Conference Paper

EXPERIMENTAL ASSESSMENT OF SUSPENSION INSULATOR RELIABILITY

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EXPERIMENTAL ASSESSMENT OF SUSPENSION INSULATOR RELIABILITY

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ABSTRACT

After reminding readers of the difficulties in attempting to assess in advance the behavior in service of cap and pin suspension insulators, the authors summarize the studies they have undertaken in order to recommend suitable test methods for predicting long term insulator performance.

INTRODUCTION

Many technicians dealing with high tension suspension insulators believe that the tests recommended in national and international Standards do an incomplete job of giving useful information on the ability of the insulators to sustain mechanical stresses while in service.

These mechanical stresses are due to forces applied by conductors and to the widely-differing thermal characteristics of the components of an insulator.

They may cause either an electrical puncture of the dielectric or a complete mechanical breakdown of the insulator.

The resistance to such stresses depends upon several factors:

- -design of the insulator
- -nature of the dielectric
- -quality of the dielectric, especially its homogeneity and its surface condition in the stressed area.

Time loading tests and thermal shock tests were introduced in ANSI Standard C29.2-1962 (paragraphs 9.3.5 and 9.3.6) as design tests. 24-hour mechanical tests were introduced in IEC Publications 75 and 87 (Paragraph 50.04) as quality conformance tests.

Unfortunately, the application of these Standards did not prevent the occurrence of either short-term or long-term failures.

The lack of success of the 24-hour test caused the IEC to cancel it from their recent publication 274 (1968) without replacing it by any other test.

A Working Group was set up by Subcommittee 36B of the IEC in order to study the possibility of introducing a more significant test of the behavior of insulators in service.

Preliminary tests presented in a previous paper[1] showed that it was possible to establish a correlation between long term laboratory tests and service experience.

The purpose of the present report is to give the results of new long-term tests and to suggest suitable test methods as design and quality conformance tests.

Test Procedures and Results

The tests were made on porcelain and toughened glass suspension insulators of 12 different types called A, B, C, D, E, F, G, H, K, L, M, N.

The test results presented in 1969[1] will not be repeated here.

We carried out six new different tests which are described below.

Table I summarizes the results of the Test series No. I through No. VI.

Test Series No. I

Insulators were submitted to a combined mechanical and electrical strength test in accordance with paragraph 5.2 of ANSI C29.1-1961.

Test Series No. II

-Time Loading: Insulators were submitted for a 2000-hour period to the following stresses:

- . Static mechanical load: $S = 0.6R$ (R being the M&E rating)
- . Dynamic mechanical load: $D = \pm \frac{R}{80}$
- . Electrical stresses at industrial frequency $U = 30$ KV
- . Thermal stresses: Local outdoor atmospheric conditions (Continental climate)

-M&E Test: The remaining insulators, after the 2000-hour time loading, were submitted to a combined mechanical and electrical strength test in accordance with paragraph 5.2 of ANSI C29.1-1961.

Test Series No. III

Insulators were submitted to tests similar to those of Test Series No. II but with different thermal stresses during the 2000-hour time loading:

Thermal stresses: 12 hours at $\theta_1 = -50^oC(-58^oF)$
12 hours at $\theta_2 = +50^oC(+122^oF)$

See Figure 1 for temperature curve in temperature-controlled chamber.

Detailed results are shown in Table II

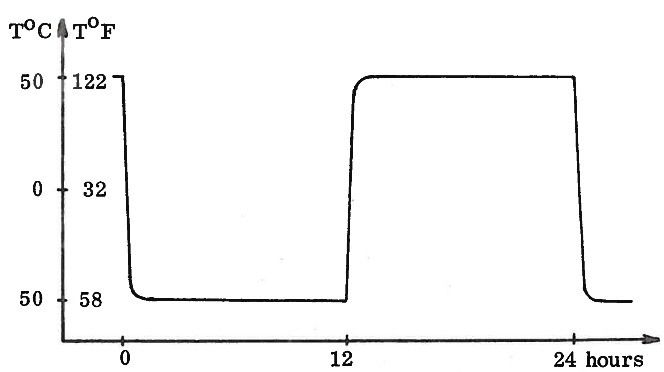

Figure 1: Temperature curve (Test Series No. III)

Test Series No. IV

-Time Loading: Insulators were submitted to the following stresses for four cycles of 24 hours each:

. Static mechanical load: S = .6R (R being the M&E rating)

. Thermal stresses during one cycle:

4 hours at θ_1 = -30°C (-22°F)
4 hours at θ_2 = +50°C (+122°F)
16 hours at θ_a = ambient temperature

At the end of the first three cycles the mechanical loading was released and the insulators checked for soundness by an application of an increasing low frequency voltage until puncture or flashover, whichever occurred first.

See figures 2 and 3 for temperature and load curves.

-M&E Test: At the end of the fourth cycle of time loading the remaining insulators were submitted to a combined mechanical and electrical strength test in accordance with paragraph 5.2 of ANSI C29.1-1961.

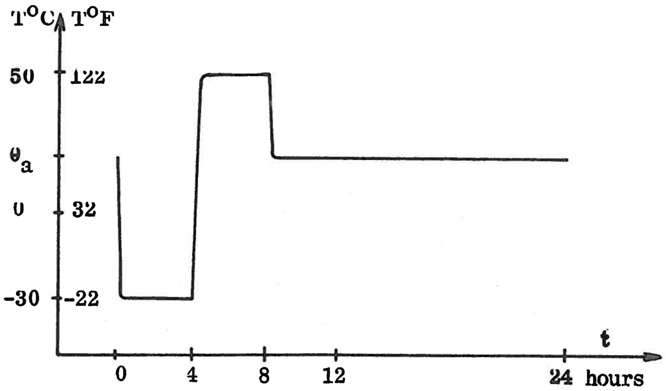

Figure 2: Temperature curve (Test Series No. IV)

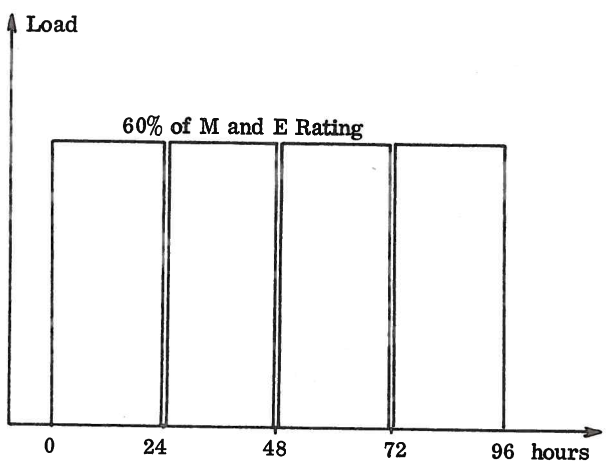

Figure 3: Load curve (Test Series No. IV and V)

Test Series No. V

Insulators were submitted to tests similar to those of the Test Series No. IV with different temperature conditions :

Thermal stresses during time loading.
θ_a = ambient temperature.

See Figure 3 for load curve.

Test Series No. VI

Insulators were submitted to an "accelerated fatigue" test which can be completed in 9 hours.

The test procedure was as follows:

Phase	No. of Cycles	Description
a	5	The insulators were placed for a time of (15 + 1.55 G) minutes in a water bath at 169°F followed by an equal time in a water bath at 38°F, G being the weight of one insulator in pounds.
b	20	M&E test: Rapid rise to 50% of M&E rating; then up to 80% at an increased rate of mechanical loading equal to half the M&E rating per minute, followed by a return to zero.
c	1	Insulators in water bath of 38°F for (15 + 15.5 G) minutes.
d	1	Maintain (100 + 1.55 G) minutes in a temperature chamber at -13°F.
e	20	Repeat Phase b while insulator still frozen.
f	2	A weight equal to $\frac{\text{M\&E rating}}{10,000}$ is dropped on the ball of the pin from a height of one meter; then two consecutive M&E tests up to 80% of rating with rate of load application same as Phase b.
g	1	Insulators are placed for (15 + 1.55 G) minutes in a water bath at 169°F.
h	20	Repeat Phase b while insulators still hot.
i	1	M&E test. Repeat Phase B but up to 90% of rating.
j	1	M&E test as in Phase B, but to failure.

Results are shown on Table VI.

In view of the poor behavior of the insulators of type G during Test Series No. II, we continued the application of the time-loading stresses. Every 2000 hours, five specimens were subjected to an M&E strength test.

Results, given in Table III, show that most of the failures occurred during the first period of 2000 hours.

Analysis of results

The insulators of types E through N used for the present study are insulators sold in large quantities throughout the world and/or in particular areas (USA, Europe...)

Types E and K insulators are recognized widely as giving excellent results in service. Type F is used very little because of its cost.

First, let us compare the behavior of the different types of insulators by looking at:

-the number of failures during the time-loading period;
- the ultimate M&E strength after time loading;
-the nature of failures (D: dielectric, M: metal fittings, C: cement)

Insulators of types E, K and F did not have any failure during the time loading and gave satisfactory results in the following M&E tests. However, Type F insulators show a smaller safety margin because of the occurrence of dielectric puncture before the mechanical failure of metal fittings (Test Series No. III).

Insulators of Type N were satisfactory except in Tests III where 60% of the units failed during the time loading.

Insulators of Type L had a behavior similar to that of the preceding one but the strength of the dielectric was inferior.

Insulators of Type M gave results systematically lower than those of the previous types.

Finally, insulators of type G had very poor behavior in all tests. They should be considered as overrated.

Now let us analyze the test methods themselves.

The M&E test (Test Series No. 1) lets the user believe that the insulators are satisfactory.

The accelerated fatigue test (Test Series No. VI), much tougher, shows the relative weakness of Type M insulators and the mediocrity of Type G insulators.

The 96-hour tests (Test Series Nos. IV and V) and the 2000-hour test at ambient temperature (Test Series No. II) confirm the results of the preceding test and therefore have a limited interest due to their duration.

The 2000-hour test with controlled temperature (Test Series No. III) is the only one which permits a study of reliability as was done in the previous paper[1] with the 5200-hour test.

Reliability Study - (Test Series No. III)

We recall the definitions and laws involved in this study.

If h(t) is the rate of instantaneous failure, h(t)dt will be the probability that a failure occurs during the interval of time (t, t + dt).

Now we can define Reliability R(t) as the probability that an apparatus functions properly during a given time t in specified operating conditions.

Reliability can then be expressed by:

$$R(t) = e^{-\int_0^t h(t)dt}$$

In our particular application of Test Series No. III, we shall consider as "defective" any insulators which failed either by puncture or mechanical breakdown during the time-loading period. The unit of time will be 200 hours.

Let us liken the law of breakdown as a function of time to a law of Weibull for which the rate of failure and Reliability are expressed:

$$h(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1}$$

$$R(t) = e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}$$

with γ, β and η being parameters which can be determined by experience.

Table A shows the cumulative percentage of failure as a function of time.

Table A
Cumulative Percentage of Failure
Test Series No. III

No. of Time Units	Time Range Hours	M	N
1	0 - 200	0	25
2	200 - 400	0	25
3	400 - 600	0	35
4	600 - 800	0	55
5	800 - 1000	5	-
6	1000 - 1200	5	-
7	1200 - 1400	15	-
8	1400 - 1600	25	-
9	1600 - 1800	-	-
10	1800 - 2000	-	-

The values of Table A permit plotting the experimental curves on a graph of functional scale (Figures 4 and 5).

Then we can read the values of the parameters in each case.

Type M	$\gamma = 0$	$\beta = 4$	$\eta = 11$
Type N	$\gamma = 0$	$\beta = 0.85$	$\eta = 6$

So the respective rate of experimental failure and experimental reliability are :

$$h(t)M = \frac{4}{11}\left(\frac{t}{11}\right)^{3} \qquad R(t)M = e^{-\left(\frac{t}{11}\right)^{4}}$$

$$h(t)N = \frac{0.85}{6}\left(\frac{t}{6}\right)^{-0.15} \qquad R(t)N = e^{-\left(\frac{t}{6}\right)^{0.85}}$$

Conclusion:

From all the tests presented in this paper we retain only two which appear to be significant to us.

The accelerated fatigue test (Test Series No. VI), applicable to cap and pin insulators, gives useful information in a very short period of time. We suggest that such a test be introduced in standards as a quality conformance test.

The long term 2000-hour test with controlled temperature (Test Series No. III) was found to be a significant reliability test.

We, therefore, recommend that such a test be used as a design test.

References:

(1) D. Riviere, "Reliability of Insulators" paper 69CP66 presented at the 1969 IEEE Winter Power Meeting, New York, N.Y. January 26-31, 1969.
(2) I. Bazovsky, "Reliability, Theory and Practice" Englewood Cliffs, N.J.: Prentice Hall Inc., 1961

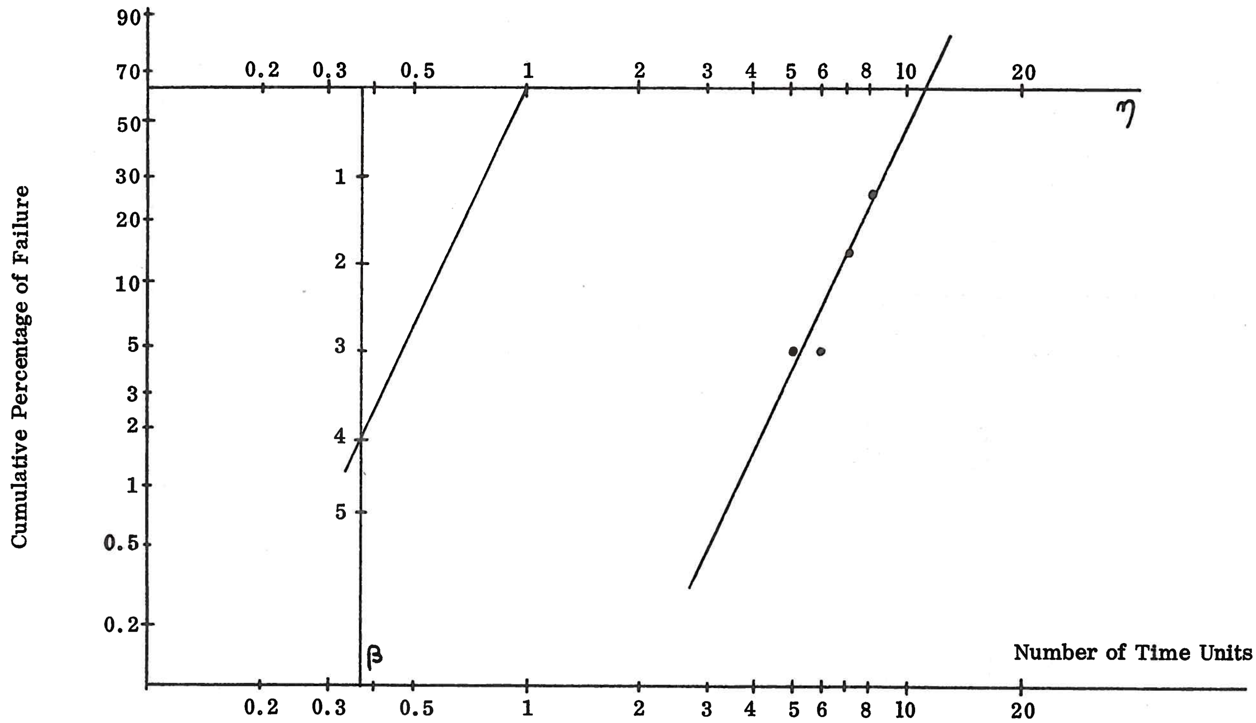

Figure 4: Type M Insulators

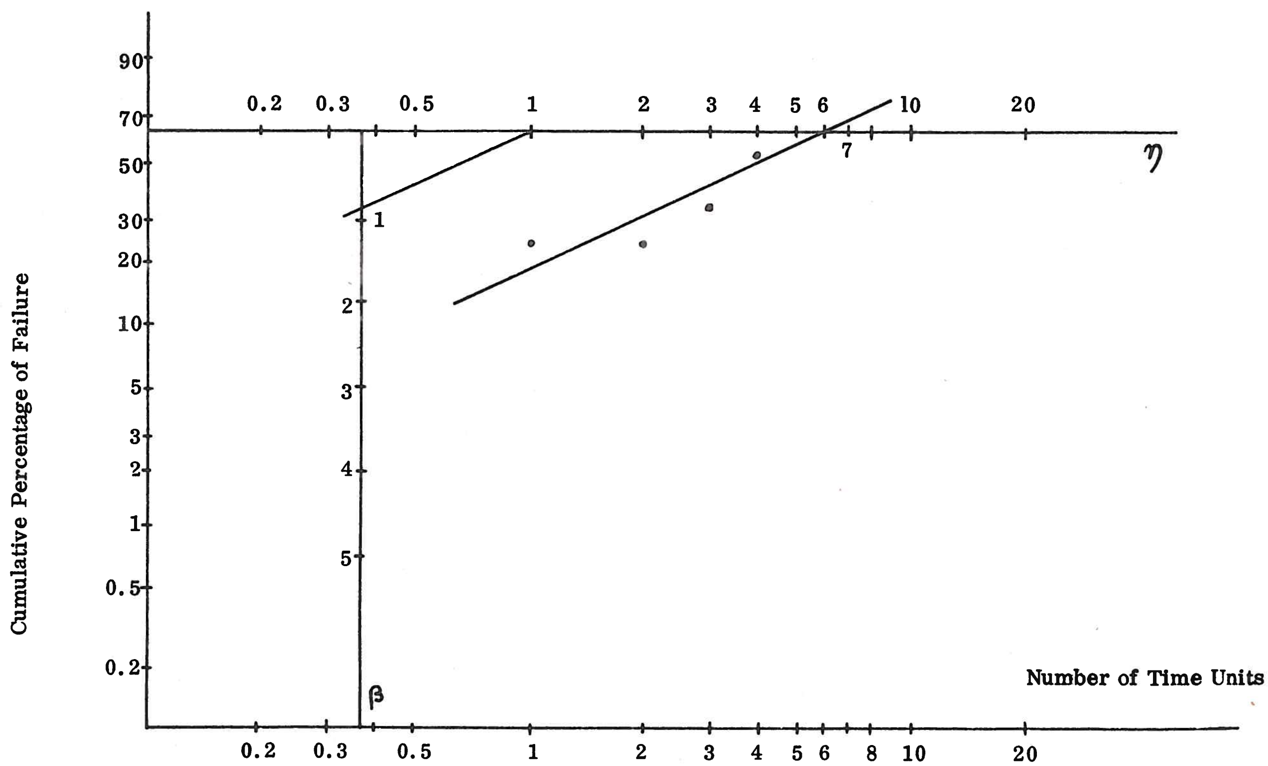

Figure 5: Type N Insulators

Table I

Results of Test Series No. I through VI

Type of Insulators	M and E Rating Klb	Test Series No.	Quantity Tested	Failure during Time Loading: Quantity %	Failure during Time Loading: Type	M and E Test after Time Loading: m(2) (% of Rating)	s(2) (% of Rating)	Type of Failure (1): Electrical	Type of Failure (1): Mechanical	
E	25	III	8	0	-	126.8	2.0	-	100% M	-
F	25	III	6	0	-	121.6	2.4	16.7%D	83.3% M	-
G	20	I	10	-	-	98.5	16.0	100% D	-	-
		II	40	60%	Puncture	92.0	15.0	100% D	-	-
		III	16	100%	Puncture	-	-	-	-	-
		IV	12	0	-	80.5	27.0	100% D	-	-
		V	0	-	-	-	-	-	-	-
		VI	4	100%	Puncture	-	-	-	-	-
K	20	I	20	-	-	129.5	7.5	-	100% M	-
		II	20	0	-	129.5	9.5	-	100% M	-
		III	15	0	-	109.5	6.5	-	100% M	-
		IV	12	0	-	127.0	6.0	-	100% M	-
		V	12	0	-	125.5	9.0	-	100% M	-
		VI	9	0	-	117.5	11.5	-	100% M	-
L	15	I	5	-	-	123.5	12.0	-	60% D	40% C
		II	20	0	-	130.7	4.7	-	60% D	40% C
		III	10	100%	Puncture	-	-	-	-	-
		IV	5	0	-	111.3	24.7	80% D	20% D	-
		V	5	0	-	105.3	7.3	-	100% D	-
		VI	4	0	-	113.3	11.3	-	100% D	-
M	25	I	5	-	-	103.2	12.0	20% D	40% D	40% M
		II	10	0	-	75.2	53.2	80% D	20% M	-
		III	10	30%	Puncture	84.0	51.6	57.1%D	42.9% M	-
		IV	6	0	-	108.8	10.4	83.3%D	16.7% M	-
		V	6	16.7%	Puncture	100.8	18.0	80%D	20% DM	-
		VI	4	25%	Puncture	121.6	2.0	-	100% M	-
N	36	I	5	-	-	124.4	11.9	-	60% M	40% D
		II	10	0	-	126.1	13.3	-	50% D	50% M
		III	10	60%	Puncture	121.7	13.9	-	100% M	-
		IV	5	0	-	120.3	7.2	-	60% D	40% M
		V	0	-	-	-	-	-	-	-
		VI	4	0	-	116.7	20.3	-	100% M	-

(1) Type of Failure: D = Dielectric M = Metal Fittings C = Cement
Electrical failure: Puncture before mechanical breakdown
Mechanical failure: Purely mechanical breakdown

(2) m = mean value S = standard deviation - expressed in percentage of M and E rating

Table II

Detailed Results of Test Series No. III

TIME LOADING

Type	M and E Rating Klb	Quantity of Insulators Tested	Stresses Applied M Klb	Stresses Applied E KV	Stresses Applied Θ °F	Failure during Time Loading: Time of failure	Failure during Time Loading: Type
E	25	8	15 ± 0.31	30 KV	- 58°F + 122°F	No failure	-
F	25	6	15 ± 0.31			No failure	-
G	20	16	12 ± 0.26			0 12.3 23.1 35.4 315.8 443.8 1660 1817 1817 1817 1935 1962 1998 1998 1998	15 X Puncture
K	20	15	12 ± 0.26			No failure	-
L	15	10	9 ± 0.19			114 114 114 114 114 114 117 134 134 134	10X Puncture
M	25	10	15 ± 0.31			961 1386 1475	3 X Puncture
N	36	10	21.6 ± 0.45			3.7 69 69 567 610 680	6 X Puncture

Table III

Results of an Outdoor Long Term Test of Type G Insulators

Time Loading: Time Range Hours	Time Loading: Time of Failure Hours	Time Loading: Type	M and E Test on 5 units taken every 2000 hours: No. of punctures < 5 Klb (1)	m Klb	S Klb	m % of Rating	S % of Rating	Type of Failure (2) Electrical
0	-	-		19.7	3.2	98.5	16.0	100%D
0 - 2000	1.3 6.7 26.1 1154 1156	5X Puncture	1	18.4	3.0	92.0	15.0	100%D
2000 - 4000	2196	Puncture		16.7	2.0	83.5	10.0	100%D
4000 - 6000	No failure	-		15.7	2.4	78.5	12.0	100%D
6000 - 8000	No failure	-	1	16.9	1.5	84.5	7.5	100%D
8000 - 10000	No failure	-		17.5	1.2	87.5	6.0	100%D
10000 - 12000	No failure	-		17.6	1.0	88.0	5.0	100%D

(1) Values lower than 5 Klbs have been ignored in computation of mean m and Standard Deviation S

(2) D: Dielectric