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ELECTRICAL CHARACTERISTICS OF THE SUSPENSION INSULATOR-II

The Line Insulator at the Higher Voltages

BY F. W. PEEK, JR.

General Electric Co., Pittsfield, Mass.

IT is the purpose of this paper to review the duties of the line insulator at voltages above 100 kv. and compare them with the duties imposed by the lower voltages. It seems desirable to do this at the present time in order to predict the reliability of future high-voltage lines as compared with those at present in operation, and to point out what changes, if any, are necessary in present practise. The discussion is based in general upon data and operating experiences of many investigations and, in particular, upon extensive investigations made by the author during the last few years. Quite complete data on that phase of the author's investigation dealing with voltage distribution will be given.

PRESENT STATUS

At the present voltages the problem is primarily a mechanical one. Mechanically, porcelain would never be selected as a line support. It is unreliable in tension, subject to cracking, and if made in large pieces subject to porosity. The greatest care is necessary in manufacture to secure a uniform, tough, non-brittle material, free from porosity. Unfortunately it is the only material that we know of at the present time that will withstand the weather without the carbonization and deterioration of organic compounds under the electrical stress.

Generally after three to five years of more or less successful operation, insulators selected by the most careful electrical tests begin to fail rapidly. There are of course exceptions, but the experience is quite general and most operating companies anticipate breakdown by periodic tests designed to weed out faulty units.

The apparent deterioration of porcelain is generally due to one of the following causes:

1. Gradual mechanical cracking, due to expansion of cement or tight-fitting metal parts, or to internal firing strains or brittle porcelain.

2. Gradual absorption of moisture due to porosity.

The greater part of the trouble has been due to cracking under stresses caused by expansion of cement or of tight-fitting or cemented-in metal parts. Cracking may also be caused by uneven expansion in very thick porcelain parts of different shapes.

The foregoing causes of deterioration are well verified in practise, because the type of insulator in which the porcelain units are strung together by loose fitting metal parts or cables shows no deterioration after ten years or more of service. This was found to be so even when some of the earlier units were made of poor material. The absorption of moisture seems to be due to a considerable extent to breathing. The presence of a damp sponge of cement is thus also undesirable from this standpoint as it keeps moist the air breathed by the porcelain.

The solution of the deterioration problem seems to be to start with a design as free as possible from expansion troubles and the selection of a tough, non-porous porcelain. Years of service have been the best criterion of design. Regarding the selection of material, no present, practical electrical test will anticipate future cracking due to internal strains or brittle porcelain or will indicate porosity in dry porcelain. The desired results can probably best be attained by testing a small percentage of the product to destruction from day to day after the usual electrical and inspection tests have been made, the object being to determine if the product is up to the standard and of uniform quality. This idea is not new, but is used in the manufacture of lamps and in other industries. Electrical, mechanical and porosity uniformity tests are necessary. Extremely accurate tests are not necessary, but it is necessary to have tests that can be quickly made so that any fault can be at once detected and remedied.

In our investigation we made first the electrical

tests, followed by mechanical impact tests to destruction. Samples were then taken from the head and thick parts of the units and subjected to a porosity test. In this test the samples were placed in a dye solution under pressure, after which the depth of penetration was noted. The porcelain was placed in three arbitrary mechanical and porosity grades and a graphical chart made indicating the percentage in each grade as shown in Fig. 1. We found this method of great use not only in checking the product and comparing different materials, but also in studying deterioration of insulators in service.

FIG. 1—SAMPLE SHEET SHOWING METHOD OF PLOTTING ELECTRICAL, MECHANICAL AND POROSITY TESTS

INSULATORS FOR THE HIGHER VOLTAGES

The problem of deterioration discussed above is independent of the voltage. Its effect on operation should be less at the higher voltages because of the greater number of units used in a string. There are, however, certain factors unimportant at the lower voltages, which become of increasing importance as the voltage is increased.

Uneven Voltage Distribution. It has long been known that when insulators are placed in series in a string the

arc-over voltage is not the sum^m of the arc-over voltages of the individual units, but less. This is due to the uneven division of voltage on the different units. A

FIG. 2—TYPICAL VOLTAGE DISTRIBUTION CURVES ON STRINGS OF SUSPENSION INSULATORS

very high percentage is across the unit nearest the line. Typical curves are given in Fig. 2. Fig. 3 shows the percentage of the total voltage across each unit of a string of ten. Even distribution would put 10 per cent on each unit as indicated by the dotted line. It will be noted on examination of Fig. 2 that for strings over five units in length, there is always about 30 per cent of the total voltage across the insulator nearest the line. This will vary from 20 to 30 per cent with different types of insulators and with different hardware on the same type. The

FIG. 3—VOLTAGE DISTRIBUTION ON STRING OF TEN INSULATORS

FIG. 4—CAUSE OF UNEVEN DISTRIBUTION
The capacities to ground C_1 cause an uneven distribution of current through the insulator capacity C_2 .

importance of a consideration of this factor at the higher voltage is at once seen since the maximum unit stress increases directly with the voltage. At 100 kv. the operating stress on the line unit is 17.4 kv.; at 220 kv. it is 38 kv., which is higher than is desirable.¹ It is desirable to lower the operating stress on the units near the line.

FIG. 5—GRADING BY MAKING INTERNAL CAPACITY OF INSULATOR UNITS C_2 LARGE COMPARED TO THE CAPACITY TO GROUND C_1 .

A mathematical analysis of the cause of uneven distribution has already been given.² It seems best, however, to give here an elementary review of the causes of uneven distribution in order better to discuss the methods of remedying it.

A string of line insulators may be considered as being made up of a number of capacities in series. There is also capacity from the hardware and fittings

1. $\frac{220}{\sqrt{3}} \times 0.30 = 38$. In the case of a grounded line on a

system with isolated neutral this voltage would be $220 \times 0.30 = 66$ kv.

2. Peek, "Electrical Characteristics of the Suspension Insulator—I," A. I. E. E. TRANSACTIONS 1912, Vol. XXXI, page 907.

FIG. 6—GRADING BY CHANGING THE C_2 CAPACITIES IN PROPORTION TO THEIR RESPECTIVE CURRENTS

of each unit to ground. The capacity may be represented diagrammatically by Fig. 4. This arrangement

FIG. 7—GRADING OR SHIELDING BY ELIMINATING THE EFFECT OF THE CAPACITIES TO GROUND

is approximate, but suitable for the purpose of illustration.

It is at once apparent that the capacity currents cause unequal voltage distribution. If i is the total current through the first insulator, the capacity current through the second one from the line is $i - i_1$ where i_1 is the capacity current to ground; and third from the line $i - 2i_1$; the fourth $i - 3i_1$, etc. The current and, therefore, the drop is greatest on the line unit; the current decreases successively on each unit from the line by the current to ground of one unit. Correction of voltage distribution may be made by eliminating the effect of the ground current or the capacities to ground, C_1 .

This may be done by any one of the following methods:

FIG. 8—VOLTAGE DISTRIBUTION ON STRING OF TEN INSULATORS

1. Increasing all of the C_2 capacities without increasing the C_1 capacities so that the effect of the current to ground is relatively less. See Fig. 5.

2. Increasing the C_2 capacities of the insulators along the string in proportion to the currents flowing through them. This means highest C_2 capacity on the line unit, less on the next unit, etc. See Fig. 6—This is generally called grading.

3. Elimination of the ground capacities by means of an antenna shield from the line. See Fig. 7. This may be called shielding.

In order to get appreciable results by method 1, it is necessary to add capacities with solid insulation, or plates in intimate contact with the porcelain. Plates along the string will not help materially, as the percentage increase in the C_2 capacities will generally be smaller than the percentage increase in the C_1 capacities.

Method 2 is practical but it must be accomplished

by adding capacities with solid insulations. In practise it means the addition of metal caps or plates in intimate contact with the units, or varying the wall thickness of units, or placing a varying number of

FIG. 9—GRADING BY METAL CAPS

units in multiple along the string, or using different sizes of units. Very good results can be obtained by this method. Its undesirable feature is that it requires different kinds or sizes of units in the same string.

Figs. 8 and 9 show the voltage distribution in a string graded by placing different sizes of caps along the string.

Very good voltage distribution can be easily obtained by method 3. The ground capacities may be thought of as being due to grounded antenna extending along the string. The effect of this antenna may be eliminated by a similar antenna connected to the line and extending along the string as in Fig. 10. In practise

FIG. 10—SHIELDING BY ELIMINATING THE EFFECT OF THE CAPACITY TO GROUND

the antenna is the very simple shield shown in Fig. 11. The hardware shown in Fig. 11 is not standard but was selected for laboratory purposes to give the worst distribution. The shield readily corrects it. The maximum unit stress would be less on a 220-kv. shielded string than on present non-shielded strings operating successfully at 100 kv. and less. The distribution with and without the shield is shown in Fig. 12. A standard hardware giving better distribution with and without the shield is shown in Fig. 13.

This method requires no special units. The antenna

has an additional advantage of acting as a corona shield, eliminating corona from the string and tending to keep the power arc from the insulators and from burning the conductors. Even if the voltage were

FIG. 11—ANTENNA SHIELD FOR EQUALIZING VOLTAGE ON
INSULATORS
(Laboratory hardware)

evenly distributed a corona eliminating shield would be advisable at the higher voltages.

Heretofore the main argument given for equalizing voltage distribution has been to reduce the string length by increasing the arc-over voltage for a given

number of units. It is much more important to reduce the operating stress on the line-end units.

With certain types of units the wet arc-over voltage may be higher than the dry arc-over voltage for long strings.³ This is because rain may assist in grading a badly unbalanced string. As a general rule, a string cannot be very greatly shortened in practise by grading because of the effects of rain, dirt, etc. on the perfectly graded string. There would be little gain in increasing the dry arc-over voltage if the wet arc-over voltage

FIG. 12—VOLTAGE DISTRIBUTION ON A STRING OF TWELVE INSULATORS
(See Fig. 11—Laboratory hardware.)

were decreased. Rain would not increase the wet arc-over voltage of a graded string. The wet arc-over voltage would generally be lower if the string length were decreased.

There is an additional reason why grading will generally not make possible an increase in the arc-over voltage or a decrease in the string length. For any unbalanced string there is more or less complete automatic grading as the arc-over voltage is approached. Near arc-over excessive corona forms on the line unit, to a less extent on the next unit, etc. These sheets of corona act as capacity plates and grade the string, thus

3. Peek, "Electrical Characteristics of the Suspension Insulator—I." A. I. E. E. TRANSACTIONS 1912. Vol. XXXI, page 907.

automatically raising the arc-over voltage. If this were not so, it would be expected that the arc-over voltage for the non-graded string above could for five

FIG. 13—ANTENNA SHIELD
Insulators strung with standard hardware.

or more units, never be higher than $\frac{1}{0.30} = 3.3$ times

the arc-over voltage of a single unit. As a matter of fact, it is much higher, due to the automatic grading of corona.

FIG. 14—METHOD OF MAKING DISTRIBUTION MEASUREMENTS

The wet and dry arc-over voltage of insulators decreases almost directly with barometric pressure. The insulator problem for the higher voltages is therefore more difficult at higher altitudes.

It has been found that the wet lightning arc-over voltage is usually as high as the dry lightning arc-over voltage.⁴ The lightning arc-over voltage is, to a great extent, a question of string length. If the string length is decreased due to grading the lightning arc-over voltage will also be decreased.

TESTS

It may be of interest to describe the method of making tests. A water resistance with 50 taps was

FIG. 15—THE EFFECT OF PROXIMITY TO WALLS
Voltage Distribution on String of Five Insulators.

placed across the line in parallel with the insulators as shown in the illustration, Fig. 14. Each tap had a fixed and known potential above ground, *i. e.*, a given percentage of the applied voltage. Connection was made between the particular unit, the potential of which was being investigated and various taps on the resistance until a tap was found of the same potential. In making this measurement a wire was fastened to a tap and the other end of the wire fastened to a steel point at the end of a fibre rod. When the rod was brought up to the cap a spark would indicate a difference of potential. The connection on the tap was then changed, or the operation was repeated until no spark occurred when the point touched the insulator cap.

4. Peek, "The Effect of Transient Voltages on Dielectrics," A. I. E. E. TRANSACTIONS, 1915, vol. XXXIV, page 1857.

It was found that the steel point, because of the color of the spark, indicated the smallest difference of potential. In making measurements it is necessary to prevent as far as possible any distortion of the field by the wire and point. A distortion is indicated by different potential readings when measurements are made at different points around the insulator. A stream of water was kept running through the tube in order to keep the temperature constant. Approximate potential readings can be obtained by placing a very small gap shunt-

FIG. 16—THE EFFECT OF APPLIED VOLTAGE ON THE DISTRIBUTION OF A STRING OF TEN

ing a forked stick across the units. This method gives fairly accurate results on the two or three units near the line, but quite inaccurate results on the others.

The effect of proximity to tower, etc., is given in Fig. 15. It will be seen that it is not great. The effect of corona on distribution is not great at the operating voltage. For instance there is very little difference in the voltage distribution between 30 and 130 kv. 130 kv. is approximately the voltage to neutral of a 220-kv. system. Fig. 16 shows the distribution at 30, 50 and 125 kv. The 50 and 125-kv.

FIG. 17—ANTENNA SHIELD ON A DOUBLE STRING
Laboratory hardware—See Fig. 18.

FIG. 18—VOLTAGE DISTRIBUTION ON TWO PARALLEL STRINGS
OF TWELVE INSULATORS

FIG. 19—ANTENNA SHIELD
(See Fig. 20.)

FIG. 20—VOLTAGE DISTRIBUTION ON STRING OF TWELVE INSULATORS
(See Fig. 19.)

FIG. 21—ANTENNA SHIELD FOR EQUALIZING VOLTAGE ON INSULATORS

curves were made with a spark gap and are accurate for the three units near the line only. Fig. 17 shows the shield used on a double string. The distribution is very good as shown in Fig. 18.

FIG. 22—TWO AND THREE UNITS IN PARALLEL AT LINE END OF STRING OF 12 UNITS AS A MEANS OF IMPROVING VOLTAGE DISTRIBUTION ON THE STRING

Figs. 19 and 20 show the shield and distribution on other types of units. A corona shield is also desirable on this type at 220 kv. The effect on voltage distribution of placing a shielded string in a horizontal position was investigated and found to be negligible. See Fig. 21.

The method of grading shown in Fig. 22 was not found to be very satisfactory.

Fig. 23 shows a form of shield that gave fairly good results.

Distribution tests were made to see if there would be any disturbing effect due to the proximity of other insulator strings as in operation on a three-phase line. There was found to be no appreciable effect.

It is not possible to show all of the various shields tried, but it is believed that the above fairly well covers the field.

SUMMARY

From the above discussion it may be concluded that:

Insulator troubles have been due mainly to cracking caused by expansion of metal parts, cement, etc. and to porosity.

Certain designs with loose-fitting parts have been free from deterioration. Other designs should be so modified as to relieve them as far as possible from expansion troubles.

Tough non-porous porcelain is desirable.

The old method of basing everything on electrical tests should be abandoned. Severe electrical tests are often harmful. The electrical strength is often secondary to other characteristics. An electrical, mechanical and porosity uniformity test should be established, in which a small percentage of the product is tested to destruction from day to day to ascertain if it is running brittle or porous or is weakened by firing strains.

For the very high voltages that are at present being considered, greater reliability may in many respects be anticipated than for the lower voltage lines. The lightning arc-over voltage and dielectric strength will be relatively higher and induced lightning voltages, sufficient to cause arc-over, will be less than on low-voltage lines. Increasing the number of units in series decreases the probability of complete string failure.

Uneven distribution of voltage on the string becomes more serious at the higher voltages because of the high stress on the unit near the line. For strings of more than four or five units the stress is practically a constant percentage of the operating voltage independent of the string length.

Uneven distribution can be corrected by shielding, shielding prevents excessive corona on the line end units and tends to direct the power arc away from the string. The maximum unit stress on a 220-kv. shield

FIG. 23—ANTENNA SHIELD FOR EQUALIZING VOLTAGE ON INSULATORS

string can be made less than on a 100-kv. non-shielded string.

Briefly, outages due to insulator troubles will probably be less frequent at the higher voltages than at present.

The author acknowledges the assistance of Mr. W. L. Lloyd, Jr. in making this investigation.

DISCUSSION ON "FACTORS CONTROLLING THE DESIGN AND SELECTION OF SUSPENSION INSULATORS" (PEASLEE), "UNIT VOLTAGE DUTIES IN LONG SUSPENSION INSULATOR STRINGS" (RYAN AND HENLINE) AND "ELECTRICAL CHARACTERISTICS OF THE SUSPENSION INSULATOR AT THE HIGHER VOLTAGES" (PEEK), WHITE SULPHUR SPRINGS, W. VA., JULY 21, 1920.

J. B. Fisk: I am going to make the statement that this idea of shielding a string of insulators by means of an antenna shield is not new but has been in operation for many years, and then I am going to explain that statement.

Some eleven or twelve years ago I designed a power line for 60 kv., the conductors on which were to be of aluminum without steel core. Now most of us know what the effect of an arc on an aluminum wire is. It is disastrous; and I was afraid of it. So in designing this line I thought of some way of taking care of that arc, and as there was little experience to guide me at that time, I designed an arcing rod, which was placed just above the wire in the same plane with it and extended it out five feet on either side of the insulator. It is the most abominable thing to look at you ever saw. That line was put in operation ten years ago, and notwithstanding the troubles that have been had generally with suspension insulators there has not been one single failure of a suspension unit on that line from a natural breakdown. The insulators have been damaged by lightning and have been damaged by the small boy with the rifle, but there has not been one single failure. I may be all wrong, and I want Professor Ryan and Mr. Peaslee to discuss it, if they will, and tell me whether I am right in claiming to be unwittingly the inventor of the antenna shield.

M. T. Crawford: The development of a suspension insulator that will be reliable and efficient is not only pertinent to the successful operation of present 100-kv. and future 200-kv. lines, but is of importance in connection with lower voltage lines. The cost of good pin type insulators has more than quadrupled, and we now find that the cost per mile of 55-kv. lines having heavy conductors is less with the suspension insulator form of construction than with pin type insulators. This is due to the limited mechanical strength of the pin insulator screwed on a threaded iron pin, necessitating fairly short spans. Pin insulators cemented on iron pins have additional mechanical strength but deterioration is marked due to thermal expansions and electrolytic

corrosion of the iron pins. With the added mechanical strength of the suspension insulator, span lengths may be safely increased from 50 to 100 per cent and considerable saving per mile effected by the reduction in number of line supports and insulators.

A considerable number of the Hewlett bomb-and-link type three-unit strings have been in continuous service for ten years on the 55-kv. non-grounded neutral system of the Puget Sound Power and Light Company, installed at strain points where the screwed on pin insulator did not possess adequate mechanical strength. A few years ago a number of four-unit, cap-and-pin type strings were installed, and recently a number of core-and-tine type three-unit strings have been installed, both for strain purposes and suspension construction.

In the ten years operation of the bomb-and-link type units there has been no sign whatever of deterioration and the only weak point in evidence has been the loss from straight puncture of a few strings now and then where the line was subjected to a direct lightning stroke in the immediate vicinity. It is believed that the very small point of contact between the link hardware and the surface of the porcelain is a weak point in this design, although not a serious one, as it results in a concentration of potential that renders it liable to puncture under abnormal electrical conditions. The cap-and-pin type units were subject to such rapid deterioration that their use was discontinued. The core-and-tine type units have only been in service a year, and their satisfactory operation over this period is of course not conclusive.

It seems that the principal questions about the core-and-tine type are in regard to the practical possibility of making such thick pieces of porcelain non-porous and homogeneous, and the possibility of the higher voltage rating of the individual units tending to increase unduly the maximum to average duty-ratio, resulting in low flash over values from cascading.

It is of some interest in connection with the possibility of making satisfactory thick porcelain, to call attention to an installation of over 10,000 pin insulators made in 1898. They were approximately 6 in. in diameter of solid porcelain exceeding 2 in. in thickness in places. After ten years operation on 30-kv. lines some of them were placed on 13-kv. lines and as far as is known all have operated continuously without any indication of deterioration or porosity. Another batch of about 5,000 exactly similar units made several years later deteriorated so rapidly that it was necessary to replace them within a few years. This in-

dicates that fairly thick porcelain was made non-porous and homogeneous as far back as 1898 and it should be possible now.

In Professor Ryan's paper reference is made to the undue increase in maximum to average duty-ratio and consequent cascading by the increase in rating of individual units. His investigations seem to show that the most efficient string is about 7 units on 100-kv. duty, additional units being of little value. I would like to ask why then would not a similar 5 to 7-unit string be efficient on 200-kv. duty if the size and rating of the units were correspondingly increased, and why should the tendency to cascading be any greater, assuming that proper static shields were employed in each case? Other things being equal, a reasonably short string is a decided advantage, in that it reduces the extra vertical spacing needed between wires to avoid their coming too close together when snow drops off of different wires in long spans.

E. R. Stauffacher: The Southern California Edison Company is very serious in its intention of converting its 150-kv. Big Creek line to 220 kv. within the next two or three years.

For, with the further development of our construction program in the vicinity of our present Big Creek plants, it will be necessary either to go to 220 kv. on our present transmission line, or to build new lines between the plants and Los Angeles.

Accordingly we are planning to make some investigations in the field. We have available a bank of transformers of 150,000 volts on the high side, which if connected star, will give us the potentials we would like to have for our test. The question of the ability of the transformer terminal bushings and the terminals of the windings to withstand potentials in the neighborhood of 250 kv. when grounded has been taken up with the manufacturers and we are now waiting their reply. We expect to utilize a number of miles of one of the Big Creek lines and make all kinds of field tests on the insulators that any one may be able to suggest to us.

We have made some preliminary studies in regard to the length of the insulator strings and the size of the shields which it will be possible to use on the present Big Creek Line towers when these lines are converted to 220 kv. operation.

The following notes are the results of these preliminary studies made by Mr. Michener on Mr. Barre's staff:

The string lengths used are all based on our present units which are 5.75 in. long, and our present hardware

which makes a 9-unit suspension string $63 \frac{9}{16}$ in. long from the center of the pin in the tower brackets to the center of the conductor. The minimum allowable clearance from tower is assumed as 4 ft. The distance between the conductors is approximately 17 ft.

1. *Dead Ends*

Any length of double strings with any size of shield may be used.

2. *Suspension*

a. On Outside Wires:

1. Any length of single string can be used where clearance from ground in center of span will permit, provided that the tie-down insulators or sufficient holding down weight is used to maintain proper clearance from tower in times of high winds.

Ten units with a 12 in. shield will reach the minimum clearance of 4 ft. from tower when insulators swing at 45 deg. from vertical.

A similar string with 15 units will reach the minimum clearance when swinging at an angle of 30 deg. from the vertical.

2. Any length of double strings arranged in an inverted V can be used where the clearance of the center of the span cannot be reduced below that which now obtains. As the string length is increased the angle of the V will increase to maintain the conductor at the same height.

With this arrangement the 10 and 11-unit strings can be equipped with 12 in. shields and still not reduce the minimum clearance below 4 ft. when, due to wind, the insulators hang at 45 deg. out of the vertical plane.

For strings of 12 or more units the shield can be increased to almost any desired dimensions without reducing the minimum clearance below 4 ft. when, due to wind, the insulators hang 45 deg. out of the vertical.

3. Two strings of units arranged in a V in a plane perpendicular to the length of the line, with the spread at the top and with the apex at the conductor. With 11 units in each string the conductor will be at the same height as at present, the angle at the apex will be about 70 deg. and a shield approximately 18-in. in diameter can be used since the insulators will not swing in the wind.

The length of these strings can be increased with a corresponding decrease in the angle at the apex. When the strings are 16 units in length, the angle at the apex will be approximately 50 deg. and a 12-in. shield can be used.

This arrangement will decrease the distance between conductors by 3.5 to 4 ft.

It may be necessary to put an extension on the end of the cross arm in order to make the angle at the apex great enough to hold the conductor from swinging under high winds.

b. On Middle Wire.

1. Any length of single string up to and including 20 units can be used, provided the conductor is rigidly tied down. In this a 24 in. shield can be used. With a 20-unit string the conductor will be lowered about 2.5 ft. and the point of support for the insulator string will be raised about 3 ft. from the positions now occupied.

2. The conductor can be maintained at the same height and the string length increased to 15 units (possibly a few more) by raising the point of support of the insulator string. In the case of the 15-unit string the top four units of the string will be between the steel members of the top of the tower with slightly more than one foot clearance between each edge of these units and the steel in a direction parallel to the length of the line. With the 15-unit string and a 12-in. shield, the insulator string can swing 20 to 30 deg. out of the vertical without reducing the clearance to less than the allowable minimum of 4 ft. This means that tie-down insulators or a holding down weight are required.

3. The conductor can be held at the same height and rigidly so it cannot swing by using two strings of insulators arranged in a V with the spread at the top and the apex at the conductor. The strings can be of 15 or 16 units in length without lowering the conductor and 22 or more units in length by lowering the conductor. With this arrangement shields of almost any size can be used.

From the above it seems certain that we shall be able to get by with 220 kv. without making any great changes in the towers. At present the V arrangement with the apex at the conductor for all three conductors seems most favorable to me.

If it would be possible for Professor Ryan to make some investigations of the voltage distribution when insulators are arranged in V or an inverted V it certainly would be of interest to us at this time.

L. C. Williams: I think it would be interesting to the members of the Institute who are not familiar with the Big Creek line to have Mr. Stauffacher give some idea of the type of construction. Will you give us an idea of the construction of that line?

E. R. Stauffacher: The Big Creek line consists of two duplicate transmission lines, approximately 240 miles long, running between our Big Creek plants No. 1 and No. 2 to the substation at Eagle Rock. The conductor size is 683,000 cir. mils of aluminum, with a steel core. There are three conductors per line approximately 17 ft. apart. They are arranged on a horizontal plane. There are nine units on our suspension towers and two strings of eleven units at each end of our dead end towers. As far as possible, we tried to design the line so it would keep out of the valleys and away from any chance of floods. We have had some disastrous experiences with what few floods that we have had in Los Angeles. The longest span I believe is approximately 3000 ft., near Sunland.

G. E. Quinan: It has been suggested in Mr. Peek's paper that the increase of porosity in porcelain is due to freezing. It has also been suggested, not in these papers but in the technical press, that the Piezo-electric effect may have something to do with the deterioration of the porcelain. The rapid, alternating electrical stress, tending to deform the micro-crystals, may very possibly be responsible for some of the deterioration that has been heretofore laid to expansion as the result of temperature. There is a great deal undoubtedly yet to be done in understanding just what is going on inside of porcelain under the effect of the electrical stress. We have also, all of us, I guess, had a good deal of experience with the effect of cement and the tendency to expand when used in pin type insulators, causing hair cracks in the insulator and ultimate puncture.

Now if the electrical men will study ceramics, or the ceramist will study electrical phenomena, we may hope to get enough of a working knowledge of the characteristics of porcelain to get a very satisfactory insulator.

W. A. Hillebrand: The fundamental characteristic of porcelain, the governing characteristic, is that the work must be formed before it is fired. In comparison with other ceramic products, for instance with glass, the whole is melted, fused to a fluid mass and then formed. With porcelain all work must keep its shape in the kiln. Now that means at once that you must have a body composition or it must be composed of materials with different melting points, some of which will not melt with the maximum firing temperature, so that your pieces will not be deformed by the time you get them out. As a result of experience we have porcelain composed of three constituents: Quartz, feldspar, clay. The quartz will melt around 1710 deg.

cent. The clay is decomposed during the firing, the water of crystallization driven off, and some of the quartz dissolved, leaving for the most part refractory sillimanite. The feldspar is the substance which melts, runs throughout the whole as a binder, as the vitrifying agent, forming a glass, holding the rest together very much after the manner of concrete, wherein the cement acts as a binder and the rock and sand as the aggregate. So it is that your molten feldspar after it is cooled is the binder and the other solid particles of quartz and metamorphosed clay, then probably sillimanite, are the aggregate and complete vitrification means that the interstices between all the aggregate, just as in a dense concrete, must be completely filled or very nearly completely filled by the feldspar glass.

Now the curve which Mr. Peaslee shows of temperature and porosity indicates that below, say about 1300 deg. cent. your ware is porous with generally intercommunicating pores, because you have not carried your temperature high enough and held it long enough for the molten feldspar to run throughout the entire mass and completely seal it together. You can carry your temperature a little bit higher and gas begins to be given off, the principal gas dissolved in the quartz being probably nitrogen, and under those conditions your ware comes out bloated or blistered with actual faults running through it. So that you have a comparatively narrow temperature range in which you will get satisfactory vitrification of the piece.

Now there is one point that has not been dwelt upon. That is, that your satisfactory vitrification depends not alone upon a proper firing temperature for the body composition taken as a whole, but also you must have and must maintain throughout the entire process of handling the clay uniformity throughout the piece. Bear in mind you have the three constituents: The quartz, feldspar and clay, of different weight, different specific gravity. They are ground together in a mill, about the size of flour; that is, a fine, powdery mass, thoroughly stirred together in the various forms of the mill, with water taken out as a fluid slip. That is run into a bag press, taken out and left in the clay cellar to soak.

Now it is extremely important during all this mixing that the whole mass be kept continually agitated, that is, as it goes through the bag press that you do not have segregations, a dropping out at some point and allowing it to settle and getting to a different grade of composition. So that it is not alone necessary to have accurate kiln control but it is most necessary to have

most accurate control first of all in the selection and the production of your raw materials, and then in the handling of them in every step down to the kiln.

Then the curve which Mr. Peaslee shows is absolutely controlling in the ceramic process.

Furthermore, there is an additional factor which he did not mention. That is, up to the point of about 800 deg. cent., during which time the water crystallization in the clay is given off, and there is approximately 10 per cent. linear shrinkage in the ware, the temperature must be very uniform.

There are two vital points in the firing process: The first, that during which the water of crystallization is driven off at about 800 deg. cent. and the second the approach to the maximum firing temperature.

Referring to porosity, which is vital, I will say that with the leading procelain manufacturers porosity ceased to be a matter of importance to the engineer five years ago. I think not for five years has any appreciable amount of porous ware been put out; and while all the stress which has been laid upon the matter of porosity is probably correct, weight should nevertheless be given to methods which have been tried and proven by experience for governing this matter, and I will say that there is probably no one thing which is watched and must be watched more carefully in an insulator plant than this matter of porosity.

Coming now to the other matter discussed in the three papers under question, there are two things in the use of long insulator strings today which weigh very heavily upon the mind of the operating engineer. One is the initial corona point or the point at which corona will form around the unit next to the conductor. The other is the potential carried by that unit with the possibility of cascade action. Now personally I think that danger from cascade action with a close coupled cap and pin type union has been very much exaggerated. Many of you I know will disagree with me very strongly, but on the other hand I think there is comparatively little evidence to show that the danger from cascade action in a long string is a real one. It may be under certain atmospheric conditions. We know that there are unexplainable things taking place on lines in certain sections of the country, but until that is definitely laid to a failure by cascade action with the surface of the insulator wetted down, say by dew or fog and not by rain, I personally hold to the opinion as stated.

Now for example Professor Ryan makes a statement on page 6671 to the effect that, "The curves reveal further that an increase in string length from ten to

twenty units will cause a corresponding increase in steep wave front flash-over voltage." Now I understand that he modified that to apply to 60-cycle voltage.

Now I don't know whether that statement is based upon tests or not, but figures that I have for cap and pin type units, in, for example, a 10-unit string, with dry flash-over of 480,000 and a 15-unit string, 50 per cent increase, the dry flash-over is 670,000; that is a 42 per cent increase. And the point is that as Mr. Peek has brought out, particularly the corona forming in the bottom unit, the unit next above it, will automatically grade the string so that your flash-over finally occurs at a very much relatively higher value. Furthermore, particularly in certain sections of the country, you have lines subjected to lightning. I know one case where the lightning hit in the middle of the span did not flash over the insulators on either side, although it burned down the conductor. You may have potentials up to four or five hundred thousand volts and unquestionably on that basis, those units should have gone over and yet they did not. Now for example a moderately dispersed field is I think desirable, intending to throw the arc out away from the insulator; that is, in its initial stage of formation. Mr. Peek says that a shield will in itself throw the arc away from the insulator. Under certain conditions that is possibly true. On the other hand, I think it is equally possible that due to the change in the form of the field, the fact that under certain conditions you will get the greatest stress concentration on the second unit, possibly above that, that you may actually have the arc thrown into the string.

Now I am not arguing either for or against a shielded string. The point that I do want to make is that so far as I am personally concerned, as a result of my own experience, I am not yet convinced that even for 220 kv. a shield is necessary.

On page 1671 a curve is given showing the watts lost at sixty cycles on an insulator. That curve would be rather disturbing but for the fact that I think that loss is primarily in the air about the unit, and with a very much better chance for heat dissipation. If that loss were taking place in the unit itself, it would be a matter that I would consider very serious, but under the circumstances today, under normal conditions where the heat generated can be removed, I think that is applied at the surface and can readily be taken away by air currents and that is something that I would like to hear a little bit further about from Professor Ryan.

Now as to the various types of unit that are under discussion. For example, we will take the three: The cap and pin type, the Jeffery-Dewitt and the Hewlett. I am going to rate these. That is, these are taken with just single units alone, the characteristics of the unit. I rate the cap and pin type at one hundred for corona flash-over, wet and dry. For initial corona, and that is the point just about where the corona voltage begins to be seen in the dark, the cap and pin type at one hundred; the Jeffery-Dewitt a little over two hundred; the Hewlett sixty-two; flash-over cap and pin type one hundred, Jeffery-Dewitt one hundred sixteen, Hewlett one hundred three. Wet, cap and pin type one hundred; J. D. one hundred eighty-nine, eighty-nine per cent increase in wet, the Hewlett one hundred fourteen. Dry, one hundred, one hundred ten and one hundred.

As to puncture value, the Jeffery-Dewitt is probably at least two and maybe three times that of either of the others. Now at 220 kv., with a 12-unit string of cap and pin type units, according to Professor Ryan's curves the unit next to the conductor would carry 24,400 volts. At about 21,500 sea level and on a day when the air is comparatively bad as a conductor, the first visible corona will begin to show. The stress on this unit will be 24,400. There are ten-unit strings, cap and pin type units, operating very satisfactorily at 165,000 volts on the line of the Aluminum Company in Tennessee, at elevations running from 1500 to 2500 ft. That line has been in operation for nearly a year and a half now and no trouble whatsoever reported. They have not, as far as I know, had a single flash-over.

Now 24,400 I personally do not consider a voltage at or near sea level as too high to put upon a single unit, and, as stated, I think there is little likelihood under ordinary conditions of such a string failing by cascading.

In the matter of insulator design, if you will refer to Mr. Peaslee's paper on page 1653. Now the initial corona with this unit appears, as is to be expected, in the air immediately around the pin. It spreads out until it meets the petticoat, is deflected and stopped. That is an expedient that is many years old, was called attention to at least twenty years ago. It was one of the most valuable ones in insulator designs of affording a deflecting barrier for your corona streamer, in order to prevent it running out. Now with the use of flanges, of about the proportion shown, adding something like 17 per cent dead weight over a smooth disk, you increase your dry flash-over on that account

as over a smooth disk approximately 50 per cent; you increase your leakage distance about 40 per cent. Furthermore, with light thin barriers, an arc is held down away from the body of the porcelain itself, and I have seen such a unit with the flanges completely stripped off, stripped perfectly clean as though knocked off with a hammer and the body of the flange itself absolutely uninjured and sound.

Now with a unit of this description I will ask you to note that it is extremely important to have a high corona point, for the reason that the moment you get streamers started to a point like this they begin to run together. If you have them running together the distance is shortening and there is the tendency immediately to run out and grow after the familiar manner of such streamers under a 60-cycle current. Now with this spider leg as an equi-potential surface, you will note that there can be no potential difference between these two points. That means an extremely low potential in here, and the lines of field are well thrown out in that direction (indicating with reference to illustration). The maximum concentration is well down in the porcelain, away from the air and has the weaker dielectric. The result of that is you have a high corona value, but on the other hand when you do break down it floods just like that, the whole under surface of the insulator, and this section in here will be completely dark. The characteristic is entirely different from this unit, for instance (indicating). The whole portion under here is apparently quite uniformly stressed. It all goes down at once, and with the result that you have a flash-over value for this unit with approximately ninety per cent increase in weight, with about sixteen per cent or eighteen per cent in volts. Now furthermore, by reference to the curves that are presented you will find that for say a ten unit string, with about nineteen to twenty per cent of the line potential carried by the first unit, with units of the J. D. and of the Hewlett type you have approximately thirty per cent; that is about fifty per cent more voltage carried by the line unit than the other; and it would be correspondingly desirable to have a high corona point. That is secured in the J. D. unit by the design of the insulator itself. It is absolutely necessary if you are going to use a Hewlett insulator, with corona coming at about fourteen thousand volts, if you are going to use that at high voltage, to use some sort of shield as proposed by Mr. Peek or Professor Ryan.

With regard to the matter of depreciation, Mr. Peaslee mentions current rates as high as twenty per

cent. For units manufactured within the past five years the records show that over a four year period the rate is about one thousandth part of a maximum; that is about a fiftieth of one per cent a year. That rate will not continue. Just what it will do we don't know.

The statement is made that porcelain, cement and metal are held together in an unyielding assembly. That also needs modification, because it is characteristic of cap and pin type units today that they are set together with a yielding medium between them at all points, and that has made a difference in comparison with units built five or six years ago, of at least three hundred to one in the rate of failure.

As to the importance of three hundred thousand volt or better puncture value, that is a matter largely for opinion. Punctures of suspension units today, that is of sound units, are extremely rare, even under lightning potentials. Providing you have a string that is free from arcing, that is, that will not fail by cascading, wherein you pile up a full line voltage upon a single unit, experience shows you do not get punctures, and, as in everything else, it is a compromise. If you insist upon a high puncture value per unit, then you have got to go to a certain design which has inherent weaknesses that will be brought out later.

Now on the matter of impulse ratio, while I will not pretend to argue either one way or the other, I think that is a matter that should be clearly understood, particularly by anyone buying or using insulators.

Now my understanding of impulse ratio is this: For example, if you take a spark gap, a needle gap, you have an extremely high dielectric flux concentration at the needle points. On sixty cycles you will have a brush or corona around the points that will grow and your voltage is raised, gradually narrowing the gap, and finally it will spill over. That is, you have a dispersed field. As you get away from it the field very rapidly drops off in intensity. Now under a steep wave front impulse coming on such a gap, you ionize the air in the immediate vicinity of the needle points. Your streamer runs out; it is an extension of the electrode that comes now at a point; you have an ionizing potential at the end of the electrode which is enabled to ionize some more, and so it grows just as it would on the sixty cycle, and on the sixty cycle there is time enough for this action to take place, for it to grow across. With a high-frequency impulse there may not be time enough for that to take place. The result is you have very much higher peak voltage required to spill over your needle gap than you do for

an equal distance where the field is uniform; as, for instance, in a gap between large spheres. That leads to this general conclusion, which I think will hold: That is, that the poorer the stress of distribution the higher impulse ratio. That is, I think in general you will gain a high impulse ratio at the expense of poorer stress of distribution. I myself have made one or two experiments which tend to bear that out; and that I think is also shown by the curves which Mr. Peaslee shows, where he shows a higher impulse ratio for the Jeffery-Dewitt over the cap and pin type unit. He also shows about a fifty per cent higher stress distribution on the unit next to the conductor.

One other feature with regard to the Jeffery-Dewitt unit which should be taken into account by anyone who is considering the complete insulator situation, as the titles of these papers would lead us to infer; that is that the porcelain is used in tension. There is no objection to that whatsoever so long as your porcelain is sound. The only objection comes due to the liability of porcelain cracking with time in accordance with its inherent characteristic.

Now as Mr. Crawford has shown, and as every insulator man who is familiar with insulators to any considerable extent knows, your porcelains manufactured at different times have been extremely varied. That is true of porcelain put out by a single manufacturer. Even with the most careful process and control you will have certain variations within the product of any one manufacturer running along from year to year. Now with an insulator of this type, if the porcelain does crack your line probably comes down. With an insulator of the cap and pin type, where you have an overlap, or with the Hewlett type where you have an interlink, a crack in the porcelain does not mean a line failure, and experience has shown that in that respect, that is for the same number of units under equal conditions of service, under conditions such as obtained in lines of say one hundred thousand volts, one hundred miles or more in length, that the liability of failure from that cause must be in the ratio of about two thousand to one in favor of the Jeffery-Dewitt over the cap and pin type for the same number of service interruptions.

Now as to the possibility of failure. Mr. Peek has made the statement that after ten years or more of service, insulators of the Hewlett type show no depreciation from cracking. Mr. Crawford from his experience, has supported that very definitely. On the other hand, I know of one line in which the Hewlett insulators were installed about ten years ago, wherein

they are cracking today at the rate of about one per cent a year. That is, the porcelain is falling off from the central bomb. Now that again is very likely, or quite possibly due to the different characteristics of the ware as put out in the two lots of insulators, but until the thing has been demonstrated over a sufficiently long period of years to settle absolutely, there is always that question of uncertainty. A very large number of tests may be made upon a single piece, that show externally no depreciation whatever; on the hundred and twenty-fifth it may go to pieces like that (speaker snapping his finger); go like a pistol shot, without any signs of failure whatsoever; and that is a matter of experience and a matter also of laboratorial experiment. And so while the tests given by Mr. Peaslee with regard to the temperature cycles on page 1662 are interesting and are all very valuable, I personally could not consider them conclusive until sufficient time has elapsed, as he himself has said, to settle this question.

And as to the insulator situation, as to what type should be used, that, no man at present is in a position to say. We are extremely fortunate in having had practically all the data with regard to voltage distribution obtained for us after very long, laborious and painstaking effort, because it settles a vexatious question, settles once for all just what the values are, what to expect, and enables us to talk in concrete terms and to go ahead upon some definite, rational basis, instead of one of conjecture; and there are enough units of the various types now in service so that within a reasonable time, much less than the span of life that most of us look forward to, why we will have very definite information.

J. B. Fiske: There is one question that I would like to see eliminated if it is possible to eliminate it. It is the question of the depreciation of porcelain. I don't know how many years experience are necessary to convince us that porcelain can be made that does not depreciate. Personally I believe it can and has been done. My experience is gained from a line that has been in operation now for seventeen years. The insulators on that line are standing up. It was operated for about six months or a year at forty-five kilovolts, and since then is being operated at sixty kilovolts. Of course these insulators are such that none of us would accept them today, because they are narked and blistered and uneven and they would not pass a physical inspection, but they are functioning. That is the main thing. Some of those insulators a few years ago were sent east to be tested, they were

put through the regular tests and stood up as high as when they were originally tested back about—I think they were purchased in 1901. Now it is a question of the length of time that must elapse before it is possible to say that there is no such thing as depreciation of porcelain, and I would like to hear the authors of the three papers, or at least the two that are present discuss that a little in their reply. Personally I am satisfied in my own mind that such a thing as depreciation or deterioration of porcelain does not exist, and that that can be eliminated from the discussion entirely.

K. A. Hawley: I am going to talk both as a user of insulators and then as a manufacturer's representative. In 1913, I helped to buy the insulators for the Norfolk and Western, and for the Pennsylvania electrifications. At that time, we had trouble to get the manufacturers to offer a satisfactory puncture value for the insulators; that is, punctured under oil. The specification written then called for an instantaneous test of 120 kv. Late in 1914, we purchased a third lot, and at that time we had to change our specification to read only 115 kv. of puncture value. Now at the Locke Insulator Factory, we are using in our standard specification, a test for puncture starting at ten per cent below flash-over, 70,000 volts. We apply the voltage for thirty seconds; then we raise the voltage ten thousand volts and continue that at thirty seconds, and so on by steps of ten thousand volts every thirty seconds until it punctures. We are now regularly reaching 160 kv., and a fair proportion of the porcelain goes to 170 kv. Now as against the old specification made in 1913, this test can be considered equivalent to over 100 kv. volts instantaneous application, very nearly a one hundred per cent increase in porcelain puncture value.

As to porosity, we have subjected samples that our inspectors have picked out as being along the lower limits of commercially practical porcelain to 13,000 lb. per sq. in. pressure in fuchsine dye and alcohol without any penetration that we can observe under the microscope. This indicates the improvement that has been made in porcelain within our factory in the past five years.

We all know of lots of porcelain, such as Mr. Fiskens just told us about, that have stood almost with one hundred per cent record over a great number of years. It would be a very sorry comment on the modern scientists if they could not find what that old porcelain is. We feel very confident that we know what it is and can regularly commercially supply that porce-

lain. In the assembly of a cap and pin type insulator, expansion troubles and so on, we believe are thoroughly cared for by the proper expansion joints. So that we have no fear in the future of a modern cap and pin type insulator.

L. C. Williams: There is one point in the manufacture of porcelain, which is purely a ceramic process, and which I believe to be of a great deal of value, and which the operating engineers particularly may not appreciate and that is the point of drying the clay before it is fired; and that point in itself will set up stresses in the porcelain which are only aggravated by the firing. In watching the firing of porcelain the greatest care is taken to watch the uniformity of fire, not only from its start but at the point of soaking, which is of vital importance, and, as I said, increases or aggravates any stresses which may be set up in the clay in the drying rooms. That is purely a ceramic consideration, and I think that possibly Mr. Fiske's remarks as to the operation of the insulators which he had in service can be accounted for very much on the same theory as he accounts for his arcing horns. Manufacturers ten and fifteen years ago made porcelain which has undoubtedly shown remarkable operating success. On the contrary, from operating experience, I have known manufacturers ten years ago which made porcelain which would fly into a million pieces if you gave them a hard look. The obvious conclusion to come to in our present day practise is that we have to find out and standardize those practises which made good porcelain and eliminate those causes which made bad porcelain. In other words, the performance of insulators ten years ago is no criterion of the performance of the present insulator which we are going to get today, regardless of whether it is a bomb-and-link type, a cap-and-pin type, or the core-and-tine-type. It is perhaps fortunate, that we have more operating data on the cap-and-pin type insulator than we have on the other types, and as a result we are able to forecast more accurately the probable operating results of the cap-and-pin type insulator than we are of the other types. Time alone is going to tell whether or not the cap-and-pin type insulator as it is manufactured today is going to do equal work or better work or worse work than the other types. It resolves itself merely into a question of whether the operating engineer is going to take the newer types and carry on his own experiments or whether he is going to benefit by the experience of the operating engineers who have had long experience in using the cap-and-pin type insulator.

S. C. Lindsay: There is one thing that seems to me to need investigation, and that is the effect of vibration of these insulators under tension. I am of the opinion that you are going to have a great deal of difficulty in getting anything in the nature of porcelain to stand up over a long term of years when it is used in the form of a cap-and-pin type insulator and is subjected to mechanical stresses and vibrations at the same time. I think there will be a definite length of life to those insulators with any improvement in the manufacture of porcelain that can be made, on account of vibrations. I believe the next most fruitful field for investigation is that of vibration under operating conditions.

L. Lauridsen: One of the 60-kv., 60-cycle transmission lines of the Portland Railway, Light and Power Company is of steel tower construction and equipped with suspension insulators. The line is about thirty miles in length and was put in operation about 1912. Within a year after the line was put in operation, line failures began to occur; and by the early part of 1914, the failures occurred with a frequency of about one a month. It was then decided to test the insulators of the line. This was done by means of a megger with a 1000-volt generator and two thousand megohms as its highest finite scale reading. Each insulator unit was tested from pin to cap. About fifteen per cent of the entire number of insulator units on the line was found to test below 2000 megohms. After the completion of the test, these defective units were all replaced. During the following year, 1915, the line was again tested, and about five per cent of the number of units was found to test below 2000 megohms, but none were replaced that year. A third test of the line was made during 1916, which showed that the number of defective units had increased from five per cent to eight per cent. About three per cent of the total number of units tested below 100 megohms, and these were replaced. At the beginning of 1917, there were, therefore, about five per cent of the total number of units on the line which tested below 2000 megohms. Due to war conditions and increased line loads during 1917, 1918 and 1919, the line could not be spared for making insulator tests during that period; and although no insulator replacements had been made since 1916, line failures did not begin to occur until the latter part of 1919. During the early part of 1920, the line failures became more numerous, and it became absolutely necessary to have the defective units replaced. A megger test of the entire line was therefore made which showed that the num-

ber of insulator units testing below 2000 megohms had increased from about 5 per cent in 1917 to 11.4 per cent in 1920. Only the units testing below 100 megohms were removed. These amounted to 7.7 per cent, leaving 3.7 per cent defective units, testing below 2000 megohms, at present in service on the line. Our tests seem to show that there is a gradual deterioration taking place in the insulators. An insulator unit, which one year would test a definite value between 2000 and 100 megohms, and which was permitted to remain on the line, would invariably show a lower resistance at the following test. Whether this apparent depreciation is due to original defects in the porcelain, or to defects acquired in service is a matter for investigation. In our experience we find that the number of failures is about five per cent greater in the units in strain position than those in suspension.

The gentleman who just spoke mentioned vibration as a possible cause of insulator failures. The only vibration on our line is that due to windage, and I doubt that this is of sufficient severity to be a factor in the number of failures on our line.

We consider the megger a useful instrument in weeding out defective insulator units in service on the line, and it is our plan to test our lines each year and replace all units testing less than 100 megohms.

A. C. Pratt: We have had the usual experience I think that all companies have had. Our early insulators ran six per cent a year. Our insulators since 1914 are showing very good, probably one half per cent up to date. We have 10,000-volt insulators twenty years old that are still failing. Answering Mr. Fiske's question to some extent, they are now failing faster than ever.

C. P. Osborne: I notice that a lot of insulators have small hair cracks around the cap where the metal joins the porcelain. This is not noticeable except under a microscope. But in breaking the insulators for inspection and putting ink on them, you can find these little hair cracks through the glaze. I am wondering if that is caused from corona or is it from poor porcelain or from deterioration. We are very anxious to find out what the reason for that is. I thought perhaps by getting some information from Mr. Peaslee and Professor Ryan, who are able to tell us these things, we could be enlightened on that point.

D. W. Proebstel: In Alaska, in 1912, I placed in operation a 22 kv. transmission line, only 15 miles in length, and within less than a year after the line was in operation I had no less than 20 failures of insulators; not so much from the insulator itself as

from the pin supporting the insulator. The pin that was used was an oak pin; and upon examining the pins that had failed I found that the top of each had been disintegrated until it was about the consistency of wet chalk. I did not know what the cause was at that time but I supposed it was due to the salt air. Since that time I have come to a different conclusion. My theory is that the corona set up around the insulator, liberated ozone, which is a molecule of three parts of oxygen, combined with the nitrogen, forming nitrogen tetroxide. This was absorbed by the moisture which was on the insulator pin itself, or in the insulator pin and formed nitric acid which disintegrated the pin, causing the failures. Now the question I am going to ask the authors is this: Isn't there a probable source of mechanical failure of insulators due to a forming of nitric acid in and about the metal part of insulators, causing electrolytic action and corrosion and increasing the strains and stresses about the mechanical contact of the metal with the porcelain? And further, is it not likely that the chemical action there would cause absorption of water by the porcelain, resulting in failures?

J. C. Clark: Are Figs. 1-a and 1-b of Mr. Peaslee's paper drawn from data actually obtained in tests, or are they made up from a knowledge of the relative permittivities of porcelain and air?

I find it difficult to reconcile the curves shown in Fig. 5 for "conventional" and "rational" designs of insulator with the voltage distribution given for these designs in Figs. 1-a and 1-b respectively. The improved distribution shown in Fig. 1-b would lead me to expect a *lower* impulse ratio for the "rational" design rather than the *higher* one which is given in Fig. 5.

Is it really desirable or not to have a high impulse ratio on an insulator string? I believe that this question cannot be answered without a full appreciation of all the phenomena arising on a high-voltage transmission system. Involved in the proper answer are the subjects of the ability of the porcelain to withstand arc-overs, and the design of line hardware and accessories such as arcing-horns and shields.

Reference has been made to the use of the megger for periodically weeding out defective units. I believe the megger commonly used is the Evershed instrument containing a small 1000-volt generator and a scale reading a maximum of either 2000 megohms or 5000 megohms. I wish to point out that there is great need for an improved megger to be used in this work. Let us remember that the resistance of the

conventional cap-and-pin type porcelain suspension insulator in good condition is of the order of 500,000 to 1,000,000 megohms. Assuming that a 5000-megohm megger is used, we see, therefore, that a unit which is bad enough to give a reading at the upper end of the scale is already down in resistance to say, $\frac{1}{2}$ of 1 per cent of its normal value. Thus the amazing fact is developed that if it is not quite so bad, but perhaps down to 7500 megohms or $\frac{3}{4}$ of 1 per cent of its normal resistance, the megger operator accepts it as a unit of "infinite" resistance. This means that every periodic weeding-out employing this instrument probably passes many very bad insulator units which may require only a few more weeks time to become potential sources of serious line trouble. Furthermore, it has become fairly well established that there is a "coherer effect" in such insulating materials as porcelain which manifests itself in resistance measurements by making the resistance a function of the voltage used, so that the resistance decreases greatly with increasing voltages up to a point beyond which the resistance is constant during further increase of voltage up to the point of actual failure of the dielectric. I believe it has not yet been established whether or not the voltage employed in the Evershed megger is high enough to give resistance values of the order of those generally obtaining during the normal operation of the insulator on the line.

I believe that the time is again opportune for the Institute to develop a new set of insulator specifications in the way in which such a set was attempted about seven years ago. I think that the repetition of this attempt would bring at least the valuable result of eliciting important contributions from the operating engineers. The resulting discussion would be most helpful in clarifying the ideas now prevailing regarding proper insulator specifications and testing.

In this connection, it is important to note that there are apparently coming into existence two schools of thought regarding the conduct of high-voltage insulator testing. One of these schools seems to believe that there is grave danger of using too high a testing voltage, or of applying a high testing voltage for too long a time, with the result that good material suffers permanent injury. It is alleged that, if a test of such nature be repeated again and again, a certain small percentage of failures will appear *each time*, so that the ultimate result would be the destruction of *all* the insulators. The other school apparently believes that weeding out of defective material can be most successfully accomplished by the application of a

voltage limited only by the dry flash-over of the units under test. This flash-over voltage would be applied to all units for an indefinitely long time (with intervals frequent enough and of sufficient length to prevent much heating of the porcelain due to flash-over) until no more failures within a certain definite time just before the close of the test period. This second school would contend that all of the material passing the test would withstand its repetition indefinitely, and would deny that good porcelain is ever injured by strenuous high-voltage testing.

I think that all are agreed that the first requisite of a suspension insulator is that it support the line under all conditions of operation. It should not part by pulling or breaking or burning in any case. This is of great importance.

It is evident that there is still room for improvement in the so-called bomb-and-link type. Mr. Hillebrand mentioned units of this type which are failing regularly by spalling off. Can you state whether a copper, or a steel link is used, Mr. Hillebrand?

Mr. Hillebrand: That I cannot tell. The operators of the line gave me the information about the porcelain, but that particular thing I did not get.

Mr. Clark: That point seems important because it was soon found when steel link connectors were used that the porcelain spalled off, but this trouble ceased immediately when insulators of identical make were linked up with copper.

Mr. Hillebrand: One of the most interesting and significant things in regard to that experience is that the trouble did not begin until that insulator had been in use about eight years.

Mr. Clark: Such experience as I had learned of with these units developed that when the steel link was used, the insulators developed either mechanical failure, *i. e.*, spalling, at a point where the relatively unyielding steel connector developed highly concentrated stress on the porcelain surface, or else the unit punctured electrically there. This trouble ceased immediately, however, when copper was substituted for steel.

Concerning the relation of electrical stress and porcelain deterioration, I believe Professor Ryan can tell us of some very illuminating facts which he has gathered as the result of testing of insulators which had been stored under differing conditions.

Of course, all recognize the difficulty of designing a successful cemented-type porcelain suspension unit. Great care must be taken to avoid injury to the porcelain due to difference in temperature coefficients of

expansion, or to the improper arrangement of parts so that heavy loads cannot be safely carried, or to the use of improper cement. Some engineers are pessimistic regarding even the possibility of attainment of a successful design. I have hitherto felt that there can be no such thing as deterioration of porcelain considered by itself. If it is true that deterioration takes place in the porcelain itself more or less independently of the other parts of the insulator, it would be of the greatest value to possess a fuller fundamental knowledge of the material as soon as possible.

H. H. Schoolfield: In line with Mr. Clark's remarks I think as we have representatives of the insulator manufacturers with us today in such numbers and such a variety, it would be a good time to put in a word regarding uniform rating of insulators. In looking over some of the catalogs of the different manufacturers we find that two insulators, especially of the pin type, which are practically identical in design, have entirely different ratings of wet flash-over dry flash-over and recommended line voltage. The question was brought to my attention the other day, in looking over the table of wet and dry flash-over values given the proposed electrical safety code by the Bureau of Standards. I found that pin type insulators we have been using on our 66-kv. lines for a number of years, and which have given us practically no trouble, would not come up to the Bureau of Standards' requirements in regard to wet flash-over and dry flash-over, if we took the manufacturers' catalog rating as a basis. Another manufacturer with an identical insulator, using catalog figures would comply with the Bureau of Standards. I understand this difference is due principally to the method of making the tests. Some manufacturers use the needle gap, some the sphere gap, and I think it would be well for the Institute to work along lines toward having the manufacturers get together and adopt some uniform method of testing and rating of their insulators.

W. D. A. Peaslee: With regard to Professor Ryan's remarks in his paper as to the advisability or possibility of an insulator unit having a higher corona forming voltage than at present in general practice, it must not be forgotten that there are other features of design which must be taken into consideration. The production of a unit with a higher corona forming voltage would not be of such great value unless the flash-over voltage of the unit were raised at the same time. In the production of such a unit the capaci-

tance of the unit and the capacitance of the hardware connecting the units together to ground, is another feature that comes in, and a variation in those capacitances will do things to the shape of your flash-over and efficiency curves that are rather surprising. That is one of the fields that is under careful investigation at the present time, to discover just exactly what effect certain changes in those capacitances will have, and to what extent they can be controlled and reduced to analytical laws.

The statement came up several times in the discussion as to the unreliability of porcelain in tension. Porcelain in tension, or porcelain in general has somewhat the same characteristics in a stress-strain diagram as cast iron. A somewhat distinct lack of yield points; that is, the yield point and rupture point coincide, and the tensile strength is very much lower than the compression strength. At the same time, in structural work we find the cast iron employed quite commonly in tension.

We have made a great many tests of porcelain in compression and tension, and I will introduce at this point the question of vibration that was brought up, and we have found no evidences, nor have I seen test results that give us evidence that porcelain, either in tension or compression, is injured by either repeated stressing or by vibration, which is the same thing, provided that at no point in the porcelain do your stresses exceed the critical value at which rupture occurs. We have had pieces of porcelain under tension and under compression with shocks applied to them at a rate of several per second, totaling into the millions of shocks, in which as near as could be determined the stresses were within eighty per cent of the strength of the porcelain; and we have been able to find no difference in the porcelain after that treatment than before. But it must be borne in mind that the total stress in porcelain, whether in tension or compression, is the vector sum of the initial stresses in your porcelain and the applied stresses. Now that subject has been investigated I know in more than one laboratory very carefully.

Mr. Williams brought out very well the question of drying. We claim that practically no defects or cracks occur in the firing of porcelain that have not been borne somewhere else; and that a piece of clay or a porcelain body brought to the furnace, without initial stresses, laminations or strata, and of a shape that will shrink—and remember that all porcelain in firing changes in volume—and change in volume without producing stresses, will go through the furnace

properly, and while it is extremely necessary to control very closely your furnace operations it is just as necessary to control every other operation of your plant. In showing you that, I am going to tell you a little bit of the process we employ. From the time the raw material comes into the plant it is under the control of two distinct departments, one of which is production control test, and the other of which is manufacture; and no part of the raw materials, from the time they come to the plant, can leave a process until they have received the approval of the production control test. Samples are taken at every part of the processes from one end to the other, and before the body is permitted to be fired it is fired through a shortened cycle in our laboratory kilns; if it passes those tests and is approved by the laboratory it is allowed to go to production. Now we have a great deal of trouble in our experience with this question of drying, and we have obtained some rather interesting data. Porcelain used to be dried from the outside in, by being placed in a warm atmosphere, practically zero humidity and heated up and dried. If you dried the outside skin on this body, then you dried another one, and another one, and another one, those layers contracting in different ways and at different times, bringing a body to the kiln that had stresses set up in it. That can be shown by taking a drill and cutting little cylinders out of the body in different places. If you fire those cylinders and they bend, you have initial stresses. When you take a piece of porcelain and dry it so no matter where you drill a cylinder out of it and fire that cylinder you can't get a distortion of the cylinder, you have pretty nearly eliminated the drying stresses.

Drying is now done I think in most porcelain factories by drying from the inside out. The wet body is placed in a drier in atmosphere practically one hundred per cent humidity, the temperature brought up and the humidity is gradually reduced automatically, and we find a rather startling result. With 20 per cent humidity you can get a bone dry clay. And not only that, you don't get a drying in laminations and layers, but it dries so far as we can determine from the inside out and uniformly. And I will say for ourselves that the bending and cracking trouble in our kiln was reduced about 50 per cent immediately upon placing that drier in operation. And that was before we learned to use the drier.

Mr. Williams' remarks were very much in order. There is not a process in the manufacture of porcelain that can be neglected. You have to watch it all the time, and you are confronted with operating a factory

with labor and the human element entering into the situation. An amusing little incident occurred on our night shift on the controlling of our kilns. We were having a lot of trouble. Everything was right; the written records came in fine. We put some automatic recorders on various places and found out that we busted up several fine crap games about two o'clock in the morning; so we saved lot a of insulators we had been losing. You have to watch, not only your raw material and the processes, but the human people in your factory; and the consequences of a very slight slip are very, very serious to the manufacturer of porcelain. The raw material must be watched. It is rather a startling thing to see the variation in iron, that your magnetic separator takes out of your raw materials, even when they come from the same mine at different times.

Now in regard to testing, it is true there are two schools of thought arising in testing, and I believe that both are right. I believe the testing of a certain proportion of your product to destruction at all times to keep your probability curve in a factory, to establish it and know it, is necessary; but I also believe emphatically that every unit that comes out of a factory should receive a mechanical test, and after that should receive an electrical flash-over test. A unit that will not stand an electrical flash-over should not be put on any transmission line, I don't care where it is. Furthermore, I do not agree with the people who say that testing may injure a good insulator. I venture to say that any insulator that is good originally can stand almost an infinite amount of testing without injury. I will lay the cards on the table. I have taken one of Mr. Hillebrand's units and put it for 100 hours under 200,000 cycle flash-over, and it is a good unit, Mr. Hillebrand, yet. I have done the same thing with others. And I maintain that that does not injure the insulator if it is made right. But if it is not made right it will injure it.

In our test, after the mechanical load is applied they go to the electrical testing machine to receive a two-minute flash-over at 200,000 cycles; and we have found that every unit that punctured on that 200,000 cycle test, if we broke it open carefully we found a bleb in it somewhere, and that 200,000-cycle test will get that; and if it is right, no matter whether the cap and pin type, Jeffery-Dewitt, or what it is, it will stand that electrical test, and I don't agree with the people who say it will hurt it at all. If it is made right in the first place it will be right.

The same question comes up with deterioration. We have had units under hundreds of hours of 200-cycle test; we have had them under vibration, and we have had them under combined tension and high-frequency tests, until we are perfectly satisfied that if the factory can produce in the first place the right porcelain, and if the porcelain and hardware are assembled in such a way that the differences of expansion do not make any difference, I don't believe that the combined mechanical and electrical test has any harmful effect upon the unit. I have been unable to find any cases of that. We have eliminated the 60-cycle test, for the simple reason that if we take 50,000 insulators, test them to flash-over, we will have a certain amount of rejections, and we go over to the 200,000 cycle lastly and get a few more. But we have been unable, with any uniformity, to reverse that situation. If we test clear through with the 200,000 cycle first, in very, very rare instances have we been able to puncture one under flash-over with a 60-cycle test. I am emphatically in favor of a test, mechanical and electrical, on every unit that goes out of a factory, to insure that it is right. For our own purposes, we take the tests to destruction on a certain number of units to keep control of the general trend of our factory. We keep control as closely as we can on our processes, but the destruction test will give you a general over all view of what your factory is doing and how well you are living up to your standard.

In regard to the piezo-electric effect, I think I started something when I made that suggestion some time ago. We have been making some investigations on that, and also on the fact that porcelain is slightly soluble in water, and we are carrying out some tests at the present time, using 10,000 pounds pressure and porcelain that we know is porous, forcing water into and out of the pores of that porcelain a great many times and trying to discover if there is any apparent increase in the porosity. The tests so far have been rather disappointing, but it is a very difficult thing to get hold of. The establishment of a quantitative porosity test in porosities that are in very small fractions of one per cent, very small decimals of one per cent, is a rather difficult proposition. Qualitatively you can show it; quantitatively I have not yet been able to do it.

With regard to the cascading, I agree with Mr. Hillebrand to a large extent on that subject. I don't believe we are going to run into a great deal of difficulty with cascading. An insulator on the line, as Mr. Peek has said, is automatically graded when

the voltage comes up, and I have yet to see a string of insulators brought up to voltage flash-over as a string that appeared to start as a cascade. I have seen them brought up, have brought them up myself and have had the end unit flash-over without flashing over the whole string. And I am simply unconvinced at the present time that the cascading is a dangerous thing.

With regard to the question of the design of the Jeffery-Dewitt insulator to have a high corona forming voltage, the design of that insulator is a compromise on a dozen or so different requirements. The weight and thickness of the insulator are not used directly to secure a high corona forming voltage; they are used to secure a high puncture value, a rugged strength to resist the heat of power arcs and the general shape that is desirable between electrodes.

Now the point was brought up as to why this unit shows a high impulse ratio when it should show a low, and my opinion on that is, that it is a function of two effects, and I have made tests that have indicated to a certain extent that that is the case. The hardware on those units is galvanized and covered with small needle points to a certain extent, as is all galvanized hardware, and although the spider is large and at first sight looks like a large sphere, it has sharp edges on the sides of the legs and sharp points of galvanizing. Furthermore, the electrodes are so far apart that the flux density in the air at the surface of the electrode is different from what it is in the concentrated type, and I have been able to take a spider leg, fill it in between the spider legs with alloy and polish it carefully and reduce the impulse ratio to a very small decimal over one, as would be expected from a sphere gap. But with the construction used, with the fine points and the galvanizing in existence and the sharp edges of the legs, we have the impulse ratio shown. That impulse ratio curve was a test curve and was not made by our laboratory but by an outside laboratory to confirm our own figures. So we know that we do get it, and when I found we did get it I had something of the feeling of Mr. Hillebrand and wanted to know why, and began experimenting to find out, and I believe that is the answer.

With regard to the depreciation of porcelain, I agree with Mr. Fisk. There is no depreciation in good porcelain. I have some microscope slides of some of the first porcelain I guess that was made in history. It is awfully good porcelain. An insulator is not only porcelain, and I maintain there can be depreciation of insulators even though there is not a

depreciation of porcelain; and I think one of our difficulties in getting together on it is that we are not thinking about the same thing. When we talk of insulator depreciation we are speaking in general of an insulator unit, and when we speak of porcelain depreciation as porcelain depreciation, I agree with Mr. Fiskien, there is no such animal if it is properly made.

Now with regard to the meggar testing, I have done some work with the electron tube as a meggar, using around 80,000 volts direct current. I had a bright idea that I was going to measure the electrical resistance of insulators and throw out everything below a certain resistance. I had it fine. But the trouble was I took the insulators that would measure five million megohms when they came out of a kiln, throw them out in the back yard for three weeks and they would measure about thirty megohms; under proper treatment they would come up around five million megohms, and you didn't know where you were; whereas a unit that only measured about a half million megohms would measure a half million megohms under all conditions, no matter what was done to it. I don't believe that the meggar test is good for anything except to show that a thing is so bad it ought to be taken out and scrapped immediately. If the insulator shows a reading on the meggar I would not want it on a line of mine, because it is so bad that it is in danger.

The mechanism of failure of a porous insulator is something that I don't believe is very well known. The negative temperature characteristic of porcelain I think enters into it to a considerable degree. You will have a small conducting path in your porcelain; it will become water-logged and begin to conduct; the temperature will rise, and as soon as the temperature of the porcelain rises a little bit locally you have a much better conductor and more current flows and your heating effect is a function of the square of the current, and your current is a function of the resistance of the path, and it does not take very long after your porcelain gets to a certain temperature to go pretty quickly. We have tested that out pretty thoroughly in electric furnaces with porcelain puncturing at different temperatures in electric furnaces, and the knee of the curve is pretty steep. When you get with a given body to about a certain temperature it goes pretty quick. The porous porcelain that is in existence today will be weeded out in time; and, as Mr. Hillebrand says with reference to the porcelain made in the last four years, I believe it is within probable human ability to produce a uniform product, non-porous;

but we have a great many hundred thousand insulators out yet that will have to go through a cycle to get rid of that.

I was very glad to hear Mr. Hawley's statement as to the improvement that they have been able to make in the puncture voltage. The question of how great a puncture voltage a unit should have is a question largely of the judgment of the engineer. We don't believe that a unit should have less than 250,000 volts puncture. A great many people don't agree with us. The only thing that will answer that question is the next twenty years of operation on transmission lines. I think practically all the porcelain manufacturers today are making good non-porous porcelain, practically the same quality, and from now on, excluding a lot of these old insulators that Mr. Fiskens speaks of that are out on the line, we have probably an even start. The next twenty years ought to tell pretty closely whether it is a question of porcelain or design. The porcelain manufacture has developed from a black art or science, in which everything was mystery and secret process, to a scientifically controlled process, and I think that is true of every factory in the United States of any size. Therefore we are all on an even basis now in the manufacture of good porcelain. The next few years are going to begin to give us some information as to whether or not those that have perfectly honest differences of opinion regarding the design are all wrong or all right, or part of us are wrong, or where we stand, and while the laboratory tests are of great value and help us a lot, it is pretty generally admitted that the one thing that will answer the question is service out on the line and what happens.

With regard to the failure of insulators in a strained position, I believe that the results are a little confusing in that respect, for the reason that they refer to old insulators. I do not believe, and Mr. Hillebrand may have some information on this subject, that the deterioration or failure of insulators in strained positions is any greater than the suspension, when we consider the insulators made in the last four years. They are making good porcelain now. The cap and pin type insulator have a yielding layer between their cement, steel and porcelain, and they will stand expansion and contraction. With your string in a horizontal position none of the insulators are shadowed by the insulators above them. On a frosty morning when the sun hits the top unit of the suspension string the units below that unit are to a certain extent in the shadow and are allowed to come up to temperature more slowly, but in the horizontal position the sun will strike them

all, and I believe it is simply a question of the theory of probability, that there are more exposed to being hit and there will be more that will show up with failure. But I have noticed pretty carefully the reports of operating men, and so far as I can see from the meager returns yet in, the insulators made in the last four years are not showing that wide difference in failure between the suspension and strain stress.

With regard to the immersion test, I will be perfectly frank with you. I don't regard that as in any way conclusive except as the megger test is. An insulator that will not stand the immersion test from freezing and boiling water I don't think is much good, but I don't know many made up in the last three years that won't stand it. If they don't they should not be considered. But if they should stand it, there is not much of any way of saying which is the best of all. Now I know, to be perfectly frank with you I have had cap and pin type insulators under fifty or sixty immersions in boiling and freezing water, and I have had many of our own. A few have failed and the others have gone on. But it is an indication that they will stand forty or fifty of those immersions, which are more severe generally than the climatic changes; and if an insulator appears that won't stand that I would be pretty suspicious of the insulator.

I don't believe that the corona forming nitric acid in the air is anything we have to worry ourselves very badly about. I have never seen any indications on an insulator yet of that action. We have in certain places some cases of insulators on railway construction wherein the locomotives stop under the insulator string and sulphuric acid forms on the cold insulator, which has given some trouble due to corrosion in galvanized fittings. If there was very much nitric acid formed by corona you would get that pretty positive. The fact that we haven't run into that very much makes me believe that it is not an important feature in the design.

Regarding the mortality tables of insulators—that study is being made for a rather different purpose, I believe—I don't think I brought out very clearly just what the purpose of that is; but what we are trying to find out is how long an insulator stays up on a line regardless of why it comes off. Now we have some very valuable data acquired already regarding poles, and the data were prepared in this way; we wanted to know how long a pole stayed up no matter whether it was taken down by the local councilmen or an automobile ran into it, or they changed the pavement and had to move it, or whether they got a joint pole

committee and had to put up a bigger pole. The data we want are, as follows: When an insulator fails we want to know two things,—how long that insulator has been out and how many insulators there are on the line of the same age as that insulator. That is the fundamental data we will ask of you. Eventually those tables will give you, as the data becomes more complete, how long an insulator will live, regardless of why; and in the question of financing new projects and studying the cost of maintaining lines, that information is of a great value. In fact, it is quite a serious thought among large corporations at the present time to write insurance on certain features of their line construction. They haven't got the insulator yet on the basis of these mortality tables which have already been developed to a rather large degree. As insulator manufacturers we are very much interested in the operating man's troubles, but one difficulty we find with the operating man is that he tells us his troubles without the history. He will take you into his office and will say, "Look at that insulator. It has got a hole in it you can stick your fist through." "Fine! How did it happen?" "I don't know. It was taken off of the line." "How long had it been up?" "I don't know." "When did you get it?" "I don't know. It was bought some time ago." You don't know where it was, you don't know the exposure to the sun, you don't know the temperature ranges it was subjected to, and he doesn't. He has not been keeping those records, and as a consequence we get vast volumes of data which we do not dare to use for the simple reason we can't form any conclusion because we don't know the history. If the operating men will only watch their insulators and the history of those insulators, and when an insulator fails, or any of them for any reason fail, if we can know when it failed and the history of the insulator it will be of the greatest value to us as manufacturers. I want to urge on all the operating men here to get their records in that kind of shape and let us have them, and the more we get of that kind of information the faster we can bring this insulator situation to a point where it is satisfactory and the greater progress that we will make.

S. C. Lindsay: Mr. Peaslee, before you close I would like to ask a couple of questions regarding those vibration tests. Now in the first place on what types of insulators did you make those tests?

W. D. Peaslee: I made those tests on three makes the cap and pin units, our own units, and the Hewlett.

S. C. Lindsay: You said the vibration tests ran

into the millions. Did those millions approximate the number of millions of vibrations they would be likely to experience over a period of eight or ten years of service?

W. D. Peaslee: Well, that is a little hard to say. We had a rig set up with a string of insulators on it and a cam raising and dropping a weight on it, and some of the tests we ran as high as eleven to twelve million repetitions, shown by a revolution counter; some were only four or five millions; and after those tests we could find no change in the average tensile strength of the units. Not only that, we have taken porcelain and made up special test pieces, placed them in tension and placed them in compression and run up into ten and twelve and thirteen million impacts on those, and in that case we had the stresses absolutely controlled and we knew to what value we were stressing the porcelain. Naturally in the insulator we had no idea of exactly the value of the maximum stress in the porcelain, and in all of our cases we have found an absence of results that indicate that there is. And furthermore, from the standpoint of theory, I am unable to see any reason why it should be so. A piece of porcelain has the strength, we will say, of 5000 pounds in a given area. If you stress that porcelain to 2000 pounds and bring it back, you can stress it as many times as you wish, you won't get any permanent set. There seems to be no molecular or other kind of flow or motion in it. So as long as you keep the stresses below the rupturing stress of the porcelain, how can there be any deterioration?

S. C. Lindsay: There can't. That is just what I was bringing out. After that it went through several hundred thousand million vibrations probably, over a period of ten years that those stresses were set up by the vibration beyond the limit of the porcelain to stand up.

W. D. Peaslee: Well, it will break at the first vibration that goes above the ultimate strength. Those stresses are not cumulative. The porcelain is elastic within its strength and those stresses don't add up. If you have got a permanent set you may expect an addition of stresses, but without permanent set and with porcelain of the vitreous character that it is—and I have never seen melted feldspar crystallized by vibration; and under the microscope this porcelain that had been through several million cycles showed no difference in structure from what it had before it was subjected to test. So I can't see any reason that, as long as the stresses are kept within the critical strength, there would be any weakening in strength

due to repeated load. And that is all the vibration is anyway: It is the repeated load, very rapidly applied.

S. C. Lindsay: Your conclusion then is that there is nothing to this theory that vibration ultimately breaks down the insulator?

W. D. Peaslee: No, I don't believe there is. I can't accept that as a theory at all.

There is one question that was asked which I forgot to answer. That was whether the figures shown there were tests or made up from a knowledge of the shape of the field. Those figures are made up from a series of a great many hundred tests on different shapes and forms of dielectric boundaries between the air and dielectric, and are one of a great number of tests that we have made in that study.

F. W. Peek, Jr.: The Hewlett type suspension insulator is the original suspension insulator. The first suspension insulators put into practical operation were of this type. We have, therefore, a longer practical experience with this type than any other. After a considerable number of these insulators had been put into operation, the cemented type insulator came into extensive use. This followed because given electrical characteristics could be obtained at less cost with the cemented type than with the Hewlett type. It was soon found, however, that in general a very large percentage of the cemented type units failed after several years of operation. The great importance of the mechanical design is now well understood and undoubtedly great improvements have been made in the mechanical design of the cemented unit. I have made a study of Hewlett insulators located in different parts of the country, and have not found any evidence of appreciable deterioration either in operating records or in electrical and mechanical tests made on the many units returned to the laboratory. The recorded cases of trouble were confined to failures of the more or less crude early types of hardware.

Mr. Crawford's experience with the Hewlett insulator is practically the universal experience with this type. Mr. Hillebrand states that he has found a case where the Hewlett type of insulator has depreciated 1 per cent after ten years of service. This is unusual. Although I have investigated practically all systems using Hewlett insulators, this case has not come to my attention. It may be due to steel hardware as Professor Clark points out. It is of interest, however, that this case cited against the Hewlett would be considered an unattainable record for the older cemented types, where the depreciation is sometimes 25 per cent after three to five years.

Regarding the discussion on transient arc-over voltages, it is my belief that an insulator should have high impulse ratio. It is possible to obtain this without a sacrifice in the characteristics at normal frequency.¹

While it is true that the maximum unit voltage stress for a long string is less on the cemented types than on the other types, the same shield reduces the stress to practically the same value on all types. As I have already pointed out in my paper, the ring or antenna type of shield corrects uneven voltage distribution, prevents excessive corona on the line end units and tends to direct the power arc away from the string. The maximum unit stress on the 200-kv. shielded string can be made less than on the 100-kv. non-shielded string.

In conclusion I wish to state that I have faith in the successful operation of transmission lines at 220 kv.

Harris J. Ryan: In regard to the original application of the insulator shield by Mr. Fisken: The purpose of the shield brought forward in the present papers has particular reference to the problem of the suspension insulator when used for line voltages in excess of 150 kv. Its purpose is twofold: (1) To limit the maximum voltage duty to be carried by any unit in the string; (2) To lessen the punishment of the string units when flash-over occurs. Undoubtedly Mr. Fisken's design was in effect, an early application of the static and flash-over shield to pin type insulators. Probably the excellent durability noted is due to the improved flash-over characteristic caused by the shield and good fortune in securing insulators in which the porcelains are so made and assembled that cracking is virtually absent.

Mr. Crawford is right in bringing up the possible value of holding to *seven* units in a string and of making them larger than at present for line voltages in excess of 110 kv. Two problems are involved in this proposition: (1) The quantity production of such larger units; (2) Their electrical characteristics, which in any event would have to be checked or adjusted by actual test.

In regard to Mr. Stauffacher's remarks concerning the proposition to elevate the voltage on the Big Creek-Los Angeles transmission from 150 to 220 kv. We will gladly do all in our power to cooperate in the undertaking to determine the values of the insulator factors that will enter into such undertaking.

Too little is known at present (July 1920) of the

1. Peek, The Effect of Transient Voltages on Dielectrics, A. I. E. E. TRANSACTIONS 1915.

details of flash-over formation to deal with the subject in the manner presented by Mr. Hillebrand. What he has said in this instance is to be taken as an excellent effort to define the problem of flash-over with and without cascading rather than to present factors which are definitely understood in reference thereto. Regarding his reference to porcelain as "cracking with time in accordance with its inherent characteristic": I can not agree that this has been demonstrated, as yet, for good grade high-voltage porcelain. It is an open question today as to whether good grade porcelain has such liability to crack when exercised by thermal or mechanical cycles to a reasonable extent. Herein, I share Mr. Fiske's impression that there are many evidences that porcelain can be made which will not deteriorate. Laboratory tests and observations in the field should be undertaken to settle this question as quickly as possible.

The suspension insulator when used as such can not be subjected to severe mechanical vibrations. Mr. Lindsay, however, is right in emphasizing the importance of knowing just what the effect of such vibrations is upon the durability of the units. It must be that in dead-end duty these effects are occasionally severe due to longitudinal resonant mechanical vibrations set up by the wind, particularly in long spans.

Regarding the "watts lost" curve on page 1671: Mr. Hillebrand is entirely right in his surmise that the loss occurs for the most part in the air surrounding the unit and not in the unit proper. It is well to remember that the air is there and necessarily a part of the insulator assembly; that no good comes from operating it overstressed or ionized.

"Impulse ratio" considered by Mr. Peaslee and discussed by Mr. Hillebrand must be a highly uncertain factor in flash-over characteristics of insulators. For example the results of measurements made since the date of this discussion, of the maximum r. m. s. values of 55,000-cycle voltage transients required to break down air columns between a one-inch tube terminated with a three-inch sphere as the main electrode and a grounded square plate having an area of 25 square feet are given in the following table:

Gap in inches	Required for flash-over		Impulse ratio
	R. m. s. max. 55,000 cycles transient, kilovolts	Appx. estimate for 60 cycles, kilovolts	
10	250	140	1.78
25	300	290	1.03
50	370	540	.69
75	440	790	.56
100	500	1040	.48

The values here given are only approximate and may be subject to some revision when finally reported.

Piezo-electric effect in the undissolved quartz crystals in the porcelain has been brought up as a possible cause of cracking of porcelain. Now it is true of the quartz crystal that in a plane parallel to the face of the crystal and at right angles to the optic axis the crystal will expand or contract on direct or reversed electrification. In so doing it also expands or contracts under such electrification in a direction that is at right angles to the face of the crystal and to the optic axis. It should be remembered that these expansions and contractions are enormously small due to electric fields set up by 10,000 volts per inch; and that the quartz crystal remaining in good electrical porcelain is a body so small that its matrix of elastic amorphous material easily accommodates such dimensional changes without mechanical overstress. The radio engineer has used porcelain extensively in intense high-frequency fields without noting a tendency to deteriorate.

Professor Clark has referred to our studies of insulator durability in relation to the daily variation of the elements. The results obtained through these studies have been published in: Discussion, TRANS. A. I. E. E. Vol. XXXVI, p. 563, 1917 and the report of the Insulator Committee, John A. Koontz, Chairman, of the National Electric Light Association, Pacific Coast Division, 1920.