. In addition, the presumably highest copper temperature—that in the slots—cannot be measured, while the rotor copper temperature cannot be taken at any point owing to the construction of the modern rotor. The following figures, taken from comparatively recent tests, supply a commentary on the uselessness of figures obtained by thermometers. Stator temperature by thermo-couple, machine running, 84° C.; reading with load off and fan off, 92·7° C. (This shows the serious effect of incomplete shielding from the air blast.) Temperature by thermometer, machine standing, 79·5 ° C. (thermometer under clamp on end windings). Average temperature by resistance, machine standing, 73·5° C. Rotor (water-cooled, water circulating until at rest); average temperature of copper by resistance, when running, 123·7° C.; average temperature, standing, 85° C. Another rotor (air-cooled by fans on rotor): Temperature of rotor end-cap, 61° C.; average copper temperature by resistance, 126·3° C. The operating engineer requires the maximum safe temperature for his stators and rotors, and a reliable means of indicating the same. For operating work the instruments used should be as simple as possible. For this purpose I should rule out resistance thermometers, and also the zero-current method to measure thermo-couple electromotive force, as these involve the use of a cell and adjustable resistances. The essential details of thermo-couple indication are covered in the paper, so that it is quite unnecessary to comment on them, with the exception that it should be emphasized that the absolute accuracy of the temperature indicators is not so important as reliability and relative accuracy. The possible saving to be effected by the operation of alternators right up to their maximum safe capacity is quite considerable, whether viewed from the point of view of capital expenditure or from that of operating cost. There are three representative cases:—(1) *Multiple station undertaking.* Load allocation: Assume that one station (A) has a coal figure 10 per cent lower than the next best station (B). Assume also that a 10 per cent increase in load over the rated full load of the turbine increases the consumption by 1·0 per cent. Then, neglecting distribution costs, any extra load that can be carried on (A) will result in a net gain of 7·5 per cent on the units so generated. (2) *Single station.* The wattless current increases so that an extra generator is put on load. Assume 4 generators on load in the first instance, and that the no-load steam consumption of a turbo-alternator is 10 per cent of the full-load consumption. Then, if the extra generator is put on with no increase in the load, the steam consumption for the output will increase by 2·5 per cent. (3) *Single station.* The load rises. Making the same assumptions as in the two preceding cases, it will pay to run on overload capacity up to the point where the increase in steam consumption of the machines on load balances the no-load steam consumption and the auxiliary power for another machine. These three cases, or a combination of them, cover the field from an operating point of view, and illustrate the probability that, given the extra necessary generator capacity through scientific rating, considerable economies would often be possible.

Mr. C. H. Davidson: There is no doubt, bearing in mind the temperatures being successfully worked to abroad, that British makers must follow suit unless they are indifferent to the loss of foreign markets. Experience has shown that the present B.E.S.A. limits are on the safe side, and the tendency for some time past has been for manufacturers to quote on machines having maximum temperatures considerably higher than those laid down in the Rules. I am not quite clear whether the author wishes the increased temperatures he advocates to apply to machines built to the present B.E.S.A. standards, or to others which would show a gain in the utilization of material. Does he mean that the increased temperatures are only to apply to thermo-couple measurements, whilst normal

B.E.S.A. temperatures would be obtained by the methods laid down in the Rules? If so, it is difficult to see where any gain comes in, and he is apparently asking for the Rules to be altered to cover conditions which thermo-couples have exposed as existing in hot spots in machines which otherwise conform to the Rules if the temperatures are measured as laid down. It is rather disquieting to think that we have still to deal with hot spots, as designers have been trying for years to eliminate them. In some cases they have been very successful, although no machine can ever have an even temperature all through, radially and longitudinally. It is certain that, with the use of increased temperatures, more attention will have to be paid to the various materials used in building up mica to form tubes, etc., as it is these materials and not the mica itself which determine the limit to which machines can be run. If the temperature limits for alternators are to be raised, progress should be along very conservative lines, and full advantage should be taken of the experience gained at home and abroad, and new limits should not be fixed until more experience has been obtained.

Mr. R. M. Longman: The author is quite right in condemning the method of determining the temperature of a machine by applying a thermometer to the hottest accessible spot, as the larger the machine the smaller the chance of getting at any hot spot; in fact, one would almost think that the makers particularly rendered inaccessible any spot which might possibly be warmer than the rest. It is the actual temperature of the copper which is the danger point of a machine, and no temperature can be permitted which allows the insulation next to the copper to be charred. The slight movement of the copper due to expansion, and the far more important movement caused by a short-circuit on the system, rapidly create a pounding action, which will soon cause a breakdown on the machine. On page 284 the temperature-drop between the copper and the iron of a 6 000-volt machine is given as 28 degrees C., and for a 10 000-volt machine as 48 degrees C. This, at first sight, seems to be a point in favour of the 6 000-volt machine, particularly as the extra difference allowed by the B.E.S.A. is only about 9 degrees C. I should be glad if the author would give us his views as to the relative safety of the two machines. I believe the 10 000-volt machine is quite as safe and is a better proposition than even the 6 000-volt machine. With regard to the use of thermo-couples in conjunction with a multi-contact switch, it is of the highest importance that these contacts should be kept absolutely clean, and that the switch should always make thoroughly satisfactory contact, otherwise very incorrect readings may be obtained which, it should be noted, would always be on the low side. The test under which the bars were heated for six weeks continuously would have been made much more severe had the heating not been continuous and if cooling had been allowed to take place at times. I should like to ask the author whether the heating and bending tests on page 289 were carried out on the bare copper, with no insulation whatever. Another point which should be noticed is that if a specification allows of a maximum temperature of 150° C. it does not allow of the overloads being put on to the turbo-alternators, to which station engineers have in the past been accustomed. After rating a machine at, say, 10 000 kW for a maximum temperature not to exceed 150° C. one must not expect to be able to add another 25 per cent overload with safety. The question of rotor insulation is only touched on in the paper. This is an extremely important point and must only be carried out with the best materials. Many of the failures during the last 10 years have been due to insufficient attention to the insulation, and in some cases also to the use of soldered joints.

Mr. G. A. Juhlin (*in reply*): Mr. Fawssett's remarks are of considerable interest, and especially the diagram of the Harris ohmmeter, which apparently is used in connection with turbo-alternator temperature measurements. I am pleased to note that Mr. Fawssett's experience, in general, agrees with the suggestions made in the paper.

I agree with Mr. Carter that the definition which he gives in connection with heat flow is better than the one adopted in the paper. As regards the question of temperature-rises measured by resistance and by thermometer, it is hardly possible to give any definite statement on this point, as it of course depends entirely on the cross-section of the coil under consideration. In general I think one may say that the difference is hardly sufficient; probably a figure of 10 degrees C. would be better for an average coil.

Mr. Waite gives some very interesting figures, which show clearly the discrepancies between temperature measurements by thermometer and by resistance. It is very interesting to find operating engineers agreeing that it is advantageous to operate machines on ultimate temperature rather than on temperature-rise, and the examples quoted by Mr. Waite show that economies would often be obtained by doing so.

With regard to Mr. Davidson's question, I would say that the suggestion made in the paper is that machines should be rated on 160° C. ultimate temperature obtained by means of thermo-couples in the stator, and by resistance in the rotor. The B.E.S.A. Rules give only 75 degrees C. rise by resistance, so that there would be a definite gain by adopting the higher limits, especially as regards the rotor. I think it is necessary to recognize that hot spots have not been eliminated altogether, although great improvements have been made. At the same time there is certainly no reason to be uneasy about this point, as the hot-spot corrections are very small for well-designed machines.

In connection with the comparison between the temperature-drop for 6 600- and 10 000-volt machines, raised by Mr. Longman, it should be remembered that the temperature-drop is given on the assumption that the electrical loading is the same in each case. There is no difficulty in building 10 000- to 12 000-volt machines with the same degree of safety as for 6 600 volts. No bending tests were carried out on the bare copper. The question of overloads would, of course, have to be taken into account when specifying the rating of a machine. Short-time overloads should be avoided, as they tend to produce uneconomical designs. More consideration was given to the stator insulation because this problem is more difficult than that of the rotor insulation. I think all engineers will agree with Mr. Longman that only the very best materials should be employed for insulation, whether for stator or rotor. Ordinary soft solder should not be used for joints in the rotor.

Liverpool Sub-Centre, at Liverpool, 28 February, 1921.

Mr. E. M. Hollingsworth: We should try to further any proposition towards reduced capital cost and increased efficiency of electric generating plant, provided it is not at the sacrifice of reliability. I think the crux of the question is this: Are we going to sacrifice anything in the direction of reliability by adopting the proposals put forward by the author? Experience with alternators has been generally satisfactory during recent years, and unless there is going to be a very great advantage obtained it is not advisable to make any great change in the design or construction of such plant. Many engineers have from time to time been concerned about "hot spots," and I can sympathize with the author in his desire for more co-operation between manufacturers and users of detectors. In the case of one machine of which I had control, manufactured by Messrs. Dick Kerr of Preston, and designed by the author, I passed some sleepless nights owing to a hot spot on the top of the yoke. It is not an easy matter to ascertain the correct temperature of such a surface, and the spot in question seemed to get hotter every time we felt it. The machine has not to my knowledge given any trouble and, in all probability, is working at a higher temperature than that which the author advocates. I do not think engineers will disagree with the author's plea for the adoption of temperature detectors, and I am rather surprised that manufacturers have not done more in this direction in the past. In this connection I should like to ask what increase in capital cost the temperature detectors suggested would represent. I consider manufacturers have been backward in this respect, for, speaking as an operating engineer, I should have welcomed years ago such an instrument to give us some indication that we were not exceeding at any spot the temperature guaranteed. I should like to ask the author what is the possibility of exceeding the guaranteed temperature in the case of an alternator which has been allowed to become dirty. He will probably advocate the closed air system, but not all engineers are using this system. Now we are all agreed that some revision of the determination of temperature-rise is required, and the author will tell us it can be done at very little expense. I should like to refer to his summary of the arguments in support of an increase in temperature (see page 292): "In the case of machines running at the same speed, those with high temperature rating are cheaper." That is true, but will this mean any great decrease in capital cost? It is a question of material; I know that there will be a reduction in material, but the labour costs will not be reduced very much, and in any case will the reduced capital cost compensate for the reduced reliability? I cannot understand what the author means when he says: "Higher efficiencies are obtainable," for I cannot see how a decrease in copper can mean increased efficiency. Perhaps he will clear up this point in his reply. He goes on to say: "Larger units can be built, or higher speeds can be adopted for machines of certain sizes," but I maintain that with our present knowledge of the steam turbine this is the limiting factor, and we cannot deal with the alternators without taking the turbines into consideration. The author states that he is prepared to build alternators of considerably greater capacity than at present, at a speed of 3 000 r.p.m. With my present knowledge of turbo-alternators I should not like to install one of more than 8 000 kW capacity at 3 000 r.p.m., therefore I do not see that any great claim can be made for higher alternator speed until we can get a reliable turbine. I should like to endorse what the author says in reference to the rotor windings and the present methods of building up the same. On two or three occasions one of our machines broke down owing to the movement of the coils in the rotor, but the rotor in question was not on the lines of the one shown by the author on the screen, the design of which gives much more confidence.

Mr. F. J. Teago: The two fundamental points in the paper are: first, that maximum total temperature is the rational way of specifying the output of a machine in terms of safe heating; and second, that the current maximum value of the total temperature is, if anything, low. I am surprised that one still hears temperature-rise referred to. With regard to the second point, the author proposes that the limit of the ultimate temperature, as measured on the conductors in the core, should be 160° C The existing rule is that, for mica, paper, and such materials, the limiting ultimate temperature shall be 125° C. This figure, then, would be measured on the end windings and not in the slots, since the insulation in the slots is practically pure mica. Now, in general, if the end windings were worked at a total temperature of 125° C., the temperature of the windings in the slots would be 160° C., which is perfectly safe, since micanite tubes will withstand temperatures far in excess of anything yet proposed. Since the end windings form the weak spot, and 125° C. measured there would rate the machine as high as 160° C. measured in the slots, why not use the end windings as the point of reference? The end windings also have the advantage of accessibility. In any case, the author's proposals are in no way revolutionary, because the running temperature of existing plant is close to the figures which he gives.

Professor E. W. Marchant: I should like to ask the author whether he has ever adopted a method of measuring the temperature-rise of windings by means of their increase in resistance, that is, to measure the increase in resistance by superimposing a small direct current on the alternator supply. I do not think a scheme of that kind would be impracticable. It would not, of course, be of very great value if thermo-couples were fitted, but if a machine were built without thermo-couples and one wanted to find the average temperature-rise of the windings, it would be useful. With regard to thermal resistivity, we made a few experiments on some insulating materials used on buried cables and we found that apparently, although the alteration was not very marked, there was a diminution in the resistivity with increase of temperature. I should like to know whether the author has found that in his mica wrappings.

Mr. A. E. Malpas : In his opening statement the author gives 40 degrees C. as the limiting temperature-rise generally adopted in this country, but on the Continent I have generally seen 45 degrees C. specified, and the difference of 5 degrees, of course, gave the Continental makers an advantage in competition. The measurement of the temperature of a machine externally by means of a thermometer has always struck me as being a very crude method, leaving the true internal temperatures very much in the region of the unknown, and this fact, no doubt, has led to the adoption of the low temperature-rise of 40 degrees or 45 degrees C. measured externally. I have always been struck by the anomaly of the same temperature-rise being specified in any given case, no matter whether the machine was to be installed in an airy room where normal temperatures would always exist, or in a warm locality—for instance, a hot engine-room or in the tropics. With an inside temperature of 43° C. in the shade I have wondered how the insulation of a large installation of motors and other electrical machinery would stand up, although nothing very serious actually happened. Report No. 72 of the B.E.S.A. does not lay any very great stress on the use of embedded temperature detectors, except that it suggests that a liberal number of these devices should be employed if their use be adopted. This would add something to the cost of the machine, although the addition may not be very serious in the case of really large apparatus. With regard to rotor circuits, it is easy, by means of the increase-of-resistance method, to ascertain the working temperature of most of the existing machines while running, but a knowledge of this temperature alone would not enable an overload to be carried with safety. The temperature of the stator copper also must be known. With regard to the type of indicating device, some years ago I used a Le Chatelier thermo-couple instrument to measure the temperature of hot gases, but I found that the millivoltmeter used in conjunction with the thermo-couple was so sensitive as to be seriously interfered with by stray fields. There were no direct currents anywhere near the instrument, but the conclusion I came to was that atmospheric disturbances caused a great deal of interference with the readings. It was very hot, dry weather at the time, such as is very seldom experienced in this country, but it is conceivable that atmospheric influence could at times have the same effect here. For this reason, the resistance thermometer would appear to offer a great advantage, more especially as the " Null " method of measurement is more accurate than any direct-reading method, since a Clark cell or other cell of constant voltage can be used for the balancing. I agree that in the case of large machines of new design it is highly desirable to provide such embedded temperature detectors in order to determine what are the safe limits at which to run the machine, but whether the advantage to be gained by fitting these devices to every large machine constructed would justify their cost is open to some doubt. It must not be lost sight of that their use would involve some danger since, if the detectors did not happen to be placed at the hot spot of maximum temperature, their readings might induce the operator to overload his machine beyond the real danger point. Referring to Fig. 7, it may be recalled that a good many cases of breakdown have occurred in the insulation of bars at the point where they left the protection of the slot, and this was proved to be due to vibrations set up at the end connections, and was surmounted, at all events in some Continental makes of machines, by increasing the thickness of the insulation at that point of the bar. It is interesting to note that many American machines of large size have been built to a specification of a maximum temperature of 150° C., the presumption being that this guarantee applies chiefly to the rotor circuits, with some economy in field copper.

Mr. C. Rettie : Although I am chiefly interested in the electric propulsion of ships, perhaps it will not be out of place to raise one or two points in connection with the paper. I refer in particular to the design of alternators for ship work, particularly where large units are concerned, such as the battle cruisers which are being built in America, the horse-power of which is as much as 180 000 for one ship alone, the motors being of 22 000 h.p. I take it that the paper refers to present practice only, but it is within the sphere of this subject to discuss future requirements in the design of alternators and motors for ship propulsion, the conditions of which are totally different from anything we have on shore. The sudden reversal of motors totalling 180 000 h.p. from full-speed ahead to full-speed astern, and also the question of the propellers rising out of the water and sudden turning movements, when the excitation of the alternator field has to be increased much above the normal to prevent the motors falling out of step, necessitate a safe temperature limit in the design of machinery for the same. In the *General Electric Review* for April, 1919, there is an interesting account of the temperature of the alternators during the trials of the U.S. battleship "New Mexico":—

"An evidence of the conservative design of the generators is the recorded temperature-rise during the maximum-load endurance run, the power developed being 31 000 h.p., and the speed of the ship 21·3 knots. The maximum temperature-rise on the armature windings as measured by temperature coils was 30 degrees C. The temperature coils were located between the upper and lower layers of the windings in the slot at the centre of the coil, and recorded the approximate hot-spot temperatures. The rotor or field temperatures as indicated by increase in resistance of the field winding indicate a safe working margin on the guaranteed actual temperature of 150° C., allowing for the temperature of the air entering the generator to be as high as 45° C."

In the later ships, as well as in the "New Mexico," a new instrument has been installed for measuring the field temperatures, an account of which is given in the *General Electric Review* for February, 1920, an extract from which bears on the present paper:—

"The field temperature indicator is an instrument that shows the temperature of the field conductor and depends for its operation on the change in resistance of a conductor with change in its temperature. It really indicates electrical resistance, but instead of a scale of resistance a scale in temperature in degrees Fahrenheit is used. This instrument is employed on the alternator field only, no such instrument being necessary on the field of the synchronous motor."

The author's remarks on the construction of alternators remind me of the time when I was engaged on the construction of dynamos in Canada. We used wooden pins on the spiders for holding the coils, but the centrifugal force set up when the armature was revolving wore away the pins so much that the end wires broke. On this account the wooden pins were done away with and iron pins (insulated with asbestos and paper) used instead. In conclusion, I should like to say that though I have not had any actual experience with large alternators, particularly with reference to ship work, I feel that we should be alive to any new developments which take place from time to time. We have no experience of ship work in this country to draw from, unless we take into account the "Wulsty Castle." I feel that we are being left behind in the development of the electric propulsion of ships; other countries such as the United States are building electrically-driven ships of all kinds, and these are proving very successful.

Mr. G. A. Juhlin (*in reply*): With reference to the question of reliability which has been raised by Mr. Hollingsworth, it would not be sound policy to suggest any change in the temperature limits unless one could be perfectly satisfied that it could be done without sacrificing reliability, and I believe this to be the case. The cost of a temperature-detector equipment complete would not exceed £200, so that the expenditure is relatively small. It is, of course, quite possible to exceed the temperature guarantees on a machine which is allowed to become dirty, but by the use of embedded temperature detectors this is guarded against, because the internal temperatures are measured, whereas with the surface-temperature measurements it would be quite possible to have internal temperatures which could not be detected, with consequent danger of burning out the machine. A closed air circuit undoubtedly has very great advantages in the way of keeping machines clean, and this system is rapidly gaining favour amongst operating engineers. With regard to the question of efficiency, it is not so much a question of reducing the amount of copper in machines by adopting a higher temperature limit, as of a general change in design, and this change means higher efficiencies. The amount of copper in a machine may actually be increased on account of the higher electrical loading, which enables us to obtain lower iron losses; and in many cases it would be possible to design machines with smaller rotor diameters, which also means a gain in efficiency due to the reduced windage losses.

I think Mr. Hollingsworth is taking a pessimistic view of the turbine situation, as there are certainly no difficulties in producing satisfactory turbines of much higher output than 8 000 kW.

In reply to Professor Marchant, I would say that we have tried at different times to obtain resistance measurements on machines running on short-circuit by superimposing a small direct current on the alternating-current supply, but we have not attempted to apply it to a machine running at full voltage. With regard to thermal resistivity, we have not been able to obtain any definite figures as to whether there is a diminution in the resistivity with increase in temperature.