Test and Investigations on Extra High-Tension Insulators

From a Purchasing Engineer's Point of View, with Special Reference to Methods of Test for Acceptance, Tests for Porosity and Deterioration.

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Review of the Subject:—Owing to repeated failures (the number of which increased as time went on) of 66,000-volt transmission line insulators (pin type) of the first Hydroelectric undertaking, carried out by the New Zealand Government, in 1914, and having in mind that Hydroelectric Power was to be developed to the utmost of the Dominion's power resources—of which there are many—the investigations contained herein were commenced at the suggestion of Mr. E. Parry, B.Sc. M. I. E. E. late Chief Electrical Engineer to New Zealand Government, and has been continued for the past five years with the sanction and support of Mr. L. Birks, B. Sc. M. I. E. E. Chief Electrical Engineer to New Zealand Government, with a view to ascertaining the cause of such failures.

It is the purpose of the paper to show

1. To what extent deterioration has set in on the 66,000-volt line referred to.
2. That the cause is due to the fact that the insulators were initially porous.
3. That tests at present in vogue with regard to ascertaining the porosity of insulator porcelain are totally inadequate, as the authors consider, immersion of the complete unbroken insulator under a pressure ranging from 1500 to 2000 lb. and the total amounting to 250,000 to 300,000 lb.-hours the least that will give reliable results.
4. That non-porous insulators can be made that will remain good in service for an indefinite period and withstand perfectly the tests for porosity as recommended.
5. That individual testing with high frequency seems to be the only reliable method for testing for dielectric strength.
6. That a percentage test of each batch of insulators by the maker is unsatisfactory, because unless each shell of each insulator, in the case of pin insulators, and each disk in the case of suspension

insulators, is definitely flashed over before being put to service, then breakdown trouble seems bound to ensue.

7. There is room for more cooperation between the insulator manufacturer and the purchasing engineer in regard to acceptance tests and the handling and maintaining of the insulator in service. If manufacturers will not agree to the tests as recommended by the authors, being made in the factory, then in countries such as this (New Zealand) which is situated so many thousands of miles from the point of manufacture, a public testing bureau should be established where undertakings could be arranged for, such tests to be made as described herein, when the cost of replacing the failures should be borne by the manufacturers.

8. That it has been found in New Zealand we have the necessary materials from which insulators can be and are being made, that will withstand the tests described equal to the imported wares.

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IN this paper we propose to give an account of some investigations which we have carried out in conjunction with the Public Works Department of New Zealand, with a view to obtaining some definite information regarding the causes of insulator deterioration in connection with the Lake Coleridge electric power supply system. It is hoped that this may be of some service to those interested in the insulation of extra-high-tension transmission lines, which are to play such an important part in the hydroelectric development of this Dominion in the future.

It is the experience not only in New Zealand but in other undertakings abroad, that the problem of pro-

ducing an insulator that will successfully withstand both electrical and mechanical stresses for an indefinite period, without deterioration or destruction, is one of the most difficult in connection with the transmission and distribution of electrical energy at extra high tension.

It is proposed to describe in detail the tests and the results of these tests, on several types and makes of insulators, including those of British, American (U. S. A. and Canadian), New Zealand, Australian, and German manufacture.

It is desirable to state briefly how the authors came to deal with such a variety of makes.

Considerable experience has been obtained with insulator failures on the Lake Coleridge electric power

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transmission line in this country, and at one time during the late war the position due to repeated failures became so acute that it was found necessary to purchase any makes available, having in mind that these investigations were about to be made. It was hoped that a careful investigation would demonstrate the best type and quality of insulator to withstand the requirements of the heavy duty called for, involving dielectric strength, mechanical strength and durability.

FIG. 1—SHOWING HIGH-FREQUENCY OSCILLATOR AND SAMPLES OF PUNCTURED INSULATORS

The apparatus employed consisted of:

- (1) A 1000-volt 2000-megohm megger set.
- (2) A 20-kv-a. 100,000-volt 50-cycle single-phase testing transformer with a double-scale 100,000-volt and 50,000-volt Kelvin electrostatic voltmeter.
- (3) A General Electric Co. high-frequency oscillator set, capable of impressing 175,000 volts with spark gap for voltage measurements (See Fig. 1.).

(4) In the hydrostatic pressure tests for porosity, a steel testing vessel with cast iron ends capable of containing a complete insulator of the largest size, and of withstanding a pressure of 2500 lb. per sq. inch, with a high-pressure compressor capable of working up to this pressure (Fig. 2).

The electrical tests were carried out at the Public Works Department test room at Addington, Christchurch, and the porosity tests at the Physical Laboratory, Canterbury College, Christchurch. For the latter purpose the special high-pressure vessel mentioned above was provided from a research grant received from the New Zealand Institute, the assistance of which is hereby acknowledged.

A detailed account of the vessel may be given, as it was eminently successful. After pumping up to a pressure of, say, 2200 lb. per square inch, it would frequently retain the pressure so well that it had not fallen below 1500 lb. per sq. inch in four days, although no further pumping had been done in the meantime.

A hollow piece of cast steel 15 inches in internal diameter, 19 inches in external diameter and 20 inches long, was turned at both ends, and a narrow spigot was left about $\frac{1}{4}$ inch from the inner edge and running round each end. This spigot was $\frac{3}{8}$ inch high and about $\frac{3}{16}$ inch wide. The spigot fitted with a corresponding groove in the covers which was $\frac{1}{2}$ inch deep. The groove and spigot were of such a width that a piece of leather sewing machine belting fitted the groove exactly in width. When the end pieces were screwed down, the spigot was seated upon the leather belting and made a satisfactory joint. The end pieces or covers were of good cast iron eight inches thick, and held on by 12 bolts each 2 inches diameter. When the pressure was first applied at about 800 lb. per sq. inch, it was seen that moisture was "weeping" through the bottom cover, but this righted itself probably by internal corrosion and no further trouble was experienced.

An illustration of this testing vessel is shown in Fig. 2.

Under this test the amount of penetration is apparently proportional both to the hydrostatic pressure attained, measured in lb. per sq. inch and to the time of immersion. The authors, therefore, propose to measure the intensity of the test by the product of these two factors or by the "pound-hours" to which a square inch of the insulator has been subjected.

FIG. 2—SHOWING LARGE POROSITY VESSEL USED FOR THE TESTS DESCRIBED HEREIN, ALSO THE SMALL VESSEL IN RIGHT CORNER USED FOR THE EARLIER TESTS

The usual test adopted was at a pressure of 1500 to 2000 lb. per sq. inch applied for a period of seven days, *i. e.* for 250,000 to 300,000 pound-hours. We wish to insist strongly that the intensity of the porosity test to be of any value should be of this order. One important firm claims credit for its insulators because they will withstand a porosity test at a pressure of 200 lb. for 24 hours—*i. e.* 4800 pound-hours! In view of the prolonged exposure to the weather to which the

insulators are subjected in service, although only at atmospheric pressure, we consider that such a test is totally inadequate, in fact that any porosity test of less than 200,000 pound-hours is comparatively useless.

With regard to the efficiency of testing with high-frequency oscillations as compared with low or working frequency, the former gives, in the authors' opinion, much the more searching and reliable results.

After the Lake Coleridge 66,000-volt transmission line had been in service about two years, the insulator failures became so frequent that it was decided to test each insulator of the remaining stock of 500 individually, so as to insure that those used to replace the failures were reliable and good, and for this purpose the high-frequency oscillator was used.

The original consignment of insulators was imported in 1913 and this stock of 500 replace insulators was obtained in 1915 and stored in the open. They had of course withstood the makers' factory tests, but on being retested two years after delivery, during which they had been exposed to the weather in the works yard, no less than 43 or 8.5 per cent were found by individual tests to be defective. In several cases these insulators were of porous material, and had absorbed moisture during the period they had been in stock, as was proved subsequently.

Each of these replace insulators as it was tested, was numbered and its position on the lines when put into service was recorded, and although over five years have elapsed since these precautions were commenced, and over 200 breakdowns due to insulator failures have occurred, and over 500 insulators have been replaced, not one of the tested insulators has yet given trouble, which shows the efficacy of the method of testing individual insulators after they have been exposed to the weather in stock for a couple of years, thus weeding out porous ones. The main cause of deterioration of the insulators that did fail was apparently absorption of moisture, and if porous insulators are detected and excluded, insulator deterioration will largely diminish.

It seems to be the practise of some makers to test insulators with a set pressure at working frequency, from head to pin, and from these results to pass the batch or otherwise. We consider that this method is unsatisfactory, inasmuch as the faulty shells will not betray themselves (being protected by the good ones) unless each shell is individually flashed.

Further, this flashing should be done by high-frequency pressure, for the authors' experience has been that, where insulators have been guaranteed by the makers, as tested at a certain pressure, at low or working frequency, they have failed decisively when tested with the high-frequency oscillator at many thousands of volts below the guarantee. Others have withstood the pressures named by the makers *from head to pin* on both high and low frequency; but on individual testing of the shells, some were

apparently mechanically perfect, but electrically were almost conductors, as will be seen later in the description of tests.

METHODS OF TEST

The following program of tests was adopted:

- (1) Measure insulation resistance of each shell with 1000 volt megger;
- (2) Subject each shell separately to bare flash-over pressure at 50 cycles (working frequency) for 15 seconds;
- (3) Subject each shell separately to bare flash-over pressure at high frequency for 15 seconds (Fig. 1);
- (4) The complete unbroken insulator was placed in the porosity testing vessel and covered with a strong aqueous solution of fuchsin (Fig. 2). A hydrostatic pressure of 2000 lb. per sq. inch was then put on the vessel, and the insulator remained immersed in the fuchsin solution under a pressure ranging from 1500 to 2000 lb. per square inch for about a week, that is, until the number of pound-hours had reached 250,000 or 300,000.

As soon as convenient after removal from the porosity vessel the electrical tests were repeated, after which the insulator was broken up for signs of penetration. If the samples submitted withstood this complete set of tests without breakdown or signs of penetration, the batch was considered satisfactory.

It is worthy of note that of twelve makes tested, samples of seven failed to pass the tests, which shows the necessity for special acceptance tests in all cases.

It was impossible with the apparatus at our disposal to subject more than a very few individual insulators of any make to the hydrostatic pressure test for porosity. Some of the insulators so tested have been chosen to ascertain the cause of certain weaknesses previously known to exist; and the weaknesses have generally been found to be due to, or at least associated with, a band of porous material in the body of the porcelain. We consider, therefore, that if any of the few insulators in any batch that may be submitted for test are found to be porous, the whole of the batch should be rejected, and the maker informed that a repetition of such an experience would seriously jeopardize his chance of securing future contracts.

MEGGER TESTS

While the megger test has its limitations, yet it seems to be advantageous in connection with the hydrostatic pressure tests; in that, after the insulator has been under the hydrostatic pressure, it is possible to obtain with the megger definite indication of the condition of the shells; but the greatest care must be taken when testing with the megger, for not only the humidity of the atmosphere, but even the handling of the insulator or the megger leads, will often tend to lead to wrong conclusions.

When testing insulators with the megger—dry as received—it has been noted with a dry contact, however thorough, that results are by no means consistent, as it is

almost impossible to "wipe" the whole of the surface of the joints between shells with the contact lead, and if any portion is missed, a puncture path or porous spot may also have been missed owing to the high resistance of dry cement.

It has therefore been found essential to cover the cement joints to a depth of about 1/16th of an inch with weak acid, which gives a sure contact over the whole area of the cemented joint, and more consistent results are obtained. But if high-frequency tests are to follow, the results of the high-frequency tests are likely to be misleading, unless the joints are thoroughly cleaned, because the oscillator cannot supply the C^2R losses due to dampness without undue voltage drop and probably the voltage would not reach flash-over owing to the poor regulation of the oscillator.

Humidity of the air, and human handling, are important factors when testing insulators with the

FIG. 3—INSULATION AND HUMIDITY CURVES—66,000-VOLT PIN INSULATOR

megger, and it is therefore only on the driest of sunny days that megger tests should be attempted.

The curves in Fig. 3 give the results of megger tests on an insulator over a period of 20 hours during a day in early spring, and show that, in this latitude, it would not be reliable to test insulators with a megger outside the hours of 10 a. m. and 2 p. m. during certain seasons, or that megger tests should not be conducted when the percentage of humidity is much over 85.

It would seem therefore, that where, owing to porosity, the insulator may be a partial conductor, as for instance an old insulator which has been in service some years, and with no other means of test at hand, the megger may be used to advantage, but with recently made insulators, being tested for acceptance, the megger test could be dispensed with. Factory inspection has reached a stage in which faulty insulators, that could so easily be detected, would surely never leave the factory.

HIGH-TENSION TESTS AT WORKING FREQUENCY

When no other means are available, this method—provided each shell is separately tested to flash-over—is useful.

This can be arranged where working pressure is available, and, provided each shell is tested separately at working pressure, the aggregate flash-over of the whole insulator may be assessed.

To subject an insulator to working pressure, applied from head to pin, as an acceptance test is misleading, and the results are of practically no value. It will find those which are defective in all shells—a state of affairs hardly to be expected with the present-day makes of insulators—but it will not betray any single shells that are faulty; and if there are any such, the seeds of trouble for the transmission line are sown.

A section of three miles of the Lake Coleridge transmission lines runs in duplicate alongside a steam railroad. After two years' service, 12 insulators were taken down at random for testing purposes. In every one of these 12 insulators the inner shell of the four was completely coated with a black deposit, and a test showed the shells so covered to be conductors, and hence it can be reasonably assumed that the factor of safety of all insulators near the railroad was reduced by 25 per cent, due to this deposit. With mechanical troubles developing on the top shell, due to cable loading, cable clamps, etc., the factor of safety is still further reduced, and if there happen to be one or two bad shells coupled with a mild surge due to switching or dropping of load, the insulator will break down so much earlier.

It is noteworthy that 47 or 19.8 per cent of the number (264) along the line of railroad have failed or had to be replaced during six years. A few of the breakages were mechanical but it is most probable some of the shells were "electrically down" before being put on the line.

On one occasion, about one-half mile from the railroad section, a single inner or fourth shell insulated the line for eight hours, the other three having punctured decisively.¹ This certainly could not have taken place on the railroad section, where each fourth shell was coated as described.

It therefore appears that it is absolutely essential that all shells must be tested individually.

TESTS WITH HIGH-FREQUENCY OSCILLATOR (Prof. E. E. F. Creighton's Method)

Where this apparatus is available, it has been found to be more effective in detecting faulty insulators, provided they are dry and non-porous, but as stated previously, to test from head to pin, by running up to the full capacity of the oscillator set, is very misleading, although if two or more shells are "down" (which is hardly likely with the modern makes of insulators), then indications will be quite clear.

1. Birks & Ferguson, N. Z. *Journal of Science*, Vol. 3, No. 4, page 184.

If a 300,000-volt set is available, then head to pin tests could be resorted to in order to save time, but it would still be very necessary to note that each shell must definitely flashover.

With the present-day makes of insulators, where perfect vitrification is aimed at, the megger and low or working frequency tests could be safely discarded in favor of testing individual shells by high frequency, combined with a percentage subjected to the hydrostatic pressure tests for porosity, for it has been found that where other methods have proved doubtful and some even shown the insulator to be apparently sound, the high-frequency pressure has shown them to be "down" at a comparatively low voltage.

Some engineers are doubtful as to the advisability of subjecting insulators to "flashover" on high frequency before being put to service, fearing undue stress resulting in possible damage.

Local experience tends to show that insulators so tested are quite undamaged, for upwards of 1000 insulators have been so tested (*i. e.* each shell up to flash-over on high frequency for 15 seconds) and as previously stated, over 500 have been put on the lines referred to and, although nearly five years have elapsed since the first replacement was made and over 200 breakdowns have occurred, not one of those so tested has yet failed electrically. One had to be replaced owing to damage due to rifle fire, but although mechanically damaged it was electrically as good as the day it was placed in service.

The authors have a special insulator, which has been used for hundreds of demonstrations of Creighton's Super Spark Potential Test²; and a certain suspension insulator which supports the high-tension lead of the high-frequency oscillator, receives full punishment every time the set is used, yet both these insulators are apparently quite undamaged. Such authorities as Creighton,³ "consider that such tests are quite mild, and correspond to a rare case of switching and further are nothing more than the insulator may get in operation in due time;" and Peaslee,⁴ states, "accumulated evidence of a large number of tests, covering combined electrical and mechanical tests, fatigue tests, and high-frequency tests, indicates such stressing has no effect whatever upon the properties of the insulators."

Many suggest, for safety, taking each shell up to bare working pressure only, but the authors have found in seven instances at least a pin hole or other fracture at or about 1 in. from the edge of the shell which it did not betray itself at bare working pressure, but at approach of flashover, the arc concentrated at the point of fracture, and in less than one minute the

shell cracked. These would have been passed on a bare working pressure test.

The authors are therefore of opinion that it is absolutely essential to see that each shell should withstand flashover pressure at high frequency for at least 15 seconds continuously.

DETERIORATION

On the Lake Coleridge transmission lines there are over 5000 insulators and over 800 or 16 per cent have had to be replaced in six years, either owing to failure in service, or to patrolmen's observations of mechanical defects, and our experience indicates that this is due mainly to initially porous insulators, coupled with mechanical weakness.

We have found from experiment and experience that porcelain can be made which is nonporous to the limit of the somewhat severe tests we have applied, and in that case, moisture will not get into it, whether the insulator be in service or otherwise.

FIG. 4—CURVES SHOWING INSULATORS REPLACED ON TRANSMISSION LINES

Curves are shown in Fig. 4 giving the numbers that have failed in a fog or mist area, and we consider that there is no doubt that the cause is due to porous insulators, absorbing moisture to such an extent as to render some shells practically conductors, when attacked by high-frequency surges or even at working pressure.

No doubt many other bad insulators are on the lines in other areas, where fog or mist is not prevalent, and in course of time these will be weeded out by breaking in service.

The diameter of the capillary tubes in even the most porous insulators we have tested is extremely small. In the first experiment we used fuchsin as the coloring agent, by which the penetration could be traced. Finding however, some difficulty in photographing the color, though it was strongly visible, we discarded it for the time being for red ink, or rather a solution of red ink powder in water. It was noticed, however, that it seemed extremely difficult to force the red ink into

2. Creighton, Insulator Testing, A. I. E. E. JOURNAL, May 1915, page 765.

3. Creighton, Insulator Testing, A. I. E. E. JOURNAL, May 1915, page 766.

4. Peaslee, W. D. A., Insulator Porc., A. I. E. E. JOURNAL, Vol. XXXIX No. 5, page 445.

the porcelain. A faint coloration was frequently noticed, but not such as might have been expected from the red ink. It seems likely that the size of the capillaries was less than 10^{-5} cm. in diameter. It must be remembered that both capillary "suction" and the tendency of moisture to condense in a capillary tube, increase as the diameter of the tube decreases. In the case of capillary "suction," the effect is inversely proportional to the diameter. In the case of condensation the ratio of the saturation vapor pressure on a plane surface and in a capillary tube is given by the expression

$$\log_{10} \frac{\omega}{\omega'} = \frac{5.6 \times 10^{-8}}{r}$$

where ω is the saturation vapor pressure for the plane surface and ω' that for the capillary.

Taking this latter effect, it is well-known that for capillary tubes, where the radius is 10^{-5} cm. the saturation and vapor pressure on a plane and in such a capillary are very approximately the same, whereas for tubes of 10^{-7} cm. radius 30 per cent humidity on a plane surface would be enough to cause saturation of such a tube.

It will therefore be seen that for the capillary tubes in insulators as we find them, the air is always practically saturated, and if tubes exist whose size is greater than 10^{-8} (the ordinary molecular size) and less than 10^{-6} , there will be a very strong tendency for moisture to condense, and it is this tendency, both owing to

capillary "suction" and to condensation, which we consider has been the cause of the deterioration that has been experienced.

It cannot be too strongly emphasized that a porous insulator is certain sooner or later to give trouble. The pores of such an insulator consist of extremely fine capillary tubes, and the whole tendency of moisture, is to condense in such tubes, which never, even on the warmest day, a corresponding tendency for the moisture to evaporate. Thus the moisture is always increasing in quantity within the body of the insulator until a time comes when the insulator is electrically so much weakened by the accumulated moisture, that it punctures and serious trouble results. The authors consider that no laboratory test for porosity, however severe, can be as drastic as prolonged exposure to the atmospheric conditions in all weathers. Any batch of insulators showing porosity should be rejected unhesitatingly, or trouble is certain in the long run.

The observations made in the fog area referred to are interesting. The area extends from Christchurch, westward for a distance of 16 miles, and is no doubt due to the prevalent easterly winds blowing in from the sea, carrying westward the smoke particles of Christchurch, and moisture laden air from the sea. It is on these smoke particles that the moisture condenses and forms the mist in the region referred to. Further out than 16 miles the effect is not so perceptible. See Fig. 4.

TABLE I.—INSULATOR REPLACEMENTS
Per Area—Per Month

Year		Jan.			Feb.			Mar.			Apr.			May			June			July			Aug.			Sept.			Oct.			Nov.			Dec.			Total per area		Total per year
		N	S	F	N	S	F	N	S	F	N	S	F	N	S	F	N	S	F	N	S	F	N	S	F	N	S	F	N	S	F	N	S	F	Fog	Non Fog				
1915	Fog	..	..	..	..	..	..	..	..	..	..	..	0	..	2	2	1	1	2	..	..	0	..	..	0	..	1	1	..	1	1	3	..	3	3	2	5	Fog	14	
	Non Fog	..	..	..	..	..	..	..	..	..	..	3	..	3	..	1	1	1	1	2	..	..	0	..	..	0	..	3	3	1	1	2	..	..	0	1	..	1	Non Fog	12
1916	Fog	1	4	5	4	..	4	..	..	0	2	..	2	..	..	0	..	..	0	3	1	4	..	..	0	..	..	0	..	..	0	..	..	0	3	1	4	Fog	19	
	Non Fog	2	5	7	..	..	0	..	..	0	2	..	2	..	..	0	..	..	0	..	..	0	1	..	1	..	..	0	..	..	0	..	..	0	..	4	4	Non Fog	14	
1917	Fog	1	..	1	1	11	12	..	1	1	1	1	2	3	1	4	1	..	1	..	..	0	..	2	2	2	..	2	..	3	3	..	..	0	..	2	2	Fog	30	
	Non Fog	1	..	1	2	1	3	..	1	1	2	1	3	2	5	7	1	2	3	..	..	0	1	1	2	3	..	3	3	..	..	0	..	1	1	Non Fog	27			
1918	Fog	1	..	1	..	4	4	2	..	2	..	..	0	2	2	4	..	2	2	3	4	7	2	1	3	2	..	2	5	1	6	2	2	4	..	5	5	Fog	40	
	Non Fog	1	..	1	..	3	3	..	..	0	..	..	0	1	1	2	..	2	2	2	5	7	..	2	2	2	..	2	6	3	9	3	2	5	..	5	5	Non Fog	38	
1919	Fog	..	..	0	6	..	6	..	4	4	..	..	0	..	2	2	6	..	6	1	4	5	2	..	2	2	2	4	..	3	3	..	..	0	2	2	4	Fog	36	
	Non Fog	1	..	1	4	..	4	..	2	2	..	..	0	..	..	0	..	..	0	1	3	4	..	2	2	1	2	3	2	..	2	5	..	5	..	3	3	Non Fog	26	
1920	Fog	1	..	1	3	13	16	10	3	13	..	1	1	8	1	9	17	6	23	..	..	0	..	..	0	..	7	7	..	..	0	6	..	6	4	16	20	Fog	96	
	Non Fog	1	..	1	..	2	2	2	..	2	..	3	3	..	..	0	7	..	7	..	..	0	..	..	0	..	2	2	..	..	0	1	..	1	1	6	7	Non Fog	25	
1921	Fog	2	6	8	14	3	17	2	..	2	..	..	0	4	3	7	..	..	0	8	5	13	3	3	6	7	..	7	3	..	3	..	4	4	..	..	..	Fog		
	Non Fog	1	1	2	1	..	1	1	..	1	..	..	0	..	..	0	..	..	0	2	1	3	..	1	1	..	..	0	..	..	0	..	..	0	..	..	..	Non Fog		

Fog Area 16 miles. Non-Fog Area 46 miles.

The two 66,000-volt transmission lines referred to were erected in 1914 and have been in continuous service since 1915, and Table I shows the number of pin insulators which have failed in the consecutive years of service.

This table is plotted in Fig. 4, and Fig. 5 shows the total replacements.

FIG. 5—CURVES SHOWING INSULATOR REPLACEMENTS

In addition to these, 72 suspension disks (12 strings of 6 each) used at anchor towers, were replaced as a result of the complete failing of two strings (12 disks).

Dealing first with the pin type, it will be seen for the year 1919-1920 that over 360 were replaced due to all causes and 100 of these were selected at random and tested on the high-frequency oscillator.

58 were found to be "down" on 2 or more shells.

42 were found damaged on top shell only. It will therefore be seen that not even one per cent was electrically whole.

36 of the suspension type were tested and 22 or 60 per cent were found to be "down" and a test under hydrostatic pressure showed the porcelain to be of a porous nature.

TESTS AND RESULTS—PIN-TYPE INSULATORS

The following is a summary of the average results of many tests on insulators by various makers.

Tables of Dry Flash-over Pressures in Kilovolts (high frequency)
4-Shell and 3-Shell Pin Type

Maker	Shell No. 1	Shell No. 2	Shell No. 3	Shell No. 4
A.	74 Kv.	55 Kv.	66 Kv.	75 Kv.
B.	66 "	65 "	76 "	60 "
C.	70 "	50 "	66 "	64 "
D.	76 "	68 "	92 "	
E.	72 "	74 "	66 "	
A. 1	82 "	56 "	70 "	
A. 2	64 "	64 "	80 "	
F.	64 "	67 "	66 "	
E. 1	58 "	74 "	58 "	
E. 2	60 "	50 "	64 "	
E. 3	45 "	33 "	45 "	
G.	65 "	55 "	..	

Maker A—66,000-Volt 4-Shell Pin Type. This insulator which had not been in service, was, after testing all right on each shell at both high and low frequency, subjected to hydrostatic pressure test of 246,000 lb.-hr. with an average of 1440 lb. per sq. in.

After immersion, a repetition of the electrical tests showed the insulator to be as good electrically as it was before immersion, and when broken up, not the slightest sign of penetration could be seen.

Maker B—66,000-Volt 4-Shell Pin Type. This insulator had been in service since 1914, but had been removed 5 years later owing to having shown signs of puncture on one shell on overhaul.

Electrical test showed the shells to be in the following condition:

	Shell 1	Shell 2	Shell 3	Shell 4
Before Immersion.	O. K.	O. K.	Punctured	O. K.
After Immersion...	O. K.	Conducting	Punctured	O. K.

It will be noted that No. 2 shell failed under the hydrostatic pressure test, which consisted of 280,000 pound-hours.

After leaving the porosity vessel and undergoing the after-immersion electrical tests, the insulator was broken up and examined for penetration of the dye. Color was seen in the crown of the first shell, but the penetration was apparently insufficient to cause the shell to fail on the electrical test. The discoloration

FIG. 6—SHOWING ON RIGHT PENETRATION IN SECOND SHELL, AND ON LEFT, GOOD PORCELAIN WHICH HAS BEEN SUBJECTED TO SAME TESTS

of the second shell was most marked. It would seem as if the dye had found its way into the shell through the glazing, and as seen above, the tests showed the shell to be practically a conductor after the porosity test.

In the third shell, the only sign of penetration was found just around the small hole in the shell where puncture had taken place prior to immersion and was evidently the cause of the puncture.

In the fourth shell, the porcelain was white and satisfactory throughout. It seems reasonable to as-

sume this insulator was sound as far as the factory tests could reveal when first put on the line, but had gradually deteriorated, owing to the material being initially porous. Fig. 6 shows the penetration in a section of shell No. 2 mentioned above.

Another insulator of the same type, by the same maker, had been on the line a year longer than the previous one, and was removed owing to a mechanical fracture having been observed, probably due to rifle fire or other external cause. Pieces of this insulator were subjected to a hydrostatic pressure of 280,000 lb.-hours, after which, when broken into very small pieces, not the slightest sign of penetration of the dye could be observed.

FIG. 7—SHOWING PIECE SELECTED AT RANDOM FROM WHOLE INSULATORS

FIG. 7A

sume this insulator was sound as far as the factory tests could reveal when first put on the line, but had gradually deteriorated, owing to the material being initially porous. Fig. 6 shows the penetration in a section of shell No. 2 mentioned above.

FIG. 8—SHOWING PIECE OF THE BAD SHELLS

FIG. 8A—SHOWING PIECE OF THE TOP SHELL

It is therefore reasonable to assume, that apart from the mechanical fracture, the insulator was electrically as good as when first put on the line and would have remained so indefinitely, had it not been replaced.

Another insulator of the same type and maker (B) was immersed in water at atmospheric pressure for four years.

The electrical tests made in 1917 before immersion,

showed the insulator to be good after flashover for one minute on each shell, at both high and low frequency.

After leaving the tub, in 1921, the insulator was wiped and allowed to dry for one hour in the ordinary atmosphere after which it was, where possible, taken up to flashover on high frequency, with the following results:

Shell 1	Shell 2	Shell 3	Shell 4
Punctured under 50,000 volts.	O. K.	O. K.	O. K.

It was then subjected to the hydrostatic pressure test of 290,000 lb.-hours, after which it was again tested, with the same electrical results.

On being broken up, no sign of penetration was visible in Shell No. 1. This was probably due to the fact that four years immersion had saturated the shell, and no more water (colored) could be forced in.

Another insulator, by the same maker (B) which had been in service over six years and which had failed in service was subjected to hydrostatic pressure test of 280,000 lb.-hours and when broken up after leaving the porosity vessel the penetration was extremely marked throughout every part of the whole four shells, it was impossible to find even a most minute part, where the dye had not penetrated.

It seems only reasonable to assume, that this insulator let the line down; not due to surge or the like, but simply that it had become impregnated with moisture, through being porous, and had therefore eventually become practically a conductor for extra-high-tension pressure (Figs. 7 and 7A).

Still another 66,000-volt pin-type insulator by Maker B, which had been in service for six years, and failed from no apparent cause, was subjected to the hydrostatic pressure test of 280,000 lb.-hours and when taken out of the porosity vessel and broken up, it was found that whereas two of the shells were the same as the last mentioned, *i. e.*, penetrated right through, the other 2 shells were of quite good material.

There seems no doubt that this breakdown was caused by the power arc tending to flash over the insulator, that the two shells were practically conductors, and therefore ruptured by being in the direct path of the arc, thus causing the complete wreck of the other shells.

The individual testing of each shell as urged in this paper, would have obviated this trouble. (Figs. 8 and 8A.)

Maker C—66,000-Volt 4-Shell Pin Type withstood all electrical tests and showed no sign of penetration after having been through the hydrostatic pressure test.

Maker E—66,000-Volt 4-Shell Pin Type. A firm which specializes in the manufacture of E. H. T. insulators, sent a special sample insulator which was expected to withstand any electrical tests applied, having withstood all the maker's tests.

Each shell was tested separately up to flashover on 50 cycle pressure, which each shell withstood.

Each shell was then tested on the high-frequency oscillator, shells 1 and 2 withstood flashover satisfactorily, but No. 3 punctured decisively in the thickest part, under 40,000 volts.

The puncture path was quite perceptible when the shell was broken up, and had the appearance of a seam of flint, which apparently had not been "found" by the low frequency test.

If such results are obtained with a specially selected sample, what risk has an undertaking in accepting many thousands which have been passed by the maker, due to perhaps less than 10 per cent of their number having passed a mild low-frequency test?

In fairness to the maker, it should be mentioned that all his tests were made on 25-cycle pressure and the whole insulator, after being subjected to the hydrostatic pressure test, showed absolutely no signs of penetration.

Maker F. Another case of a world-known porcelain firm but not insulator makers, who desired to enter the electrical field, submitted a three-shell 66,000-volt pin type insulator for test. This insulator was guaranteed tested, by certified authorities, to 125,000 volts head to pin.

Each shell was taken up to flashover on 50-cycle pressure, which it withstood for two or three seconds, but on the high-frequency pressure, one shell only stood up to flashover, while the remaining two failed decisively under 30,000 and 40,000 respectively.

The insulator was then subjected to the hydrostatic pressure test. The number of pound-hours submersion was 300,000 and the insulator was tested after immersion and showed the first shell to be satisfactory in so far as flashover was concerned. The application of high pressure completely wrecked the other two shells, and when broken up, signs of penetration of the dye were quite obvious in all shells. It is reasonable to assume, that had the hydrostatic pressure been kept on for a longer period the dye would have been forced right through, sufficiently to form a path electrically through the first shell.

This again demonstrates the necessity for individual shell testing, because this insulator had been tested by authorities as good for 125,000 volts. This was true, because even after the insulator had been under the hydrostatic pressure test, it would withstand 120,000 volts from head to pin. But should such an insulator be put on a line? And yet how many, in such a condition are unwittingly put on a line?

Maker D. A particularly good insulator by this maker, although it has only three shells, has nearly as high flashover as some of the four-shell type.

It withstood all electrical tests satisfactorily and was then subjected to the hydrostatic pressure test, after which it also withstood the repetition electrical tests. It was further given Creighton's super-spark potential tests on each shell for five minutes, and withstood this test. On breaking up, not the slightest sign of penetration could be seen; and if the maker could only guarantee consistency, this insulator, by

virtue of its shape (Fig. 13) and quality of material, should make many friends, but as seen from the foregoing tests, purchasing engineers have reason to be suspicious, unless some guarantee is given that each and every shell of each insulator has been subjected to such tests as those described.

TESTS AND RESULTS 66,000-VOLT SUSPENSION INSULATORS

66,000-Volt Suspension Type	
Maker	Flash-Over kv.
H.	110.
H. 1	98.
B. 1	88.
B. 2	80.
A. 3	80. Approx.

In addition to the several types of pin insulators tested, three makes and five samples of different shapes of suspension insulators were included in the investigations, and the results have been that three samples or 60 per cent failed to withstand the prescribed tests satisfactorily; the two that did withstand the tests coming from one Maker H who has undoubtedly specialized in this type and succeeded in attaining something unassailable in his product.

The flashover pressures are given below, and it will be noted that apparently makers have opposite aims; Maker H having, in his latest product, increased his leakage distance, while Maker B in his latest product, has decreased his leakage distances as shown:

Maker H.	received in 1917	has flashover of	98,000	volts
" H.	" " 1921	" " "	110,000	"
" B. 1	" " 1914	" " "	88,000	"
" B. 2	" " 1921	" " "	80,000	"

The product of Maker H has successfully withstood all tests, while that of Maker B has failed badly in both samples.

Maker A, who has a reputation for pin insulators, equal to the best known, had failed up to that time in his attempt to produce a suspension insulator. There is an inherent weakness in the design, in that the insulator punctures much below flashover pressure, also the porcelain was found to be unmistakably porous, illustrating the fact that even the best of porcelain makers are inconsistent in their products in the case of new types or shapes.

Maker B. (1). This suspension insulator supplied in 1913 had been in service over six years, being one of a string of six which failed completely in service, from no apparent cause, just prior to the day load coming on. It was subjected to the hydrostatic pressure test, and on breaking up, after leaving the porosity vessel, it was found that the dye had penetrated to a considerable depth. (Figs. 9 and 9A.) From the above it can be reasonably assumed that the failure of this and the rest of the string of disks from which it came, was due to deterioration caused by the material being initially porous and moisture had gradually accumulated, until the material lost its insulating properties.

Maker B. (2). This was a new type supplied recently by the same maker who was seeking to redeem his reputation, which was seriously jeopardized, by results obtained from his earlier insulators. The sample withstood all electrical tests, both before and after having been subjected to the hydrostatic pressure test, and when broken up, no signs of penetration of the dye were observed, but a second sample, when tested dry, punctured decisively at 75,000 volts at 50 cycles.

The two pieces of the broken second sample were subjected to the hydrostatic pressure test, and on breaking up after leaving the porosity vessel, it was found that the dye had penetrated deeply at the weakest and most critical point of the insulator. This was

FIG. 9—PIECE OF SUSPENSION INSULATOR SHOWING MARKED PENETRATION. MAKER B'S EARLY PRODUCT

FIG. 9A

regrettable with such a recent production (1921), but certainly goes to confirm the author's contention regarding individual tests (Figs. 10 and 10A.)

Maker A. (3). 66,000-Volt Strain Insulator. This insulator apparently has an inherent weakness in its design, inasmuch as several samples, punctured decisively under 60,000 volts (flashover should be about 80,000 volts).

One of the unbroken samples was subjected to the hydrostatic pressure test, and when broken up, after leaving the porosity vessel, it was found that the dye had penetrated throughout the whole thickness, in fact,

this was amongst the worst material handled in these investigations, although as before stated, this maker's material in the pin type productions, is unassailable and equal to the best handled by the authors.

Maker H. 66,000-Volt Suspension Insulator. This maker claims to have produced a porcelain that is unassailable in that it is perfectly vitrified and will

FIG. 10—SHOWING MAKER B'S LATER PRODUCT IN SUSPENSION TYPE

FIG. 10A

withstand any electrical, mechanical or porosity tests. The insulator was subjected rigidly to the whole of the tests mentioned herein, and after the porosity tests, was further given Creighton's super-spark potential tests for five minutes. On breaking up, after having successfully stood all tests, not the slightest sign of penetration of the dye could be seen.

It is this type of insulator that is mentioned under Tests with High Frequency Oscillators, and goes to show that insulators can be made that will successfully withstand the tests shown, and there seems no reason why such insulators should not remain good in service for an indefinite period.

Maker E. Sample (3). 33,000-Volt Pin Type Insulator. This insulator successfully withstood all electrical tests

both before and after having been subjected to the hydrostatic pressure tests, and when broken up, not the slightest sign of penetration of the dye could be seen; and the material was of a particularly good satin-like appearance.

Maker G. 33,000-Volt Pin Type Insulator. This also withstood all electrical tests, successfully, both before and after having been subjected to the hydrostatic pressure tests. When broken up, not the slightest sign of penetration could be seen, and this ranks as the finest sample of electrical porcelain seen by the authors.

11,000 VOLT PIN TYPE INSULATORS

The testing of these insulators is regarded as particularly important, because they are within the range of local New Zealand manufacture, and the difficulty and cost of obtaining imported insulators during the war made it important that local insulators should be developed if possible. Investigations were made on those of two New Zealand makers (I and L) one Australian (K) and one American (E).

FIG. 11—SHOWING LOCAL PRODUCTS, ON LEFT BY MAKER K (BAD) AND ON RIGHT BY MAKER I (GOOD)

FIG. 11A—LOCAL PRODUCT BY MAKER K. (VERY BAD)

Maker E. Sample 4. This insulator punctured just below flashover during acceptance test, and was subjected to hydrostatic pressure test. Under this it showed distinct signs of penetration through the glaze, and particularly to a depth of about $\frac{1}{4}$ inch on each side of the puncture path, which was through the thickest part of the insulator, well down from the neck. Evi-

dently there was a porous seam existing where the insulator broke down. Three other samples failed in the same way out of thirty selected at random from a shipment of 30,000, indicating a very high proportion of defective porcelain.

Maker K. A special batch of insulators by this maker failed to withstand even working pressure, and a few were subjected to the hydrostatic pressure test.

FIG. 11B—LOCAL PRODUCT BUS-BAR PILLAR (VERY BAD)

FIG. 11C—LOCAL PRODUCT (VERY BAD)

Figs. 11, 11A, 11B and 11C show broken samples after leaving the porosity vessel. It will be seen that the dye had penetrated deeply through the entire body, hence their puncture at such a low pressure. Apparently in this case no effective factory test whatever could have been employed.

New Zealand Manufacturers. The insulator by Maker I withstood all electrical tests successfully,

both before and after being subjected to hydrostatic pressure test, and when broken up showed no sign of penetration. Later insulators have given equally good results, and the quality of the porcelain has apparently improved, indicating that local manufacture of this type of insulator is quite successful.

Another maker "L", after several attempts produced a very good insulator for use on low-tension work up to 500-volts, but for high-tension work failed distinctly, all his porcelain being porous.

FIG. 12—MAKER M. SHOWING MARKED PENETRATION IN APPARENTLY A SEAM OF POROUS MATERIAL ON RIGHT AND A DEPTH OF ABOUT $\frac{1}{4}$ INCH FROM INSIDE EDGE ON LEFT

FIG. 12A—SHOWING SAMPLE OF HEAVILY GLAZED INSULATOR INTO WHICH THE DYE HAS BEEN FORCED THROUGHOUT THE ENTIRE MASS

Extra-High-Tension Bushing. A bushing for 66,000-volt circuits was supplied by Maker M—manufactured in England—who was seeking to enter the electrical field. It is assumed that the insulator was given some kind of test before being sent out such a distance, but on being tested electrically dry as received it punctured decisively in the thickest part, on approaching 40,000 volts. On being subjected to hydrostatic pressure test distinct signs of penetration were obvious, the dye being forced through the glazing to a depth of nearly

1/4 inch, and in the thickest part there was a distinct porous band, which had been apparently moulded with the insulator. Needless to say no further insulators were purchased from a manufacturer allowing such work to be exported. (Figs. 12 and 12A.)

Shape of Insulators. The shape of high-tension pin insulators has undergone a radical change since 1917, mainly on the lines suggested by Gilchrist and Kline Felter (*Electric Journal*, Vol. 15, No. 11, page 445). The original type adopted in the Lake Coleridge system, Fig. 13, manufactured by Maker B did not give good results owing to the shells practically enveloping each other so that it was impossible for the weather or wind to clean the inner shells, thus lowering the factor of safety of the insulator. In later designs the shells are more open so that not only is the weather able to displace such deposits, but the planes between the shells follow more closely the equipotential surfaces, and the body of the insulator conforms to the lines of electrostatic field as suggested by Gilchrist and Kline Felter.

FIG. 13

This improved shape, coupled with the real improvement and greater consistency in quality of the porcelain has effected a substantial improvement in the life of the high tension insulators.

Glazing. Our experiments showed that glazing, even when over the entire shell of the insulator is no protection against impregnation by moisture. In the early stages of insulator manufacture apparently some importance was attached to the insulating quality of the glaze, and experience of puncture tests either in oil or in air tend to confirm this, in that when approximately the puncture value is reached, there is a definite time lag before the glaze starts to crack or craze, but when it does so, complete puncture quickly follows. Apparently then, the glaze has some value as a dielectric, but when once it breaks down it is no further protection, and when crazed, it is of course easily penetrated by moisture. Several of the figures herewith show penetration all along the glazed edges, indicating that the moisture must have entered through the glazed surface. We consider that our experiments demonstrate that glazing is no protection against the penetration of moisture, and that the insulator can be and should be made non-porous. Glaze should certainly not be put on to make good the defects of indifferent body material, and it will not do so.

General. The great importance of the transmission line insulator in the early construction days of most undertakings is usually lost sight of owing to the numerous urgent requirements of the rest of the plant, and as a rule, testing of insulators is left until trouble arises from breakdown on the transmission line. Extraordinary care is usually taken in testing the generators, water wheels, and other details, but the insulators are left to work out their own salvation, relying in some cases, quite without justification, on the makers' guarantees. The usual method is to dump the crates of insulators in the yard or alongside the poles, and leave them there exposed to the weather until they are ready for erection. During this period any porous insulators will certainly become more or less penetrated with moisture, and unless the factory tests are very thorough, trouble will ensue sooner or later. The authors consider that their observations indicate that there is need for much more co-operation between the manufacturer and the operating engineer with the object of reducing the maintenance. It is now general practise on the part of manufacturers to reduce as far as possible the stresses due to expansion and contraction and temperature variations, and with this object various types of jointing material have been introduced between the shells, which are intended to take the stresses due to temperature changes, thus reducing the cracking of shells due to such stresses.

Annual Overhaul. Annual overhaul on the transmission line is also very essential for the detection of defects not perceptible from the ground. This work of course has to be done as expeditiously as possible and in the best weather.

SUMMARY

From the tests and investigations described herein the following conclusions may be drawn:

1. That insulators for extra-high-tension work, before they are put into service should be subjected individually in the case of suspension units and on each shell in the case of pin insulators, to flash-over pressure for a definite period at both high and low frequency, or at least at high frequency, either by the maker, or preferably by the purchaser after delivery, when the maker should be prepared to bear the cost of rejected ones.
2. That a percentage of each shipment of insulators should be subjected to a hydrostatic pressure test at least as severe as that described herein. One manufacturer describes his competitor's specification for porosity as "a joke," and proposes instead a porosity test of 4800 lb.-hours; which appears to the authors to be equally a joke.
3. That insulators can be made and are being made that will not be overstressed by such tests, and which should remain good in service for an indefinite period.
4. That a proportion of insulators supplied hitherto have been porous, and should be replaced at once by insulators that have been thoroughly tested.
5. Extreme care should be exercised in the selection

of the type and shape of insulator, having regard to the form of electrostatic field and to the self-cleansing form of the insulator.

6. There is room for more co-operation between the maker and the user in the matter of handling and maintaining insulator service.

7. That in a country such as New Zealand where it is proposed to develop hydroelectric power to the utmost limit of its resources, a public testing laboratory should be established, where various undertakings could arrange for tests herein described, thus giving them a guarantee that the material received would be of the

best quality, and eliminate the annoyance and mistrust engendered in the public mind by insulator breakdowns.

We desire to express our most cordial thanks to Mr. L. Birks the Chief Electrical Engineer for the Dominion, for the support and help he has given us in this work. Much of the information contained in the paper is Departmental, and for permission to publish this we are indebted to him.

Our thanks are also due to The New Zealand Institute which gave us the monetary grant which enabled the porosity tests described to be developed.

Conservation or Waste of Material in Educational Institutions

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THE successful operation of a republican form of government depends in large measure upon an educated people. It is obviously impossible to let the people rule unless their intellectual training has reached the point where they can distinguish between what is right and what is wrong. The better they are educated, the more likelihood there is that the governmental agencies will function in a proper manner.

These facts have been clearly recognized in this country ever since the present form of government was established with the result that our educational institutions have always received the active interest and support of an intelligent and generous people. We have pointed with pride to the country schools in which so many of our greatest men received their early educational training and have always given to such schools much of the credit for the successes achieved by those who attended them.

In other words, the American people have always believed so thoroughly in scholastic training that it was natural for them to exalt this work and to furnish funds for its continuance.

The same applies equally to the college and university. Early in our history we set up institutions of higher learning to supplement the work of the common or public schools and these institutions have constantly grown in number, size and importance to the present day.

The point we are trying to make is that no one without good reason would find fault with a system we all

believed in. We do not believe, however, in all the details of its present day administration and accomplishments. We are forced to conclude that although our system of education has an uncounted number of highly commendable features, it has also some faults which should be corrected.

In discussing the work of the educational institution as regards the conservation or waste of material, we shall compare its activities and results to those of a modern manufacturing establishment. We shall do this because it is a convenient method to illustrate the points we have in mind.

Is it fair to draw comparison between a modern manufacturer and a modern educational institution? To the writer it seems quite in order to do so. Modern business is conducted on a very high ethical plane and directed by men of education and ability who must meet the keenest competition and have their accomplishments measured by actual values. The most efficient management is the one which obtains the largest amount of high grade finished product at moderate cost from a given amount of raw material. Surely there can be no objection to applying this standard to measure our educational institutions.

In a successful manufacturing establishment, close attention is always given to the material which will enter into the finished product, and the most careful specifications are drawn to insure the material purchased being of a grade suitable for the article which is to be produced. And these specifications are always supplemented by rigid inspection of the material when it is received. When the material has been accepted, it is the obligation of the management to use it to advantage and through efficient direction to obtain the maximum