DISCUSSION ON "STARTERS." *

AT THE INSTITUTION, 2 MARCH, 1922.

Mr. J. M. L. Slater: Some valuable information with regard to the starting torques with different classes of apparatus is given in Table 2 of Mr. Anderson's paper. As far as my observations go, the figures given are correct except in the case of item 20 (air compressors). The figure given is 6 per cent. I have some figures with regard to compressors, taken from the catalogue of a very reputable firm, in which they state that by closing a compressor intake the power necessary to drive it is reduced to from 15 to 20 per cent of full load. I have generally found that these figures are rather on the low side. Perhaps Mr. Anderson has in mind some special method of unloading the compressor, and it would be interesting to know the particular method which he has in view. With regard to Fig. 11, I think that many of the inconsistencies in the results might be obviated by using a thermo-couple for measuring the temperature. Unless a thermo-couple is used in measuring the temperature of small wires, the comparatively large mass of the thermometer against the wire must give rise to considerable variation in the temperature reading. It would be interesting if the experiments were repeated and the measurements taken by thermo-couples. On page 633 reference is made to the temperature-rise of materials, and the suggestion is made that this should be increased from 600 to 700 degrees F. This figure is, I think, quite satisfactory if the correct material is used for resistance. Cupro-nickel is not satisfactory at temperatures over 300° C. (572° F.), and if higher temperatures are to be worked at it is necessary to employ the nickel-chromium group, which permits of temperatures up to 1 000° C. (1 860° F.) being used. I cannot understand the heading of col. 5 of Table 6.

On page 198 of Mr. Wilson's paper, reference is made to three electrolytes, viz. washing soda, salt and caustic soda. In general I have found washing soda to be the best. Salt creeps badly. I have had experience of two other electrolytes, viz. potash alum and potassium bichromate. Some colliery engineers prefer the first because it gives better control at low speeds. At one colliery the engineer favoured the latter for the same reason. I have had very good results with these two over a long period, and it would be interesting to know whether Mr. Wilson has had satisfactory results or has tried potash alum. With regard to the method of calculation given on page 202, no allowance appears to be made for variation in the form of starter. For example, with the types shown by Figs. 6 and 7, when the electrodes are first immersed the current passes through the small amount of solution at the top of the tank and the under layers are heated up in succession as the electrodes are lowered into the liquid. This must lead to the solution being at different temperatures in different parts, and if the maximum temperature were measured the power absorbed would vary, depending on the type of starter. In the case of the type of starter shown in Fig. 10 the whole of the liquid in the pots and above is heated uniformly from the bottom. Mr. Anderson referred to a similar point in connection with Fig. 14 of his paper. For this reason, one would anticipate that in the results given under the heading of "Calculations for Rating" the maximum temperature—not the average temperature—would not be kept within the limit stated. It appears to me to be necessary with the type of starter shown in Fig. 6 to make an experimental model and determine the amount of power it will absorb, which would give a constant applicable to all starters of the same design. In connection with the remarks on page 205 referring to the form of electrodes employed in Fig. 10, one would imagine that if two flat electrodes as shown were brought into contact, a very great jump in speed and current would result at that moment.

* Papers by Mr. J. Anderson (see page 619) and Mr. W. Wilson (see page 196).

Mr. T. Carter: Mr. Anderson's paper is, in my view, an excellent example of standardization on the best possible lines, working everything out, as it does, from first principles and using as an aid carefully determined experimental results. A paper * by Mr. A. E. Gott dealt very fully with the grading of the steps in a geometrical series, and pointed out that too high a potential difference between successive contacts sometimes made that sort of grading impracticable, and might even necessitate the use of additional steps to prevent sparking. Mr. Gott was not the first to publish the principle of geometrical grading for starters—I think Pochin did it much earlier—but he worked it out in a way that was new and useful at the time, and I think he is to be regarded as at least a semi-pioneer. I gather from his paper that Mr. Anderson would have no off-contact on starters, and I agree with this view; a circuit breaker or a switch ought always to be provided to break the circuit. I would draw special attention to Mr. Anderson's excellent principle that when many of the data are open to doubt, extreme accuracy in calculations based on them is merely a waste of time; this is a counsel of sanity that is often forgotten, as is also the recommendation to understand what rules mean before applying them. The paper draws attention usefully to certain possible difficulties in the use of eddy-current starters; their value is occasionally discounted by want of complete foresight in their application. I am sorry to find Mr. Anderson so pessimistic about the furnishing of data by manufacturers of motors; as one of them, I would say that it is perhaps better to be cautious than to be wrong, and that I have even known an instance of a starter-maker giving information about what certain starters would do that was in the highest degree misleading. Non-technical buyers of starters are naturally unable to give full particulars of the torques and other characteristics of the drives in which they are interested, and Mr. Anderson's informa-

* "Starting Resistances," *Journal I.E.E.*, 1902, vol. 31, p. 1219.

tion is therefore bound to be of the greatest possible value to the industry.

Coming now to Mr. Wilson's paper, I think a very useful point in favour of liquid starters as compared with metallic resistance starters is that an overload on the former shows its results by the boiling of the liquid, whereas with a wire starter eventual disintegration of the material takes place, often without previous warning, and renewals are obviously much more difficult than when only the addition of water to a tank is required. I should like Mr. Wilson to say whether, and if so how much, the specific heat of the liquid is altered from unity by the addition of the soda or whatever is used; his calculation is based on the specific heat of water, and I assume therefore that the difference is slight. Liquid starters are very serviceable pieces of apparatus; if trouble occurs in them it is usually due to ignorance and neglect on the part of their users, who sometimes omit to put in the liquid, and sometimes the soda. Perhaps manufacturers of liquid starters are to blame because they do not issue instructions in easily understood language; it is usual to specify a 10 per cent solution of washing soda, but it would perhaps be better to say that one pound of soda must be used for every gallon of water. I would emphasize Mr. Wilson's reference to the very important point that many starters have been designed in the past on the assumption that they absorb the whole of the energy at starting, whereas they actually absorb only half. I hope that all possible steps will be taken to make this clear, because the misunderstanding has caused starters to be supplied that are too large and that are consequently unnecessarily expensive. I would also commend Mr. Wilson's suggested specification for the rating of liquid starters on the basis of successive starts with a long cooling period following each of them, as preferable to the alternative proposal sometimes made that they should be tested on the basis of starts rapidly succeeding each other. Mr. Wilson's specification is more nearly in accord with working requirements than the other which, because of the rapid succession of starts, involves a practically unnecessary reduction of the horse-power-minutes involved in each start, and so leads to an undesirable increase in the size and cost of liquid starters. Mr. Wilson's specification is safe because even if the liquid starter is called upon to deal with a rapid succession of starts in an emergency the only result will be to boil the liquid. The use of liquid starters is to be encouraged because of their many advantages, and Mr. Wilson's rating would under all ordinary circumstances lead to the choice of a starter neither unduly small nor unduly expensive, and therefore eminently suitable for its work.

Mr. J. R. Blaikie: With reference to Mr. Anderson's paper, and the curious heating effects with high temperature peak in the middle of the elements shown in Fig. 11, the phenomenon may possibly be due to the electrostatic state of the element. I think it is generally known that in making tubular electric condensers there is a higher electrostatic strain in the ends of the tubes than there is at the centre. In that case, in the series of elements which Mr. Anderson showed, it is quite possible that the top one of the six is nearer to earth potential than the bottom one; and the difference in temperature between the centre and the two ends is very considerably less. We know that there is a great deal of dust-bombardment effect with quite low potentials, as seen in direct-current work where, if there are two conductors mounted on white insulators, one pole gets dirty while the other remains white. It is quite possible, therefore, that this dust-bombardment effect disturbs the convection currents and alters the rate of cooling. There is another suggestion I should like to offer which might help in the investigation of convection currents. If one allows a naked arc, or strong ray of sunlight, to cast a shadow of a hot element on to a screen, the convection currents can quite easily be seen. That is probably due to the refraction of the light at different temperatures of air, or possibly to the absence of dust from the air. Kelvin performed an experiment with a red-hot cannon ball, and found a dark zone round the ball which he attributed to the absence of dust. Bombardment or dustless zones might very seriously interfere with convection currents and produce this extraordinary result.

With reference to Mr. Wilson's paper, I should like to ask the author if he feels satisfied that the experiments which he has made on the small apparatus, with submerged electrodes, and the data obtained, would be applicable to many other types where the greater part of the action takes place on the surface. The case of steam or gas generation under hydrostatic pressure might greatly reduce the possibility of arcing across, by keeping the bubbles small and allowing them to rise vertically at a high speed. In other cases where the electrolyte is flooded up, the major part of the action takes place on the surface and the liquid produces big bubbles of steam and gases; consequently there is more tendency to flash over. With regard to the question of the different substances which may be used for the electrolyte, I have found a novel one in the American "Handbook of Electrical Engineering," namely, sodium sulphate. I do not know what are the advantages of these various substances. The "Handbook" to which I have referred gives the same nomenclature: sulphuric acid, 1 inch; potassium hydrate, 0·8 inch; sodium chloride, 0·3 inch; sodium sulphate, 0·18 inch and copper sulphate 0·1 inch. The potassium hydrate is exactly the same as Mr. Wilson's sodium hydrate.

Mr. H. Brazil: It is interesting to note the difference between the papers by Mr. Anderson and Mr. Wilson, particularly with regard to the material used for the resistances. Mr. Anderson, who deals with the smaller machines and requires very exact regulation, employs a wire having a negligible temperature coefficient, whereas Mr. Wilson, concerned with very much larger loads, is compelled to use a liquid having a very considerable negative temperature coefficient. On page 208 Mr. Wilson details the troubles that occur with liquid rheostats, particularly when direct current is used: electrolysis takes place and gas is given off; the anodes wear away rapidly and require replacing and the solution deteriorates and requires renewing from time to time. It occurred to me that it might improve the apparatus considerably if another material were substituted for the liquid—something which would have the good qualities of a solid without its liability to fracture and to break circuit and yet possess the property of a liquid in that it would flow and thus dispense with contact stops without the disadvantage of boiling at a comparatively low temperature. The substance I suggest is carbon powder, and I have taken some rough tests with some powder in an ordinary pail by pushing a thin metal sheet downwards into the centre of the pail. I found that the current increased steadily from 0 to 300 amperes at 80 volts, the powder behaving very satisfactorily. With regard to the capacity for absorbing power of the two substances, liquid and powder, Mr. Wilson gives 200° F. as a limit of temperature for the liquid, whereas the powder may be raised to a temperature of nearly 2000° F. without being damaged. The paper gives 3 h.p.-minutes per pint as the rating of the liquid, but I am in possession of figures which show that the powder could be rated up to 15 h.p.-minutes per pint. Carbon powder being an inert substance which does not oxidize, no corrosion of the anode and the containing vessel takes place, and the troubles due to boiling, electrolysis and the production of gas are entirely avoided. I suggest, therefore, that in those cases where rheostats are required to deal with large amounts of power for short periods, and particularly on electric locomotives, the use of carbon powder instead of liquid might profitably be considered by designing engineers.

Mr. H. C. Hastings (*communicated*): On page 626 Mr. Anderson mentions automatic contactor equipments and refers to the relative merits of current relays and pressure relays connected across the armature for controlling the closing of the contactors. He appears to convey the impression that there is very little to choose between the two systems. I think, however, that the pressure-relay method, generally known as the counter E.M.F. system, has long been recognized as unsatisfactory for general use. That this is so can be readily shown, and Fig. 1 may be used conveniently for the purpose. This diagram apparently refers to a shunt-wound machine and a 7-notch starter, the armature current being allowed to decrease to the same value on each step before notching. The induced armature volts on each step at the instant before notching will be approximately proportional to the speed of the armature, and it will be seen that there is very little difference between the speeds corresponding to notches 5, 6 and 7, the difference between the speeds for notch 6 and notch 7 being less than 5 per cent. If pressure relays were used for controlling the closing of the contactors the relay for notch 6 would have to be set within 5 per cent of that for notch 7, so that a variation of 5 per cent in the operation of relay 7, if this were on the low side, would cause it to operate at the same time as notch 6, and the current peak would be double the normal value. If, on the other hand, a current relay had been used, the 5 per cent variation in the operation would cause only a 5 per cent difference in the current peak. This is evident, since if C_s is the value of current at the instant before notching, and C_p the instantaneous value of current after notching, the relation between C_s and C_p is $C_p = C_s\ (R_n/R_{n-1})$, where R_n is the total resistance in circuit before notching and R_{n-1} the resistance after notching. This assumes that there is no series winding, and that the effect of the self-induction of the armature is negligible, which is generally the case. Thus, a 5 per cent change in C_s will give a 5 per cent change in C_p. Not only is the counter E.M.F. system of control more sensitive to error in the operation of the relays, but the relays themselves are more liable to error, since shunt coils are used, and the current in these will vary with the temperature, whereas this is not the case with the series coils of the current-limit scheme. Another disadvantage of the counter E.M.F. scheme is that it is suitable only for one line voltage without re-adjustment, as the relays are set to operate at a predetermined voltage. If the line voltage varies considerably, as in the case of many steel works, it is necessary to set the relays to correspond to the highest voltage, otherwise there will be a very high peak of current when closing the last contactor, but on low line-voltage this may result in the pressure not being high enough to close the last relay and contactor. A reference to the diagram will show that there is not the same disadvantage in using the counter E.M.F. scheme for the first notches. The scheme can be used satisfactorily where the motor is to be started against little friction and inertia load, and is generally applied to machine-tool control, where only one division of resistance is used, and where the current may be allowed to drop to 25 or 30 per cent of full-load value after switching on, before cutting out resistance. A reference to Mr. Anderson's Tables 1 and 2 will show that even under these conditions the motors will start up in 2 or 3 seconds if the current on the first notch and the maximum peak current are in accordance with the maximum allowed by the B.E.S.A. Specification. Automatic control schemes are in use where the contactors are controlled by relays having shunt coils connected across part of the starting resistance. As the current in these coils depends upon the current in the armature and starting resistance the scheme is not open to the same objections as the pressure scheme referred to above, where the action of the relays depends upon the voltage across the armature. On page 636 Mr. Anderson refers to the interesting and comparatively recent development of the so-called eddy-current starter. These have been used to a limited extent for the control of motors driving "live" rolls in steel works. The results of the few tests I have made indicate, as one would expect, that the torque per ampere from the line is less than would be obtained with resistance control, that the maximum torque which can be obtained is less, due to additional reactance in the rotor circuit, and that consequently a larger motor would be required for the same limiting service conditions. Generally speaking, a slow operation would result for reversing equipments with this form of control, and an increase in the capacity of the motor, unless this is obtained without increasing the moment of inertia of the rotor, will not increase the speed of reversal in proportion to the increase in the rating, for service conditions where the principal energy consumption is devoted to reversing the rotor of the machine. To obtain conditions equivalent to starting with non-inductive resistance in the rotor, controlled by current-limit relays, a device is required, the effective resistance of which will decrease directly with the slip, and which will not introduce into the rotor the same effect as reactance. As Mr. Anderson points out, the eddy-current starters at present made do not entirely comply with these conditions. Assuming that with the slip-rings short-circuited the slip is 4 per cent at full-load current, the resistance required with the motor at rest to reduce the current in the line to full-load value will be approximately 25 times the rotor resistance. Good results would be obtained if the effective resistance in the rotor circuit automatically decreased from this value to, say, twice the rotor resistance as the rotor frequency decreased due to the motor speed increasing. The tests I have made on one particular set used with "live" rolls show that the effective impedance of the eddy-current starter was such that with full-load torque the speed of the motor would not increase beyond two-thirds normal speed if the line current with the motor at rest were $1\frac{3}{4}$ times the full-load value. In this case the result was equivalent to leaving permanently in the rotor circuit a resistance which would decrease the speed to two-thirds the normal at full-load torque. In order to reach full speed without excessive peaks in the line under these conditions, at least two contactor notches would be required for cutting out the eddy-current starter. Many methods of starting slip-ring motors automatically without switches in the rotor circuit were proposed in the early days of induction motors between 1898 and 1900. Mr. H. M. Hobart proposed the use of wrought-iron bars of such section that, due to the skin effect, the resistance would decrease as the frequency in the rotor decreased. Resistance materials having negative temperature coefficients have also been used, but the objection to these is that after one start it is necessary to wait until the material has cooled. Mr. Anderson has referred to the method of controlling a.c. slip-ring motors by cutting out resistance unequally from the rotor circuits. This has been common practice ever since cranes have been operated electrically. The advantage is that for any particular number of speed-control points fewer contacts are required in the controller and fewer leads between controller and resistances. Mr. Anderson has covered a wide range of subjects, and apparently he does not differentiate between starters and controllers according to the B.E.S.A. definitions, as in one part of the paper he refers to the control of cranes and haulages, which should rightly come under the heading of "Controlling Devices." This leads to a little confusion, as for instance on page 628 he refers to the breaking capacity of the starter from notch to notch, and from the first notch to the "off" position, as being an important feature in the design, whereas on page 629 he points out that the circuit should not be broken on the starter. Where the conditions are such that the motor starts infrequently it is common practice to use the face-plate starter, and in order to save expense the starter element is usually not arranged for opening the circuit except where the starter arm flies back to the "off" position in case of low voltage or overload. Starters of this type are in general not suitable for notching back towards the "off" position by hand. Where starters of the drum type are used, built on the same lines as those used for controlling crane motors, the designs are generally such that notching back from step to step and to the "off" position is permissible without detriment to the starter.

Mr. W. E. M. Ayres (*communicated*) : In connection with the section allotted to liquid slip-regulators in Mr. Wilson's paper, there is considerable prominence given to the supposed "sluggishness of action" due to inertia in the moving parts. I am at a loss to understand how this fallacy continues to exist. The induction motor of an Ilgner set, supplied with constant voltage, has its load and current determined by the speed of the flywheel and the rotor resistance. As the latter is controlled by the current through a torque motor it follows that the current must first alter. But the current can alter only by variation in the flywheel speed. We see, therefore, that the slip-regulator (if of the balanced type as described) is required to operate only at the rate of change of speed of the flywheel. In an actual case where the overload torque on a motor-generator set is 5 times the full-load torque, i.e. 4 times the motor output to be supplied from the flywheel would reduce the flywheel speed 10 per cent in 3 seconds, an excess torque on the servo motor of 2 per cent is required to enable the dippers to follow the load at the necessary speed. This represents an increase in current of only 1 per cent. The armature of the torque motor is usually mounted on ball-bearings, and the dippers and counterweight are supported on knife-edges. The torque motor exerts about 30 lb.-ft. at full current, so that the solid friction is approximately 1 per cent. What might be termed the "frictional backlash" of the combination is easily kept within $\pm$ 2 per cent. Recording ammeter charts show this to be the case by the small hump where the regulator comes into operation and the small depression where it ceases to function. That the slip-regulator does function properly is proved by the fact that in many cases the substitution of a slip-regulator for a permanent slip-resistance has reduced the motor heating without lessening the output from the rolls. For short passes with long periods between passes, however, they have so little to do and the gain in efficiency is so slight that the expense is not justified. These remarks do not refer to contactor-type slip-regulators, which are not reviewed in Mr. Wilson's paper.

Mr. N. G. Langrish (*communicated*) : On page 623 Mr. Anderson gives a formula for the time to accelerate a motor, and apparently the value of T is the percentage constant torque, in excess of the load, that would speed up the motor in the same time as the variable torque obtained by the use of a step-by-step starter. If this is so it appears that the value of K should be $0 \cdot 5$, but in the paper it is stated that this value may be conveniently taken as $0 \cdot 5$. On page 628 it is stated : "In Fig. 6 the peaks and valleys are the same, giving $8 \cdot 3$ per cent effective torque." From the figure it appears that the minimum starting torque is 66·6 per cent of full-load torque and the load 10 per cent of full-load torque, so that the minimum effective torque for accelerating purposes is apparently 56·6 per cent and the mean will be considerably higher. To what does this figure of 8·3 per cent actually refer? In the above the effect of the last step is neglected, as in the paper. In a number of instances the watts per square inch of radiating surface of the wire are mentioned as being a determining factor in the temperature-rise. It should be clearly pointed out that for continuous ratings of wires freely suspended in still air the watts per square inch increase as the diameter of the wire decreases, for a given temperature-rise. The same holds good for wires carrying current under oil. When the wire is wound on an earthenware or other support, the latter, being in contact with the wire, conducts some of the heat away to other parts of the insulator and the surface of the support becomes an additional radiating surface and, while this to a certain extent complicates matters, similar results are obtained as with the wires freely suspended in air. For short ratings where the resistance units are not wound on supports and the whole of the material is active, provided that the continuous ratings of the material are known for a number of temperature-rises, the short ratings can be fairly accurately calculated from the formula

$$T_t = T_f (1 - e^{-Wt/K})$$

where T_t = the temperature-rise after t seconds;
T_f = the temperature-rise if left on continuously with the same load in watts on the unit;
e = the base of Napierian logarithms;
W = the watts lost per degree C. rise above the ambient air, due to radiation and conduction; and
K = the watt-seconds to heat the body 1 degree C.

When the wire is wound on a support the conduction of heat by the support complicates matters and renders a series of tests necessary, although for short ratings up to 10 seconds it has been found that the effect of the porcelain is very small and that sufficiently accurate results are obtained by calculations based on the thermal capacity of the wire itself. Most of the heat tests in the paper appear to have been taken with the help of a thermometer for measuring the temperature-rise, and it is suggested that in many cases a thermometer gives unreliable results. Some tests of this nature were recently carried out on units somewhat similar to those mentioned in the paper and the temperature-rise was measured by thermometer and also by the resistance method. For the purpose of this latter test the units were wound with copper wire and the input measured by a wattmeter and kept constant by means of a series regulator giving fine adjustment. The resistance of the unit was obtained from readings of a voltmeter and ammeter connected in the circuit. It was found that, although the resistance method gave only mean temperatures and the thermometer was placed in what had been found to be the hottest point of the unit, for short ratings the thermometer readings were much lower than the temperature-rises measured by the other method and were not consistent; even with continuous ratings, although the readings did agree rather more nearly, the differences that were found to exist were not consistent. The curves given in Fig. 11 are most interesting, but it must not be taken as a general rule that to mount resistance units in tiers does not affect their rating. Tests taken at the Metropolitan-Vickers works some few years ago on resistance frames mounted one on top of the other gave a considerable difference in the temperature-rises in the different tiers. It was found that with four frames mounted in this way, to obtain the same temperature-rise on each of the banks the watts per grid had to vary from 120 for the bottom row to 112 for the second, 106 for the third, and 100 for the top row. Providing the mounting is such that the air can freely rise through all the tiers, it appears that the upper banks must be surrounded by air heated up to a certain extent by the lower ones, and therefore for the same temperature-rise they must be able to dissipate less heat.

Mr. F. P. Sexton (*communicated*): The early part of Mr. Wilson's paper does not make it clear whether by "surface resistance" (see page 200) is meant an actual surface resistance or the E.M.F. due to contact of metal and liquid. If the latter, the author is in error, for the contact E.M.F. has been repeatedly determined. The curve shown in Fig. 4 does not prove this point, for if the potential difference is given by an expression $E = I(R_1 + R_2)$ it can be seen that the curve will be linear whether the value of R_1 be zero or some other value, since the current I was kept constant. Here R_1 is taken as the resistance additional to that of the liquid. The same remark applies to the expression $E = 2e + Irl$, where E is the E.M.F. over the liquid resistance, $2e$ the total contact difference of potential over the electrodes, r the resistance per unit length, l the length, and I the current. This equation should give the potential over the resistance for any condition, and would certainly be linear. Hence there is no reason why the difference of potential of 3 volts shown in Fig. 4 should not be due to a surface resistance or contact potential, or both, and not entirely to resistance of the leads as stated. I have no figures for the iron-sodium chloride solution E.M.F., but it would be from 0·25 to 0·6 volt or in that neighbourhood and hence not sufficient to account for the whole potential difference observed. Taking the figures from the curve of 18 volts per inch length and with a current density of 540 amperes per sq. ft., the conductivity is 0·68 ohm per cm³. This value can be compared with the value given by Kohlrausch and Grotrican in 1875, as

$$\lambda_0 = 0\cdot0412 \times 10^{-9} (1 + 2\cdot95 \times 10^{-2}\,\theta + 8\cdot6 \times 10^{-5}\,\theta^2)$$

or at 18° C. this becomes $0\cdot0671 \times 10^{-9}$ in mhos per cm for a 5 per cent solution. The difference is in a large measure due to the temperature of the author's electrolyte, which is unfortunately not given.

Mr. J. Anderson (*in reply*): With reference to Mr. Slater's remarks, the air compressor figure given in Table 2 was obtained from tests on two 150-h.p. compressors fitted with a by-pass, but the exact arrangement was not noted. A thermometer should give sufficiently accurate results for continuous-rating tests extending over 6 hours, as in the case of those described in the paper. Table 6 was intended to show the effect of unequal tap voltage in giving an average torque which is in excess of the torque to be expected from the lowest tap voltage. Thus, if the three taps are 0·5, 0·5 and 0·5, the torque is 25 per cent; but if they are 0·5, 0·6 and 0·75, the torque is 34·8 per cent, which is very nearly equal to the 36 per cent obtained with three taps of 0·6, 0·6 and 0·6.

I agree with Mr. Hastings that the current relay is preferable for general use and this opinion is indicated in the first two paragraphs on page 628 of the paper. As regards "eddy-current starters," I agree that more rapid reversals can be obtained with resistance control. Mr. Hastings mentions the apparent confusion between starters and controllers, but any starter may be used as a controller if operated improperly, and this possibility of improper operation has to be kept in mind and allowed for as far as practicable.

Mr. Langrish refers to the formula on page 628. The value of K is generally 0·5, but there are starting conditions where it has another value, hence the use of the qualifying phrase to which he objects. The minimum effective accelerating torque is 56·6 per cent as Mr. Langrish states, and the figure of 8·3 per cent is the average of the saw teeth, making the average effective accelerating torque 64·9 per cent as given in the paper. Mr. Langrish also refers to the heating of wires in air. The temperature-rise should be proportioned to i^2/d^3, where i is the current and d is the diameter of the wire. Actually the ratio is more nearly $i^{1\cdot 4}/d^{1\cdot 95}$. This means that a small wire is more effective than a large one in dissipating energy. When wires are wound on stoneware cylinders they behave as if they were flat strips of equal width and varying thickness, and the dissipation in watts per cylinder for a given temperature is nearly constant throughout a large range. As the heating periods get shorter the effect of the support decreases, but even for heating periods of 15 seconds it is still considerable. It is very difficult to determine the influence of the support for short ratings on continued cycles of heating and cooling.

Mr. W. Wilson (*in reply*): A number of speakers in the discussion have amplified portions of my paper and have contributed additional information, which I have found very interesting and for which I am grateful.

The curves in Fig. 14 (page 209) were intended to include the various substances commonly used as electrolytes. To these Mr. Slater has added two, potash alum and potassium bichromate, neither of which I had previously encountered. The latter I should regard as too poisonous and corrosive for safe use; but the former should form a satisfactory electrolyte lacking the corrosive effects of common salt on iron, and of washing soda on insulating materials. I have already made a preliminary test upon this substance, and find it performs quite well. Its conductivity curve lies just below that of washing soda in Fig. 14.

Mr. Brazil has proposed the use of carbon powder instead of a liquid, and it certainly seems likely that a practicable and useful piece of apparatus could be designed on these lines. One objection would appear to be the combustible nature of carbon, and another its mechanical resistance to the insertion of any but edge-wise or pointed-rod conductors. I hope, however, to make up and test a rheostat of this form in the near future.

The expression "surface resistance" was taken from an article on liquid rheostat design, in which the statement was made that "the surface contact resistance is the governing factor, for the same electrode surface passes practically the same current, whether the plates are 5 or 50 feet apart." Without seeking to define the exact meaning of this, I carried out the test on page 200 in order to test the statement generally. If it were true, the curve obtained should have been a line nearly parallel with the co-ordinate representing the spacing. If, on the other hand, the curve not only were rectilinear but passed nearly through the origin, then it could be assumed that the component in question, whatever it might consist of, was negligible. The temperature of the liquid in Fig. 3 was not permanently recorded, but was maintained constant at a definite point somewhere between 70° and 80° F.

With regard to unequal heating of the liquid in the dipper pattern, shown in Figs. 6 and 7, there is no doubt that this occurs to some extent; but in an apparatus of this shape and construction the temperature is quickly equalized by conduction through the water and the metal during the period of rest following the starting operation. The "jump" in voltage when final contact is made between the plates is frequently mentioned as a prevalent defect of the apparatus. I have availed myself of the extensive organization of an electrical firm to check this allegation, besides drawing upon my own experience. The result has been to discover not a single case where this "jump" has not been due directly to the use of too weak an electrolyte, and has not been immediately removed by making up the solution to the correct strength. The type shown in Fig. 10 is an especially favourable design in this respect, as the resistance, and therefore the voltage-drop at a given current, vary directly with the spacing. Thus the voltage drop at $\frac{1}{8}$-inch spacing will be 1/160 of that at 20 inches, provided the resistance of the solution permits the normal motor current to flow at the beginning of the operation. It will be seen that this fraction leaves no room for any appreciable jump in voltage, and therefore jumps in current and speed are alike put out of court.

In reply to Mr. Carter, the specific heat of solutions below about 10 per cent is very little less than unity, and they were assumed to have this value in my calculations. To give an actual example, however, the specific heat of a 10 per cent solution of washing soda is about 0·98. I agree with this speaker's comments regarding instructions for making up the electrolyte. In addition to lack of clearness to the untrained person, there is some ambiguity in the percentage rule, since a 10 per cent solution may be made by weight or by volume. In the former the solution contains one part of solid to only nine parts of liquid, while it is practically one to ten if made up by volume of liquid, and it will therefore be seen that there is a possibility of appreciable error if instructions are not made precise. In making up the solutions for Fig. 14, it was borne in mind that the cubical contents of a rheostat tank are known, and that the most convenient method of mixing the electrolyte would be to insert the requisite weight of solid, in the form of a strong solution, before the tank is full. Water would then be added to fill the tank to the standard height. Thus 10 per cent in Fig. 14 means one pound in every gallon of the resultant solution.

The above may explain some of the discrepancy observed by Mr. Blaikie between Fig. 14 and the curves reproduced in various handbooks. The latter curves

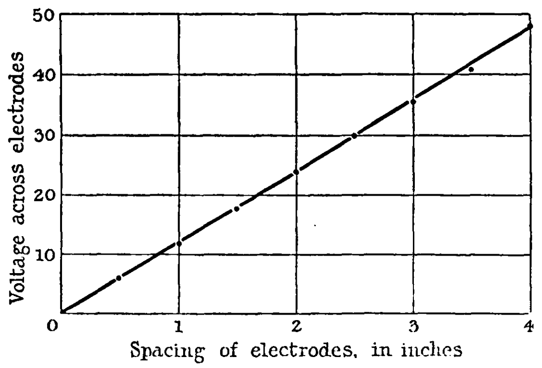

FIG. A.—Curve showing variation of potential with spacing.

are apparently obtained by calculation, the percentages being arrived at by weight, the various chemicals being pure, and the resistances derived in the first place by bridge measurements. My curves were obtained in an actual rheostat specially made for this test, by measuring the current and fall of potential due to the passage of an alternating current at 50 periods and the ordinary commercial chemicals were used throughout. Thus, practical conditions have been reproduced, and the results should be those required for practical purposes. I have dealt with the effect of surface action in my remarks on page 215.

Mr. Ayres has apparently been unable to discriminate between criticism and condemnation. His reference to the ball-bearings and knife-edges employed to minimize that portion of the sluggishness due to friction would seem to indicate that the "fallacy" is rather an urgent truth. He has quoted an assortment of data to prove that in a particular case the dippers could follow the load at the necessary speed; but it should be remembered that, whereas the load may be imposed suddenly, the "necessary" speed can be attained only after a number of usually heavy parts have been accelerated from rest by the usually small torque available. A capable designer will so proportion these factors as to reduce the effect of the inertia, and load curves are available recording considerable success in this direction. This does not, however, absolve the liquid slip-regulator in general from the imputation of sluggishness, in comparison with the statical resistor, the action of which must always be instantaneous.

Considerable importance having been attached to the curve in Fig. 4 by two speakers, I have repeated this test, employing a 5 per cent solution of common salt, at a temperature of 65° F., and a current density of 279 amperes per square foot at 50 periods per second. The resultant curve is given in Fig. A, the various readings being indicated by points on the diagram. There is very little room for doubt as to its passing through the origin, indicating that even the small contact potential mentioned by one speaker was absent. I had originally expected this, for it will be remembered that Kohlrausch employed what was practically the equivalent of this apparatus for measuring the resistance of electrolytes, as he found that, within certain limits, the E.M.F. of polarization is proportional to the quantity of electricity which has passed through the cell. The quantity being very small in the case of an alternating current, it would be expected that the E.M.F. of polarization would also be small compared with the steady value. The above test shows this to be the case.

NORTH-EASTERN CENTRE, AT NEWCASTLE, 27 FEBRUARY, 1922.

Mr. J. Schuil: Mr. Anderson has certainly succeeded in proving that the production of a good starter involves much study and design on sound principles. Referring to liquid starters and their smooth acceleration, I would mention the special resistance that I patented and brought out for Messrs. A. Reyrolle & Co., on the "wait on the first step until the motor starts" arrangement. This principle has very many advantages and is still occasionally asked for. Owing to the negative temperature effect of the carbon powder there is a current-growing characteristic which causes the motor to start at any reasonable load on the first contact, leaving the remaining studs for cutting out the resistance. In America, large starters are made with carbon plates under variable compression. The particulars of the test on resistance units mounted vertically are misleading; they may be true of a set of units in the open, but when in actual working condition with several side by side the top units get hotter than the bottom ones. The resistance now made by my firm consists of a unit which combines great storage capacity with quick heat-radiating effects. This is effected by clamping the resistance units between steel radiating plates. It makes an ideal resistance for ordinary starters, as there are no loose wires. I am very interested in the information given with regard to blow-outs. It has been my opinion for years that blow-outs on starters and controllers should not be of the series-wound but of the shunt-wound type, and I should be glad to have the author's opinion on this point. Messrs. Schuil produce a controller which includes a mono-break blow-out, where all the making and breaking is done on one set of contacts under a very heavy blow-out. Also, in a special, small starter the blow-out magnet is used as a hold-on magnet, with very satisfactory results.

With regard to liquid starters, there would appear to be little need of pushing the current density of the plates to anything like the figures mentioned by Mr. Wilson, as in most cases the size is practically settled by the heat-storing capacity of the liquid—so that allowing, say, 16 h.p. per gallon, the size of the starter is easily fixed by the cubic contents, and the plates may be as large as convenient. There seems to be some trouble in preventing the short-circuiting jump with some liquid starters. In both Mr. Anderson's and Mr. Wilson's papers many particulars of loads for special starters are given, but for ordinary design it is more useful to make a standard line of starters which will deal with ordinary requirements and give a reasonably cheap article. It is almost impossible to get a better price for a better article. The majority of orders are obtained on price only—especially when bought through trade, but, fortunately, good design tells in the end. In the standard designs it is usual now to calculate ratings by the B.E.A.M.A. rules, although for heavy duty special ratings are required.

Mr. G. G. Mallinson: A difficulty perhaps not generally recognized with starting switchgear lies in the difference in treatment by the user. Gear that gives every satisfaction with the skilled user gives nothing but trouble under the rough treatment which it receives in steel-works and shipyards. For the latter and for marine work, simplicity and robustness should be attained. Terminal and clamping screws should be large and easily accessible under the ironclad covers. Cast grid resistances have not given satisfaction, although if cast of the proper metal some have given good service. Often, however, resistances have been sent out with brittle metal, and these soon break, especially when used on a vibrating structure. A type of resistance in which the resistance element is embedded in some form of clay has often been used. This is not satisfactory, as the resistance varies with the amount of moisture in the air. If such a resistance is incorporated in apparatus controlling a creeping motion, the creep will vary considerably from day to day. A centre stop should always be provided for crane controllers, etc., and should be of a pattern that requires another hand to free as the controller handle is brought to the zero position. This avoids the violent switching-over from full speed in one direction to reverse. Most crane men try to do this when desiring a rapid stop and, naturally, electrical gear suffers. If properly designed and constructed automatic gear may be the best for practically all purposes. Control pushes or switches should, however, be double-pole. Voltage relay-operated gear has not given satisfaction in use. Starter makers have doubtless been handicapped by insufficient information from the user or from the motor manufacturer. On the other hand, however, in many cases insufficient notice has been taken of the sort of work to which the starter would be put. In this, closer co-operation than has obtained in the past is now being attained.

Mr. A. B. Johnstone (*communicated*): At the end of the paragraph dealing with the inertia of the moving parts of a slip-regulator, at the top of page 207 the statement is made that "Many loads, such as those in a rolling mill, cease abruptly, and the reverse action of the torque motor then becomes unimportant." Surely this view is incorrect. In the case of a large reversing mill with Ilgner set and Ward-Leonard control, as soon as the load goes off the d.c. motor at the end of a pass it is most important that as much flywheel energy as possible should be replenished in the short interval between passes. Obviously, therefore, unless the slip-regulator resistance is reduced quickly on a fall of load, the speeding-up of the flywheel set to an appreciable extent cannot possibly be accomplished before the next pass is commenced. This speeding-up action is especially important on the last two or three passes of a section-finishing mill. Such passes are long and in many cases the available flywheel energy is spent long before the end of the pass, although apart from the energy required for acceleration of the d.c. mill motor and rolls, the rolling load is comparatively light—a sustained light load in contrast to the heavier loads of short duration which are characteristic of the earlier passes. When we consider the energy required to speed up a 65-ton armature 10 ft. 6 in. in diameter, together with pinions and 36 in. diameter rolls, to 120 r.p.m. in 5 seconds or less, it will be realized that such energy constitutes a heavy peak load on the flywheel set and it is important, therefore, that the flywheels should be able to cope with this acceleration demand as far as possible. I find, from load curves taken during the rolling of several different sections, that the average time between passes from start to finish of rolling of one piece is about 5 seconds, and from this fact alone the need for extreme rapidity in reducing the slip-regulator's resistance the moment the d.c. load falls, is self-evident.

Mr. J. Anderson (*in reply*): With reference to Mr. Schuil's remarks, the use of a shunt or a series blow-out depends entirely on the conditions to be met. A circuit breaker which has to interrupt overloads of almost any value must have a series blow-out because the field increases with the severity of the short-circuit. A starter or controller has, however, to deal with anything from light load to full load, and a shunt blow-out is therefore the proper method as this gives a field of sufficient strength with only small load currents.

Mr. W. Wilson (*in reply*): The principal object of my paper on liquid rheostats has been to determine, to as full an extent as possible, the characteristics of the various components involved in the apparatus, and more especially the behaviour of the liquid itself under every condition likely to arise in practice. Although, as Mr. Schuil has indicated, in the usual type of liquid rheostat employed at the present time for merely ordinary purposes, there may be little need for using anything like the highest current densities reached in my tests, nevertheless there are many reasons why these figures are of importance. To begin with, it is advisable to know, with a view to contingencies of various descriptions, how an apparatus is likely to function for conditions considerably beyond its projected range, and especially what is the limit beyond which no further increase is justifiable, and what are the consequences if that limit be passed. Again, while the " 16 h.p. per gallon " rule may be considered to be satisfactory by those concerned with stationary loads of moderate amount, yet the designer of, say, a 3 000-h.p. electric locomotive may not feel disposed to provide space and carrying capacity for the number of gallons demanded by this relation if the purpose can be served with less. A similar example was given by a speaker in the Birmingham discussion, who described a liquid rheostat for the regulation of motors for marine propulsion, employing a current density of as much as 3 200 amperes per square inch (see page 213). Even for ordinary purposes it is by no means certain that the design will remain in its present state for an indefinite period, and further development may well call for higher densities. I am afraid that I do not quite follow Mr. Schuil's argument *re* standard lines, prices and design. The examples which I have described include a complete range of standard starters for ordinary working, and this seems to be what Mr. Schuil is advocating ; but it is surely asking rather too much to require the control of all motors, engaged upon all species of loadings, to be effected by a standard apparatus, more especially as controllers for 10 000- or 30 000-h.p. motors hardly call for quantity production as yet.

I quite agree with what Mr. Johnstone has said regarding the advisability of losing no time in re-accelerating the flywheel of an Ilgner set. The statement in the paper that the reverse action of the torque motor was unimportant referred only to its effect upon the particular cycle under consideration. If the load ceases abruptly, the regulator will return to the off position in the same time whatever its setting, and the latter then becomes unimportant for the reverse action of the torque motor. Mr. Johnstone's data graphically enforce the necessity of reducing to the smallest possible amount sluggishness in the slip regulator.