

ALTERNATING CURRENTS AND FUSES.

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This paper is a report of an investigation made by Mr. Ochsner in the electrical engineering laboratory of the University of Wisconsin. The results are positive, and of sufficient practical value to justify consideration. They set at rest all questions regarding the direct effect of the alternating current upon the average commercial fuse wire. Practically speaking, there is no such action. Mr. Ochsner's report is as follows:

The following work was undertaken with a view to studying the disintegrating effect of alternating currents on fuse metals which has been reported, and, if possible, ascertaining the cause. As the work done at Cornell University¹ last year showed such a remarkable rise of resistance, and a lowering of the fusing points of the fuses placed on the alternating circuits, I decided to repeat the experiments, and if any change in the resistances should take place to prolong them.

1.—THE EFFECT OF ALTERNATING CURRENTS ON THE RESISTANCE OF FUSES.

Samples of fuse wire of five amperes rated capacity were obtained from five different manufacturers, and to these were added a 30-ampere fuse wire which we happened to have, and a copper, a german silver, and an iron wire. Pieces of wire from each sample, each of them varying from nine to ten feet in length, were wound upon cylindrical pieces of pine wood about a foot long and one and one-half inches in diameter. The table

1. "The Action of Continuous and Alternating Currents on Fuse Metals," by C. P. Matthews; TRANSACTIONS, vol. x, p. 251.

below gives the names of the firms from which the samples were obtained and their rated capacities.

	Rated Capacity.
Ansonia Electric Co. (Wirt fuse wire)	30
Shawmut Fuse Wire Co. (two samples)	5
The Independent Electric Co.	5
Peru Electric Manufacturing Co.	5
The E. S. Greeley & Co.	5
Taylor, Dee & Mack	5
Iron wire	
German silver wire	
Copper wire	

To prevent the turns of wire from crowding together on the cylinders, thus causing short-circuits ; short, helical grooves were made with a file. To the end of each fuse, short pieces of heavy copper wire were soldered, and the joints were wiped with a damp cloth. These terminals were fastened to the wood by light staples, and the ends were amalgamated.

A simple rack was constructed so that all the fuses could be put in series, the copper terminals dipping into mercury cups.

The resistances were determined by means of the Anthony bridge in the laboratory of the University of Wisconsin, the readings being taken to the fourth decimal place. Connections were made by dipping the copper terminals of the fuses into mercury cups, and using short, heavy copper wires for leads. A dead-beat galvanometer was used, and in this way it was possible to do the work in about twenty minutes. As it was impossible to keep the laboratory at a constant temperature it was necessary to make temperature corrections, and, therefore, to determine the temperature coefficients of all the samples. It was, however, possible to keep the temperature within a few degrees of 20° centigrade, which I considered the standard temperature, and to which I reduced all my results.

Therefore it was thought sufficiently accurate to determine the coefficients in the following way, a small error in the coefficient introducing only a slight error for a correction of a few degrees. On one occasion the room was allowed to cool to the outdoor temperature and the resistances were measured, and the next day the room was heated as high as possible, and the resistances were again measured. A range of about 16 degrees centigrade was obtained. The average rise of resistances for one degree, and the coefficients, were then calculated.

The bridge has a temperature coil, from the resistance of which the temperature of the bridge coils is quickly found. The temperature coefficient of the bridge coils is only .00023, and, therefore, the corrections for them can be made very accurately. The rise of resistance for one degree centigrade and the coefficients, together with the data from which they were obtained are given in the following table, in which t is the higher temperature, t_1 the temperature of the bridge coils, and R the measured resistance corresponding. Similarly the letters marked with a prime correspond to the lower temperature.

No.	t	t_1	R	t'	t'_1	R'	Ri e for 1° C.	Coeff.
1	23.2	22.8	.4794	7.26	10	.4505	.00190	.00400
2	"	"	.858	"	10	.0813	.00364	.00357
3	"	"	1.3025	"	10	1.2354	.00444	.00344
4	"	"	.8273	"	9.9	.78 6	.00301	.00368
5	"	"	.980	"	9.9	.9259	.00357	.00368
6	"	"	.8683	"	9.9	.8209	.00313	.00364
7	"	"	.9701	"	9.9	.9107	.00390	.00406
8	"	"	.2184	"	9.8	.2001	.00119	.00535
9	"	"	.8309	"	9.8	.8302	.00020	.00024
10	"	"	.4792	"	9.8	.4503	.00190	.00401

The fuses were now put on the alternating lighting circuit which furnishes the light for the laboratory. Enough resistance was put in series to give a current of about three amperes. The pressure is 110 volts, and the frequency, approximately, 125. The lighting circuit is run continuously, except for about nine hours on Sundays; but to have a check on the time that the fuses were subjected to the current, a Thomson recording wattmeter was placed in circuit.

The resistances of the fuses were measured at fairly regular intervals, and the corrected results were plotted.

The following table is a sample of one measurement. The resistance of the temperature coil was considered to vary uniformly during the test.

No.	Temp.	Resis. Temp. Coil.	Resis. Leads.	Resistance.
1	20.30	267.2	.00322	.4785
2	20.30	....	.....	.0883
3	20.35	..	.. ..	1.2950
4	20.38	.....	.....	.8221
5	20.40	.....	.....	.9754
6	20.44	.....	.....	.8643
7	20.56	.....	.....	.9647
8	20 60	.....	.....	.2190
9	20.60	267.4	.00320	.8347

Average = .00321.

While making the ninth measurement, I noticed that touching the fuses with the hands caused a decided increase in the resistance, and upon investigation it was found that a rise of

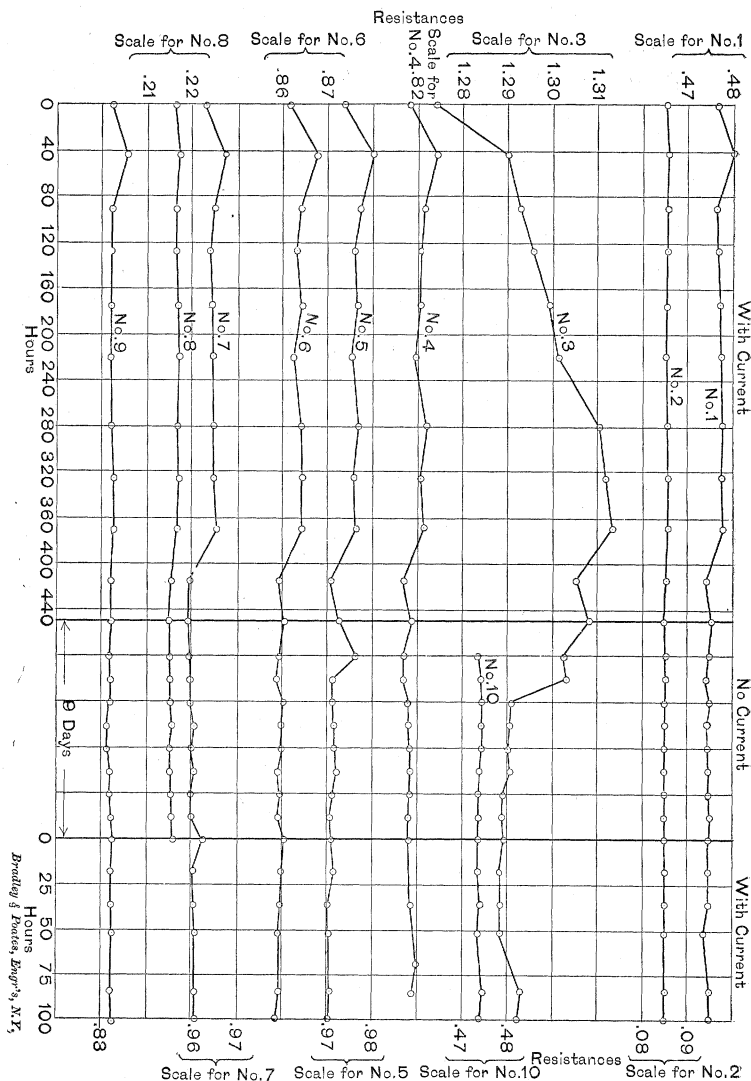


FIG. 1.—Changes in resistance of fuse wires, subjected to the action of alternating currents.

over one per cent. resulted from the heating of the fuses when holding them firmly with one hand. After that discovery they were handled with greater care, and a drop which is noticeable

in the curves was the result. The heating effect of the bridge battery, although very small, was also found sufficient to introduce a slight error, but by depressing the keys only for an instant, the error was rendered negligible. A little later I dis-

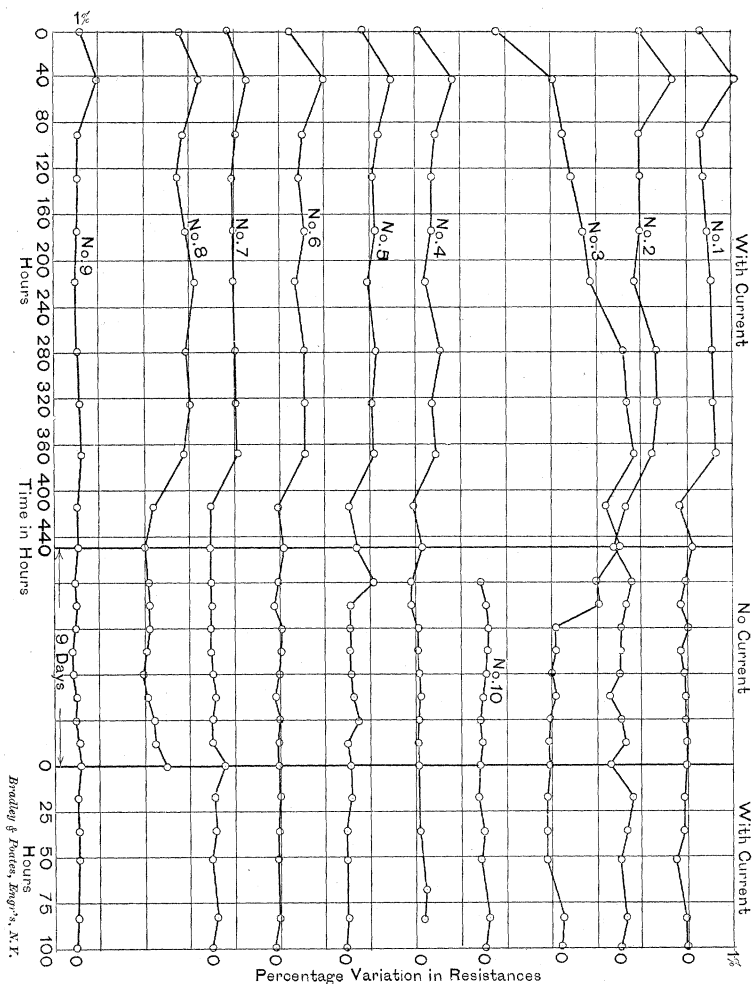


FIG. 2.—Percentage variations in the resistance of fuse wires subjected to the action of alternating current, vertical scale, 1 division equals 1 per cent.

covered that the indications of the thermometer which was hung near the fuses did not, by any means, represent the true temperature of the fuses. They had been heated by the alternating current to about 50° centigrade, and had not been given suffi-

cient time to cool down to the temperature of the room, the pine wood retaining the heat for a considerable period. It was therefore decided not to pass any current through the fuse for some time, but to measure the resistance, as before, from day to day, being very careful in getting the temperatures accurately; but in the latter I was not entirely successful. It was found practically impossible to get the temperature of the fuses correct within a few tenths of a degree, because the temperature of the room would vary in spite of all care, and the fuses would not follow this variation so rapidly as the thermometer indicated it. Nevertheless, far better results were obtained than before.

The result of this part of the work is shown by the curves, Figs. 1 and 2, between the two heavy vertical lines.

After this, the fuses were again subjected to the alternating current for about 100 hours, measurements of resistance being made daily. Each day, as the current was turned off, they were cooled down rapidly by taking them into a cold room, and leaving them for some time, after which they were brought back to the working room and allowed to stand for about five or six hours before measuring the resistances. The results are shown by the last part of the curves. As fuse No. 3 seemed to show greater irregularity than the others, another piece of the same sample was added. It is the one numbered 10, and the curve is plotted directly under No. 3 for comparison.

From the fourteenth point on, the curves are all practically straight horizontal lines, the irregularities being about the same when no current passed, as when it did. Nearly all the points on the curves before the fourteenth were considerably higher. This shows plainly that the fuses had not cooled down to the temperature of the room when the resistance measurements were made, the variations depending on the length of time they were allowed to stand. Considering the average values of the last parts of the curves to represent the true resistances, the greatest variation was 1.8 per cent. in the case of No. 3, and even this is not too large to be explained by the above errors. In proof of this, I measured the resistance of one fuse immediately after turning off the current, and also 15, 20, 35 and 50 minutes later, and found the errors to be respectively 8 per cent., 6.2 per cent., 3 per cent., 2.3 per cent. and 1 per cent.

That the first point on each curve is nearly as low as the final values, is due to the fact that current had not been passing

through the fuses before that measurement was made, and the fuses were, therefore, at the temperature of the surrounding air which was recovered by the thermometer. Another proof that the variations are due to temperature is shown by curve No. 9. This represents a wire which has a very small temperature coefficient, and accordingly, it varies the least of any. While the actual rise in curve No. 3 is much greater than in any of the others, the percentage rise is only slightly greater, the resistance of the fuse being the largest of all.

These experiments prove that there is no appreciable rise of resistance in fuses subjected to alternating currents, at least not within a period of 550 hours. More accurate results might undoubtedly have been obtained, had the fuses been mounted in such a manner as to avoid contact with any large masses of solid material, but the accuracy is amply sufficient to prove the case.

These results are diametrically opposed to those given in the report of similar work, published in the *TRANSACTIONS*, vol. x, p. 262 already referred to. While in the latter investigations, corrections were made for the standard resistance with which the fuses were compared, no such corrections were made for the fuse wires. The fuses were subjected to larger currents than in my tests, with consequent greater heating. The resistances were apparently measured without allowing sufficient time for the fuses to acquire the temperature of the room, and even if this was done, the variation in temperature of the room as given in the original report of the investigation (which Mr. C. P. Matthews, Instructor at Cornell University, kindly sent me) was sufficient to introduce serious errors. The resistances were measured by the fall of potential method. According to the drawing, showing the arrangement of the apparatus, no extra resistance is put in series with the battery to reduce the current strength. This current may have been sufficiently great, in the smaller sized fuses at least, to cause considerable heating. For these and other reasons relating to the accuracy of the tables, I think that this part of the work reported by Mr. Matthews is not to be relied upon, and, therefore, the conclusions based upon it are of no value.

2. THE EFFECT OF ALTERNATING CURRENTS ON THE FUSING POINTS.

Next the fusing points before and after passage of current were determined. As the continuous current from the dynamo which was available was too variable, I was obliged to use a few storage cells for fusing the wires.

A small, sensitive resistance which could be varied slowly was needed. A long german silver wire, stretched tightly, with a good spring clamp for a sliding contact, was found to serve admirably.

Six-inch lengths of the fuses were soldered to short, heavy copper wire terminals, the ends of which were amalgamated and dipped into mercury cups in making connections. The fuse, variable resistance, storage battery, and a Weston ammeter reading from 0 to 15 amperes, were placed in series. As the current approached the fusing point it was varied very slowly and gradually, giving it ample time to heat the fuse. Only the five ampere wires were tested. A number of pieces of each of these were tested; half of these had been subjected to the alternating current, and half had not. I shall call these the "old" and the "new" samples respectively. Pieces of the old and the new of each sample were tested alternately so as to eliminate the errors caused by a change in the temperature of the room. The results are given in the following tables:

FUSING CURRENTS.

Nos. 3 and 10 New.	No. 3 Old.	No. 10 Old.
7.40 7.30 6.98 7.19 7.30	7.25 7.10 7.10 7.09 6.80	7.30 7.29 7.10 7.20 7.05
Average, 7.23	7.07	7.188
	Lowered 2.22 per cent.	Lowered .58 per cent.

No. 4.		No. 5.		No. 6.		No. 7.	
New	Old	New	Old	New	Old	New	Old
8.75	8.50	8.90	8.82	8.85	8.80	8.80	9.07
8.83	8.60	8.97	8.84	8.69	8.69	8.96	9.06
8.80	8.60	8.20	9.12	8.87	8.88	8.90	9.02
8.70	8.70	9.20	8.88	8.78	8.98	8.80	9.05
8.76	8.65	8.95	8.88	8.75	8.98	8.90	9.10
8.70	8.70	9.10	8.97	8.60	8.80	9.06	8.85
8.62	8.64	9.06	8.70	8.75	8.74	9.10	8.95
8.71	8.64	9.08	8.80	8.50	8.70	8.78	9.10
8.50	8.64	8.93	8.79	8.95	8.95	8.66	8.80
8.88	8.65	9.09	8.83	8.77	8.90	8.90	9.12
Average 8.725	8.632	8.941	8.863	8.743	8.842	8.895	9.012
Lowered 1.07 per cent.		Lowered .87 per cent.		Rise of 1.13 per cent.		Rise of 1.32 per cent.	

Four of these samples show a slight lowering, while two show a slight rise in the fusing point, but the differences are of the same order as the differences between individual test pieces. While a test of only a comparatively small number of fuses in this way hardly establishes the correctness of the results, a slight change in the fusing points probably did take place, as is shown by the fair uniformity of the figures in each sample.

That such slight change as did occur was due to oxidation there is also little doubt, for all of the old fuses showed slight oxidation, and the effect is too small to be of practical moment.

As to the results in the earlier investigation already referred to [TRANS. Vol. x, p. 65.] on the fusing points, only the averages are given, and no mention is made of temperature; therefore it is impossible to properly judge of their accuracy. As far as can be determined from the original report, however, the tests do not seem to be any more reliable than the resistance tests.

Sir David Salomons in the discussion of a paper, by Mr. A. C. Cockburn, read before the Society of Telegraph Engineers and Electricians in 1886, stated that fuses alter in two ways with time. Most of the metals, especially alloys, according to Alexander Siemens, being subject to slight oxidation, which lowers the fusing point.

Dr. Salomons' own experience, he says, was rather the other way, the fusing point being raised with long use.

Mr. Cockburn had the same experience. Mr. Matthews also states that the formation of oxides in the case of tin, and the tin

and lead alloys, may delay the fusion almost indefinitely, while the oxidation of copper and iron wire seems to favor its prompt fusion.

3. CONCLUSIONS.

In the light of the experiments herein described, and the statements made by Cockburn, Salomons, and Matthews, is it necessary to ascribe a slight change in the properties of the fuse to the disintegrating effect of the alternating current? I think not.

In practice, a fuse is seldom obliged to carry a current equal to its full rated capacity. In electric lighting, for instance, the lamps protected by a fuse are not likely to be all turned on at once, and therefore the fuse is seldom carrying more than a small part of its rated capacity. The experiments that I have made, therefore, represent the conditions of ordinary practice and prove that a fuse as used in practice is not directly affected by the alternating currents.

Fuses on alternating current circuits are sometimes found to blow without apparent reason, but something outside of the disintegrating effect of the current is the cause. Under some conditions, the result has come about through the mechanical shaking to which an alternating current fuse is sometimes subjected when not tightly clamped by the terminal screws.

DISCUSSION.

DR. LEONARD WALDO:—Papers of this class would have a very much higher value if they were accompanied by an analysis of the metals that were used. The theory underlying such a paper is this:—that the fuse wire is made up of homogeneous material like a copper conductor. Nothing can be further from the truth. A fuse wire as usually made, consists of two or more metals which have very little affinity for each other, which have low melting points, and which under the repeated action of a heating-to-softness current simply shift the position of the relative metals. Any theories based on the resistance of the metal, must take into account the actual condition of the metal as the heating current is sent through it. I think the literature of fuse metals is in a very imperfect state, and if we are to have a theoretically perfect metal for fuse purposes it must embody the condition of not changing the physical condition of the metals of which it is composed in the act of heating, and it must therefore be a homogeneous metal, of the quality of pure tin, or iron or steel, or of aluminium-bronze, for instance. The valuable qualities of fuse metal must depend upon using the minimum amount of energy to affect the heating to a melting point, and it is actually finishing

its existence as a continuous conductor at the point where the current becomes unsafe. I only wish to make the two points, that papers on fuse metals, should inform us of what the fuse metals were composed; and that the essential quality of a good fuse metal is that it should be homogeneous.

PROF. J. P. JACKSON:—I do not think the paper was intended to indicate what would be a good fuse metal. A few commercial samples of fuses were taken directly from the factory and careful tests made with as many corrections as possible. The tests were not as full as they should have been. Nevertheless they are quite accurate, and the results show a very even loss of resistance all through the period of the test of each fuse. They also show exceedingly small variation in the fusing points due to the effect of alternating current upon them. Of course if the fuse is not homogeneous—if it is made of cast iron or some such metal—the alternating current may possibly rack or crystallize it. In this case it will be affected. But on the commercial fuses under consideration—and I put stress on the word commercial, because the paper is given to show what the practical effect is on such fuses, without going into the chemical theory—on these commercial fuses the paper indicates that the effect of alternating currents is *not* injurious.

[COMMUNICATED BY SIR DAVID SALOMONS, OF LONDON.]

With regard to the remarks made in the paper on alternate currents and fuses, I will venture to give my experience with fuses since the time referred to, now many years ago. I still find that the fuse wire is apt to alter, and that in no two samples of wire is the alteration in the same way; which is chiefly due to impurities in the metals. I am a great advocate for tin wire, since it is cheap and very good in practice. If a fuse is to be of service the whole time during which the current is passing, the wire will be raised to a very high temperature; and from an exhaustive series of experiments made on various metals and alloys kept at high temperatures and periodically cooled, I find that it becomes more or less crystalline or granular after a time. In this respect, I observe that the experience of others agrees with my own; also that, when the wire is in the crystalline or granular state, a larger current may be passed before it gives way than when the fuse was new. One of the chief reasons why the alternate current appears to alter the fuse wire more than the direct current does, is I think, the fact the variations in the E. M. F. with the alternate current system are greater than with the direct. Consequently, the variations in the temperature of the fuse wire with the alternate current is greater than with the direct.