STUDY OF ELECTRICAL INSULATION PROPERTIES OF FIPE, LINE TOOLS AND ROPES USED IN LIVE LINE MAINTENANCE

By

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Abstract

The electrical properties of rubber insulating blanket, line hose, fiber–reinforced plastic (FRP) line tools and insulating rope used in live line maintenance were investigated experimentally. Samples of class 4 blanket were tested in an oil bath vessel to determine the AC, DC and switching surge breakdown voltages. The correlation among AC and DC voltages and AC and switching surge voltages were determined. This led to the conclusion that the equivalence in testing between power frequency and DC, and power frequency and switching surge overvoltage now used in the industry and standard may be incorrect.

Class 2 and 4 line hoses were tested with eight electrode configurations under AC and switching surges to consider the electrode effects on electrical insulation properties and four of them were used to simulate a lineman's body on line operation. Furthermore the correlation between AC and switching surge voltage were discussed. This led to understanding the effects of electrode configurations and further proved that the equivalence in testing between power frequency and switching surge overvoltage now used by the industry and in the standards may be incorrect.

The insulating qualities of new and used FRP line tools and insulating ropes were evaluated by measuring the leakage currents through the samples in dry and moist conditions. The experimental results showed that the insulation quality of FRP line tools and insulating rope is high if the samples are kept clean and dry.

The experimental results and the conclusions presented in the thesis may be useful for electrical utilities in conducting live line maintenance.

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Chapter One

INTRODUCTION

1.1 Preface

The ever–increasing importance of continuity of service in the electric power industry demands a constant search for adequate and safe methods of performing line maintenance. Usually, line maintenance on power system equipment is performed with the system still energized. Such live–line maintenance requires proper insulation protection against electrical shock for the maintenance workers. Elements in worker protection systems include special safety procedures, use of insulating line tools, manlifts, and flexible insulating protection equipment (FIPE) such as rubber gloves, sleeves, covers, blankets and line hoses. All pieces of line tools and equipments must be designed to withstand the highest expected voltage levels and must pass periodic verification tests. The line tools and equipments serve as the first line of protection. Since line tools and equipments are used to provide an insulating barriers between maintenance workers and energized parts, proper understanding of the electric insulation characteristics of line tools and equipments is essential for both design purposes and safe application.

1.2 Categories of FIPE , Line Tools and Ropes

FIPE is composed of all pieces of flexible insulating protection equipments for line maintenance, which must satisfy the requirements of shorter insulation clearances to isolate workers from electric shock in line maintenance on certain voltage level. FIPE includes rubber insulating gloves, rubber insulating sleeves, rubber insulating covers, rubber insulating blankets and rubber insulating line hoses.

Based on electrical properties, FIPE is classified into five classes (class 0, 1, 2, 3, 4). Every class of FIPE is designed to meet a certain standard requirement which include test voltage level , minimum breakdown voltage and thickness. These requirements are summarized in Table 1.1 and Table 1.2 [26] .

Table 1.1 Required Voltage Ratings for FIPE Used for Distribution Live–Line Maintenance

FIPE Class	Max. Use Voltage		Test Voltage		Min. Withstand Voltage	
	AC,kVrms	DC,kV	AC,kV rms	DC,kV	AC,kV rms	DC, kV
0	1.0	1.5	5	20	6	35
1	7.5	11.25	10	40	20	60
2	17.0	25.5	20	50	30	70
3	26.5	39.75	30	60	40	80
4	36.0	54.0	40	70	50	90

* Except for class 0, the maximum use voltage is based on the following formula:
MUV= (0.95 AC Test Voltage – 2), kV.
* Min. Withstand Voltages are only suitable for rubber insulating gloves.

Table 1.2 Required Material Thickness (mm) for FIPE

Class	Glove	Sleeve	Blanket	Line Hose (min.)
0	0.51–1.02	0.51–1.02	1.6–2.2	3.2
1	0.76–1.52	0.76–1.52	2.6–3.6	5.1
2	1.27–2.29	1.27–2.54	2.8–3.8	5.6
3	1.90–2.92	1.90–2.92	3.0–4.0	6.4
4	2.54–3.56	2.54–3.56	3.2–4.3	6.4

Line tools (hot sticks) are made from fiberglass–reinforced plastic (FRP) tubes filled with foam or solid FRP rods and metal parts. In our research work, the electrical properties of FRP tubes are mainly discussed. The maximum AC leakage current requirements for 12 inch long test samples, cut from FRP tubes and rods, are listed in Table 1.3 [26] . Foam–filled FRP tube and solid FRP rod must meet the outside diameter dimensions shown in Table 1.4. The tolerances shown will assist in assuring interchangeability with interfacing equipment.

Table 1.3 Required Maximum Leakage Currents of FRP Tube and Rod Test Samples

Type	Outside Diameter, mm	Leakage Current I_1, μA
Tube	25.4	5
	31.8	6
	38.1	8
	44.5	9
	50.8	10
	63.5	12
	76.2	14
Rod	9.5	6
	12.7	6
	15.9	6
	19.1	6

* I_1 is the maximum leakage current through samples in dry condition. Values listed for maximum I_1 are based on pole constructed of a relatively thin wall and filled with foam. In some special applications a thicker wall, denser foam, or different materials are required, which could change the dielectric constant of the test setup and consequently I_1. Tubes such as these will still meet the requirements of this standard if the dry leakage is less than twice the listed maximum value of I_1 in the tube.

* I_2 is the maximum leakage current after ** moisture conditioning. The difference between I_2 and I_1 shall be less than 20 μA.

**Moisture conditioning :

Relative Humidity : 93 % or greater,

Temperature : 23 ± 2 5 ° C ,

Time : 168 h (7 days).

Table 1.4 Standard Outside Diameters of Tube and Rod

Type	Nominal Diameter mm	Min. Diameter mm	Max. Diameter mm
Tube	25.4	24.9	25.9
	31.8	31.0	32.3
	38.1	37.3	38.9
	44.5	43.9	45.2
	50.8	50.0	51.8
	63.5	62.7	64.5
	76.2	75.3	77.2
Rode	9,5	9.4	9.8
	12.7	12.4	13.0
	15.9	15.5	16.1
	19.1	18.3	19.4

Insulating ropes are made of synthetic and natural fibers. In IEEE Standard 516–87, the wetting tests for ropes are specified. The currents obtained over 24 in (60 cm) of the test samples should not be exceed 1 mA at applied voltage of 30 kV for 30 s from the time of initial application of voltage until the end of the test .

1.3 Components of FIPE , Line Tools and Ropes

FIPE is mainly made of natural or synthetic rubber that includes elastomer and elastomeric compounds. According to rubber material characteristics relating to ozone, there are two types of FIPE: Type 1, non–resistance to ozone, is made from a high grade cis–1.4–polystyrene rubber compound of natural or synthetic origin properly vulcanized.

Type 2, ozone–resistance, is made of any elastomer or combination of elastomeric compounds. Physical requirements for FIPE used in live–line maintenance are listed in Table 1.5 .

FRP Line tools are made from fiberglass–reinforced plastic (FRP) tube filled with insulating foam, homogeneous unicellular thermosetting foam filling with closed cells blown with noncombustible gases. The external surface of FRP line tool must be uniform, symmetrical, and free of abrasions, scratches, blemishes, and surface defects. The mechanical requirements for FRP tubes are summarized in Table 1.6 [26].

Table 1.5 Physical Requirements for FIPE Used in Live–line Maintenance

Property	Glove	Sleeve	Blanket	Line Hose
	Type 1—Type 2	Type 1—Type 2	Type 1—Type 2	Type 1—Type 2
Tensile Strength (Min,DieC,Mpa)	10.2—10.3	17.2—10.3	17.2—17.2	11—4.8
Elongation (Min, %)	600—500	600—500	500—500	350—500
Tension Set (at 400%)	25—25	25—25	6.4—6.4	6.4—6.4
Tear Resistance (Min,kn/m)	21—14	21—14	21—26	17.5—13.1
Punc. Resistance (Min,kn/m)	18—18	18—18	18—26	
Hardness (Shore A)	47—47	47—18		
Flex. Stiffness				
(at 25 C)			0.028—0.028	
(at –10 C)			0.034—0.034	
Mois.Absorption (Max. %)		1.5—1.5	1.5—3.0	1.5—3.0

Table 1.6 Mechanical Requirements for FRP Tubes Used in Live–line Maintenance

Diameter mm	Flexure Force N	Crush Strength N	Tensile Strength N	Shear Strength N
25.4	978.6	2891	62275.1	2624.5
31.8	1201.0	3336	80068.0	2624.5
38.1	1645.8	3559	128998.4	3625.3
44.5	2446.5	3781	186825.3	4448.2
50.8	2980.3	3959	191273.5	3958.9
63.5	7373.0	5382	284686.2	4670.6
76.2	13478.1	6672	440374.0	6005.1

Synthetic ropes include poly–dacron, polypropylene and composite fiber braided ropes. Poly–dacron rope is a three strand flexible combination of synthetic fibers. Its excellent dielectric properties, and high resistance to mildew, rot and chemical damage make it an excellent handline rope. Polypropylene rope was selected for its strength, light weight and resistance to moisture. Water accumulation on the surface can be readily removed by shaking vigorously and wiping with an absorbent cloth. The three strand constriction is yellow in color. Composite fiber rope is made of polyester fiber plied over polyolefin fiber in each of the 12 strands. The composite strands are braided together to provide a rope with an excellent strength to weight ratio. Natural fiber ropes are not used very often now in the live–line maintenance.

1.4 Equivalence of Test Voltage Stress

The line tools , FIPE and ropes can be subjected to various voltage stresses when used to protect workers during line maintenance operation. In AC power systems, the line tools, FIPE and ropes are usually exposed to steady state sinuosidal AC voltage, but may occasionally also experience surges of various waveshapes, produced as a result of switching operations or possible lightning strokes to power system. In DC power systems, the predominant stress is DC voltage. For proper selection of the test criteria, several important sets of data are needed. One must have a good understanding of the expected stresses that are likely to be present during the use of line tools, FIPE and ropes. That is, If live–line maintenance work is not to be conducted when‘ lightning is in the vicinity’, then it may not be important or instructive to study the performance of the line tools , FIPE and ropes under lightning related voltages stresses. On the other hand, if a distant lightning is likely to cause breaker tripping, then it is necessary to know the resulting switching overvoltages that may propagate to the work location, ant it may be necessary to confirm that the line tools , FIPE and ropes indeed can withstand these expected switching surges. The magnitudes and the waveshapes of switching surges are determined by the system characteristics and the magnitudes may in addition be controlled (reduced) by other means, such as temporary protective gaps, blocking reclousures and so on. The line tools, FIPE and ropes must withstand without failure all maximum agreed upon electrical stresses to which they will be subjected in service, in order to provide protection for the maintenance workers. Appropriate electrical tests must be developed to ascertain that the line tools, FIPE and ropes can withstand these voltage stresses.

A thorough knowledge of the electrical insulation characteristics such as breakdown voltages and leakage currents of the line tools , FIPE and ropes is also necessary. This information can only be obtained by actual exploratory research tests. It should be noted that these exploratory tests for the line tools, FIPE and ropes are destructive in nature since the determination of the breakdown voltages or strengths requires application of sufficient voltage stresses to cause FIPE and line tools to fail. The punctured FIPE and cut line tools and ropes can no longer be used and must be discarded. Hence, these exploratory tests are not recommended for the general use, and are done only on limited scales. The breakdown strengths obtained from these tests define the maximum capabilities of the line tools and FIPE, i.e., they determine the maximum stresses which the line tools and FIPE will withstand without failure. The line tools and FIPE's withstand levels should be based on the maximum anticipated switching overvoltages and equated to the critical flashover values determined by experiments. The leakage currents obtained from the tests define the safe levels to keep the maintenance workers from electric shock.

1.5 Purpose of Present Research Work

In the Standards [26], are drawn up the specifications for acceptance and in–service care of line tools and equipment. But from the review and analysis of present Standards, it becomes apparent that these are not sufficient for the guide of today' s live–line maintenance. Further research and classification are needed.The main problems in present Standards include :

1) the effects of working conditions such as weather conditions, electrode configurations and mechanical stress on line tools and equipment are not considered.
2) the effects of surge voltages on line tools and equipment are not considered.
3) the aging effect of line tools and equipment are not considered.
4) the test voltage stresses are not clearly defined.

In the wake of accidents, two linemen deaths in live–line work on distribution systems, Ontario Hydro organized a special task force in 1991 to reconsider all aspects of live–line work on distribution systems [15]. The new investigation came as the results of the second death in two years of a line crewman during a live–line work. The report stated that, at the time of the accident, the crew had been observing all proper precautions and the line man also did a good job. The problem came from the live–line work method and procedure. From this accident, it could be seen that some problems really exit in today's live–line work.

The problems have drawn attention of electrical utilities worldwide. For solving those problems and harmonizing present Standards, in 1989, a worldwide special test program was organized by IEC–TC 78 Special Group, IEEE/PES ESMOL Subcommittee and ASTM Committee F–18 chaired by Mr. N. Kolcio from American Electric Power Service Corporation. The members in this Special

Test Program, who are experts in high–voltage engineering and live–line maintenance, come from electrical utilities and universities in different parts of the world. Now eleven international Laboratories, including The University of Manitoba, have joined this test program. The aim of this special test program is to improve the methods and procedures for live–line maintenance and harmonize the methods of testing materials and equipment used in live–line work. In 1991/92, we have participated in two test programs. The studies included tests with mutually accepted electrode configurations under AC, DC and SS voltages applied to two types of FIPE : rubber insulating blankets and line hoses. Our part of the work was completed on time and the reports [36–37] had been submitted to the committee chairman. The two test programs are introduced in Chapter three and Chapter four.

Some of the problems mentioned above have been discussed on line tools and equipment [27–39]. The discussions and suggestions are useful but not complete because they center on the area of rubber insulating gloves, only one of the line tools and equipments, and the discussions on other line tools and equipments are few or none.

The objective of the present research work is to help the electrical utilities to understand the live–line work. The research work included investigations and analysis of the electrical insulation properties of line tools , FIPE and ropes for live–line work, based on a collection of large amount of test data.The research work focused mainly on the study of the effects of humidity, certain electrode configurations and different electric stresses applied to line tools, FIPE and ropes, and the study of the aging characteristics of line tools, FIPE and ropes. The tasks are :

1) to determine the electrical insulation properties of line tools and FIPE at different humidity, electrode configurations and electric stresses.

2) to assess the aging effects of line tools, FIPE and ropes, which have been used in live–line maintenance for a certain period of time.

3) to compare the hydrophobic properties on the surface of new and aged line tools, FIPE and ropes. This included measuring leakage currents in both dry and moist conditions after applying standard washing techniques and etc.

Chapter Two

CORRELATION OF AC, SWITCHING SURGE AND DC BREAKDOWN TEST RESULTS FOR RUBBER INSULATING BLANKETS

2.1 Introduction

This is one of the test programs organized by IEC–TC 78 Special Group, IEEE/PES ESMOL Subcommittee and ASTM Committee F–18. The aim of the test program was to determine the power frequency, DC and switching surge breakdown voltages of selected small circular (150 mm in diameter) samples of blankets tested in oil. Based on the test results, correlations were made between the observed performance under power frequency, DC and switching surge voltages. It is interesting to note that these correlations are different than what is now being used in the applicable standards. For example, test results for blanket samples show that the average switching surge breakdown voltage is higher than the power frequency peak breakdown voltage. Also, the ratio of the DC to the power frequency breakdown voltages appears to be greater than the value of $\sqrt{2}$ presently used in the standards. Compared with the existing standards, the experimental results indicate that the equivalence in testing between power frequency and DC, and power frequency and switching overvoltage now used in the industry and standards may be incorrect.

2.2 Testing Setup and Procedure

In this test program, blanket samples were tested in an oil bath. Power frequency AC, switching surge and DC tests were conducted. All tests were conducted in the High Voltage and Power Transmission Research Laboratory of The University of Manitoba.

2.2.1 Test Samples

The test samples are round in shape and 150 mm in diameter. The test samples were supplied to our High Voltage Laboratory. The samples were labeled as to their original locations on the complete blanket from which the samples were cut out. Figure 2.1 is the drawing of the blanket showing the sample positions. The drawing also indicates the measured sample thickness. All samples were shipped in plastic envelopes, which also contained sample identification numbers. All blanket samples were tested in an oil bath.

2.2.2 Test Vessel and Electrodes

A plastic vessel, filled with liquid insulant (oil), contained a grounded (larger) electrode located at the bottom.The sample was placed on the top of the grounded electrode, and the energized (smaller) electrode was placed on the sample. The sample and the top electrode were centered with respect to the bottom electrode. Electrodes were made of brass. Figure 2.2 shows the test setup.

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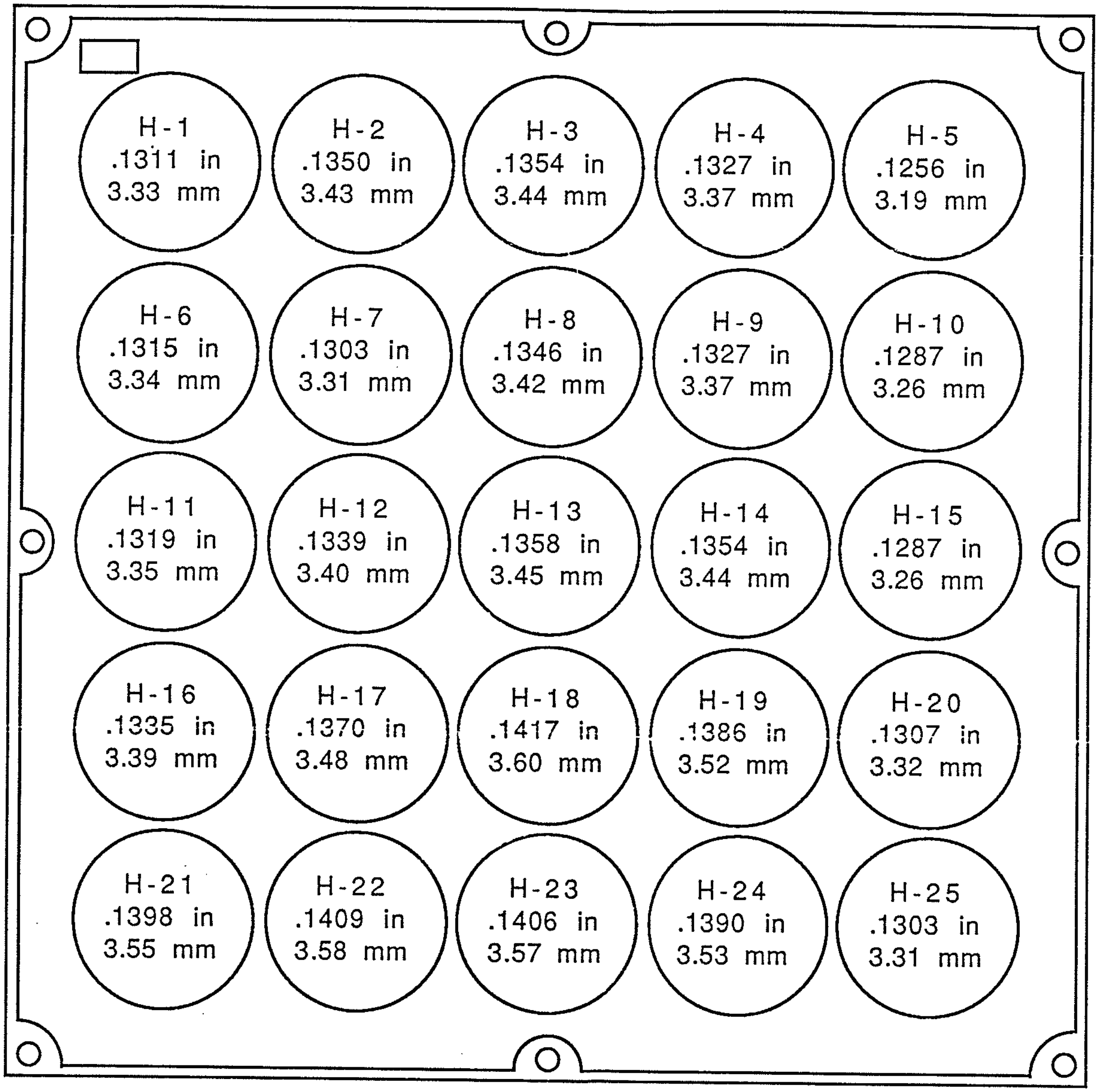


These test samples go to:

University of Manitoba

* All measurements were taken from the center point of samples.
Average thickness = 3.41 mm (.1342 in.)

Figure 2.1 Drawing of the blanket showing the samples

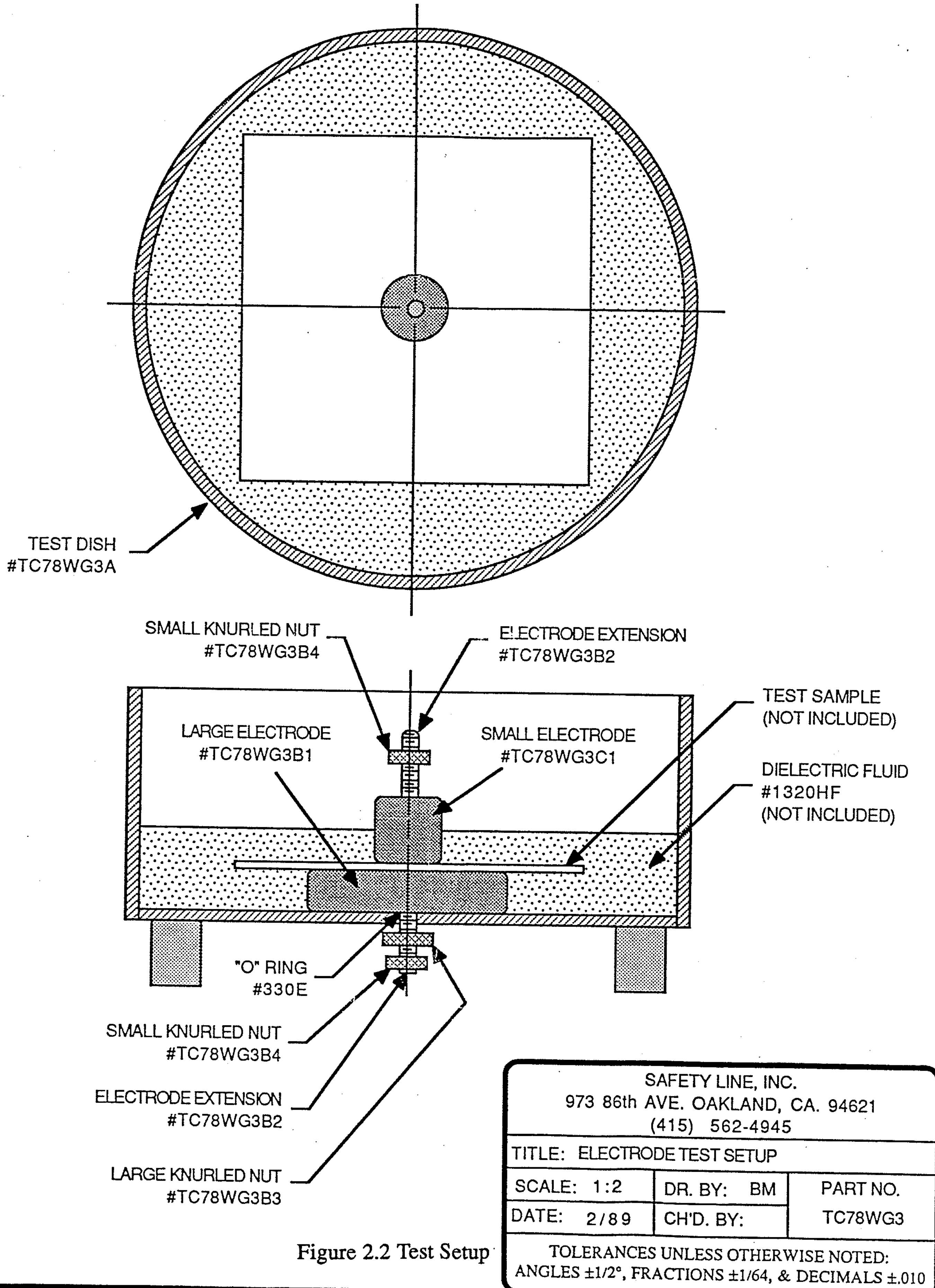


Figure 2.2 Test Setup

Puncture of the sample left carbon marks on the electrodes. Electrodes were removed from the vessel and cleaned (wiped off) after each breakdown occurred.

2.2.3 Liquid Insulant (Oil) Used for Testing

In the test, Shell Diala AX type mineral oil was used. The dielectric breakdown voltage of the oil was determined by the ASTM Test Method D 877 and the test results of breakdown voltages are listed in Table 2.1. An oil bath of adequate depth and size was maintained to ensure that the tested samples and the top (smaller) electrode were completely immersed in the oil.

Table 2.1 Breakdown Voltages of Oil in Standard Cup under AC Voltages

No.	1	2	3	4	5
B.V. kv peak	32.3	30.5	30.5	33.0	34.2
Average	**32.1kvpeak**				

2.2.4 Power Frequency AC and DC Testing Procedures

The test vessel containing the test sample was connected to the voltage sources (300 kV test transformer, 220 kV DC generator). The test voltage was increased at a rate of 1000 Vrms/sec for AC, and 3000 V/sec for DC, until breakdown occurred.

2.2.5 Switching Surge Test Procedure

The test vessel containing the test sample was connected to the output of the surge generator (2.4 MV impulse generator). The up and down method was used to determine the 50 % puncture voltage. The generator was charged to an appropriate voltage level, and then triggered. For the next voltage surge application, the charging voltage was lowered or raised by an appropriate value (about 2%

of the expected 50% puncture voltage). The switching surge used normally had a waveshape of 50/1000 μs. If the application of a particular voltage surge resulted in withstand of the sample, the same sample was used for the next shot at the appropriately higher voltage. If the application of a particular surge resulted in puncture of the sample, a new sample was used for the next shot at the appropriately lower charging voltage. This up and down method was continued until all samples were tested to destructive.

2.3 Test Results and Discussion

2.3.1 Test Results

Table 2.2 and Table 2.3 list the test results for the samples of rubber insulating blankets under AC and DC voltages. The average breakdown voltage was calculated as the arithmetic average of the individual breakdown voltage determined experimentally. The experimentally found spread in the breakdown voltage is also indicated below the values of the average breakdowns. The thickness of the individual samples is also included in the tables. In the DC tests, positive polarity was used. The puncture breakdowns occurred mainly at the edge of the small electrode.

Figure 2.3 gives the plotting of the test results (the average breakdown voltage and the average sample thickness) for the switching surges with the recommended waveforms (50 / 1000 μs). Positive polarity surges were used. It should be kept in mind that the samples are of the non–self–restoring insulation type, and the tests are destructive in nature, i.e., when a breakdown occurs, a new sample must be used. While this seems to give reasonably consistent results for AC tests, the results obtained by the up and down method under switching surge voltages were often quite inconsistent and included continuous sequences of withstands as shown in Figure 2.3, in which case samples were not

Table 2.2 Test Results under AC Voltages in Oil

Blanket Material NO.	Thickness , mm	Puncture Voltage, kV rms
H–11	3.35	56.6
H–6	3.34	60.8
H–15	3.26	50.9
H–13	3.45	55.9
H–25	3.31	52.3
Average Value	**3.34**	**55.3**

Table 2.3 Test Results under DC Voltages in Oil

Blanket Material NO.	Thickness , mm	Puncture Voltage, kV
H–12	3.40	186
H–21	3.55	172
H–2	3.34	162
H–10	3.26	182
H–7	3.31	178
Average Value	**3.39**	**176**

replaced for each sequence of switching surge voltage application, as well as long sequences of breakdowns, in which case a new sample was used for each voltage application. To make matters worse, these long sequences of one type of outcome (withstand or breakdown) often followed each other without an easily identifiable pattern. In other words, the outcomes of the up and down method deviated from the classical behavior seen, for example, for air insulation, for which normally an increase in the applied voltage results in breakdown while a decrease in withstand, and the outcomes

B.No	11	13	15	16	23	24	25	27	28	30	32
M.No	H–16	H–14	H–23	H–4	H–18	H–5	H–9	H–22	H–24	H–17	H–19
T,mm	3.39	3.44	3.57	3.37	3.60	3.19	3.37	3.58	3.53	3.48	3.52

M.No – Blanket Material No. ; T – Thickness of Materials ; B.No – Breakdown No.

× – Breakdown ● – Withstand

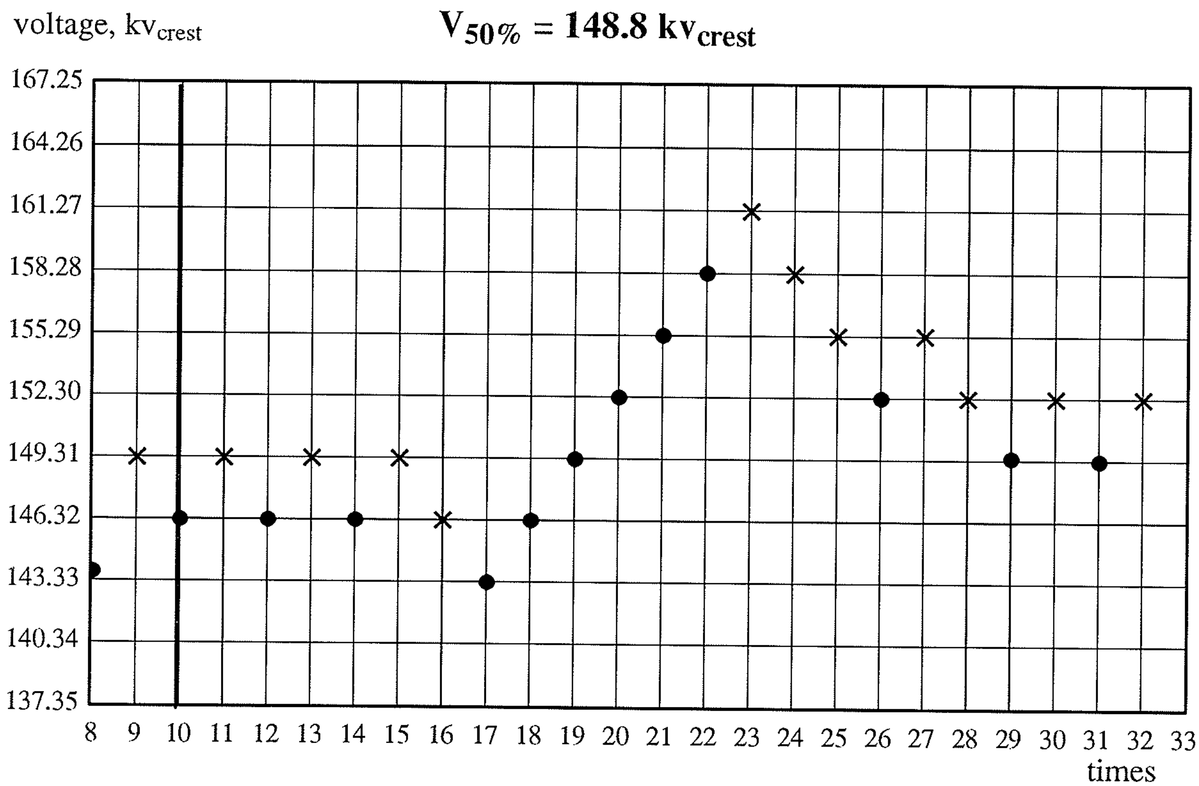


Figure 2.3 Test Results under Switching Surge Voltages

tend to produce a " saw–tooth" shape. In view of this difficulty and the fact that only a small number of samples was available for the up and down method, the normal equations for determining the 50% breakdown value of voltage were not used. Instead, the average breakdown voltage quoted in Figure 2.3 for switching surge tests is the arithmetic average of the actual voltage values of the switching surges which produced breakdowns, as measured experimentally by the oscilloscope. Typically, breakdown occurred on the wave tail, and the crest value of that wave was taken as the breakdown voltage in finding the average values in Fig.2.3. It is recognized that surge breakdown characteristics obtained in this way are rather crude, and further research is needed to improve the accuracy of the results. Nevertheless, the collected surge data are informative.

In order to facilitate meaningful comparisons among the results obtained for various blanket samples, the experimentally determined breakdown voltage data were expressed as equivalent average dielectric strength of the samples by dividing the average breakdown voltage with the average thickness (see Table 2.4).

Table 2.4 Dielectric Strength Values for Blankets

AC Avg. Strength kVpeak/mm	SS Avg. Strength kV/mm	DC Avg. Strength kV/mm
23.3	**43.0**	**51.9**

2.3.2 Characteristic Ratios

In order to meet the objective of the test effort to determine the relationships between power frequency AC, DC and switching surge breakdown performance of the various samples, the data in Table 2.2 were used to calculate characteristic ratios for each case. The power frequency AC data are used as the base for determining the characteristic ratios. Table 2.5 lists the characteristic ratios for blanket material.

Table 2.5 Characteristic Ratios of Blanket Material

Switching Surge / ACpeak	DC / ACpeak
1.9	**2.25**

2.3.3 Discussion of Results and Suggestions

Due to a rather small data base, strict statistical treatment of the data is not possible and the questions of interpretation of the results and confidence in the obtained data need to be addressed in a simplified manner. One way of interpreting and using the experimental data is to concentrate on the calculated arithmetic average given in 2.3.1 and 2.3.2 . Such an approach is useful as it leads to some general conclusions.

A recommendation reached during the IEC TC–78 Committee meeting in Toronto in June of 1990 stated that the maximum electrical stress on power lines (69 kV and below) can be expressed in terms of switching overvoltages and in general, this stress has been assumed to be 3 p.u. of the maximum line–to–ground use voltage. In order to provide adequate protection to workers, all FIPE must withstand this stress. For example, Class 4 FIPE is rated for maximum use voltage of 36 kV rms line–to–line or 21 kV rms line–to–ground. The maximum anticipated switching surge voltage on this 36 kV line would be $3 \times 21 \times \sqrt{2} = 89$ kV peak. Now, all Class 4 FIPE should be rated to withstand 89 kV peak switching surge or an equivalent power frequency voltage. Based on our experimental results, for 36 kV power lines or Class 4 FIPE, the AC and DC withstand levels of FIPE were listed in Table 2.6.

Table 2.6 Implications of Withstand Level for 36 kV Power Lines

AC, kV rms	DC, kV
$89 / (\sqrt{2} \times 1.9) = 34$	$34 \times \sqrt{2} \times 2.25 = 109$

Comparing data in Table 2.6 and Table 1.1 for 36 kV power lines, it can be seen that the withstand level given in the Standard is higher than the one in Table 2.6 for AC, whereas lower for DC. This result may point out that the present AC withstand test voltages could be decreased or remain the same, whereas the DC withstand test voltages would need to be increased.

Table 2.6 Breakdown Voltages and Corresponding Thickness under AC, SW and DC Stresses From 11 International Laboratories

COMPANY	AC AVG BR kVRMS	THICKNESS mm	SW AVG BR kV	THICKNESS mm	DC AVG BR kV	THICKNESS mm
A.B.Chance	64.0 61.6–65.0	3.45 3.26–3.66	91.9 83.3–102.0	3.35 3.23–3.48	212.4 200.0–219.0	3.45 3.30–3.62
BPA	68.5 65.0–70.0	3.58 3.38–3.78	124.8 115.0–129.3	3.43 3.26–3.63	173.2 157.0–190.0	3.45 3.38–3.51
E de F	61.5 59.6–62.4	3.52 2.81–3.94				
Ontario Hydro	48.2 41.3–53.4	4.02 3.53–4.42			151.3 128.0–174.0	4.07 3.31–4.59
Powertech Labs	53.4 50.0–61.0	3.82 3.22–4.22	108.8 107.6–110.4	3.58 3.18–4.04	120.0 110.0–130.0	3.52 n/a
Safety Line	22.6 20.5–26.9	3.41 3.36–3.47			175.6 160.0–187.0	3.35 3.34–3.36
Severoceske Energ. Zav.	40.4 39.0–42.0	3.57 3.43–3.66	105.2 101.0–109.0	3.53 3.31–3.77		
U of Manitoba	55.3 52.3–60.8	3.34 3.26–3.45	148.8 146.3–161.3	3.46 3.19–3.60	176 162–186	3.39 3.26–3.40
U of Missouri–Rolla	47.6 43.0–51.0	3.94 3.87–4.16			215.9 164.0–252.0	4.02 3.80–4.23
U of Waterloo	39.4 35.0–41.0	3.47 3.26–3.58	93.7 89.9–95.6	3.38 3.26–3.45	118.0 116.0–122.0	3.46 3.32–3.60
Von Corporation	51.2 47.0–55.0	3.91 3.80–4.00				

Our test results were compared with other laboratories's. Table 2.7 lists the experimental results of breakdown voltages under AC, switching surge and DC stresses from 11 international laboratories and the corresponding thicknesses of tested samples are also given in the table. From the values in the table, it can be seen that there is a spread of test data among different laboratories. For AC and DC stress tests, the breakdown voltages obtained in our laboratory fall in the middle in the values of other laboratories. For switching surge tests, our breakdown voltages are the highest among the laboratories. Even though there exists the difference in the experimental results obtained by the different laboratories, the conclusions from all laboratories were similar. i.e., the equivalence in testing between power frequency and DC voltage, and power frequency and switching surge overvoltages now used by the industry and in the standards may be incorrect.

Table 2.8 Ratios of Proof–Test to Maximum Use Voltages

Class Level	0	1	2	3	4
Ration	5.00	1.33	1.18	1.13	1.11

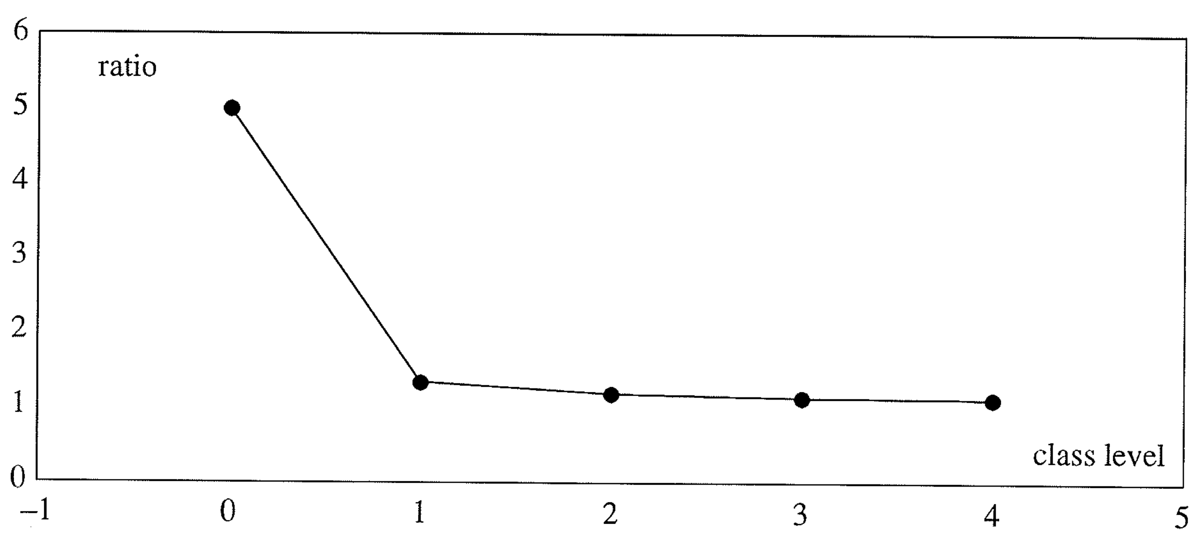


Figure 2.4 Relation between Ratio and class level

The relationship between the proof–test and nominal maximum use voltages for line hoses or other insulating protective equipments were also discussed. the ratios of proof– test to maximum use voltages are listed in Table 2.8 and presented in Figure 2.4. It can be seen that the ratio falls down sharply as the class level increases. The drop from the maximum to minimum ratio is about 78%.

Chapter Three

EFFECT OF ELECTRODE CONFIGURATIONS DURING LINE HOSE TESTS UNDER POWER FREQUENCY AC AND SWITCHING SURGE VOLTAGES

3.1 Introduction

This is the second test program organized by IEC–TC 78 Special Group, IEEE/PES ESMOL Subcommittee and ASTM Committee F–18. The aim of this test program was to determine the effects of the various electrode configurations on the test results of line hoses and also, to establish a correlation between power frequency and transient overvoltages for line hoses tested with several electrode shapes. From the test results, it can be seen that the electrode configurations during line hose tests influence the values of flashover. Similar to the conclusion reached in the first test program, this test program also indicates that the equivalence in testing between power frequency and switching overvoltages now used by the industry and in the standards may be incorrect, i.e., the average switching surge flashover voltage is higher than the power frequency peak flashover voltage for each electrode configuration during line hose tests.

3.2 Testing Setup and Procedure

In this test program, line hoses were tested in air. Power frequency AC and switching surge stresses were used. All tests were conducted in the High Voltage and Power Transmission Research Laboratory of The University of Manitoba.

3.2.1 Test Samples

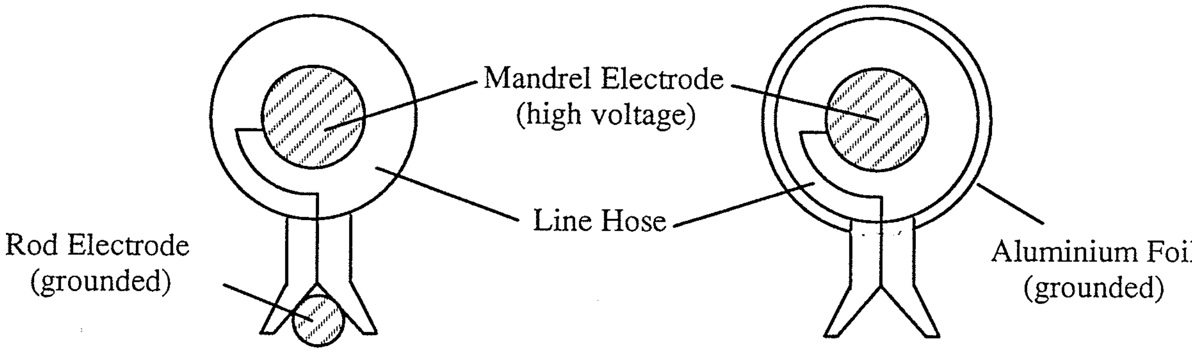
Two new line hoses were used in the tests. One was of Class 2 and the other Class 4 (see Chapter one for corresponding voltage level). A complete line hose was used as the test sample.

3.2.2 Electrode Configurations and Testing Setup

A copper mandrel (210 mm long and 25 mm diameter) was used as high voltage electrode. A 20 mm diameter copper rod and 480 mm wide aluminium foil were used as ground electrode. Figure 3.1 shows eight electrode configurations used in the tests. Four electrode configurations were used to simulate linemen's situations during the operation. The general test setup for Class 2 and Class 4 line hoses is shown in Figure 3.2 .

3.2.3 Power Frequency AC Testing Procedures

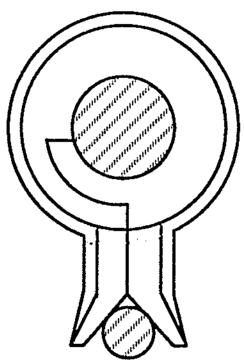
The mandrel electrode was connected to the voltage source (300 kV test transformer). For each test, the power frequency voltage was raised at a rate of 1000 Vrms/sec until breakdown occurred and the results were recorded.



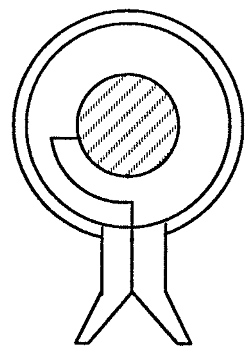
see Figure 3.2 a)

see Figure 3.2 b)

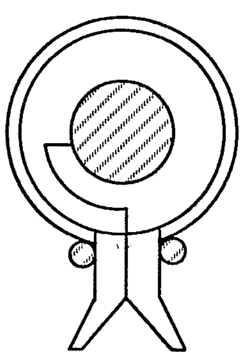
Cross Section of Line Hose and Electrodes



1A



1B



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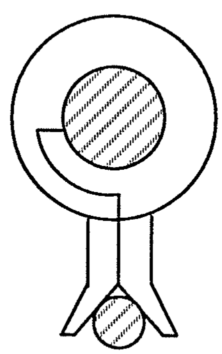

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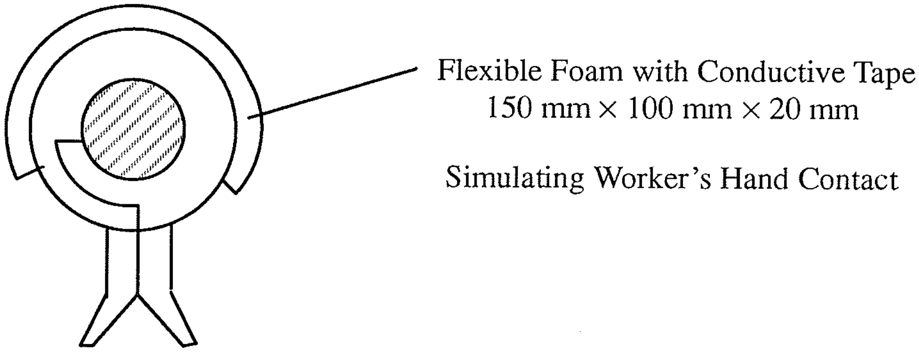
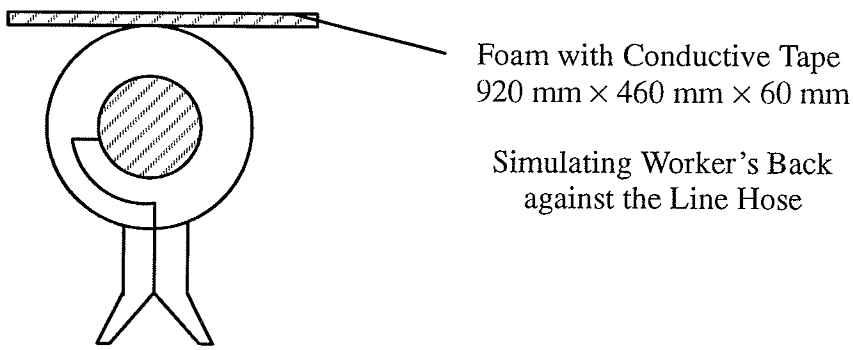
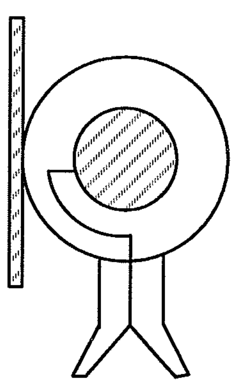


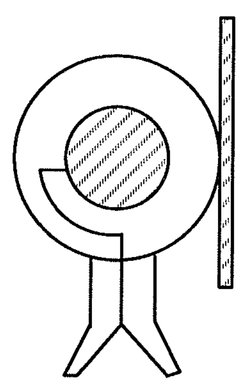
4



5A

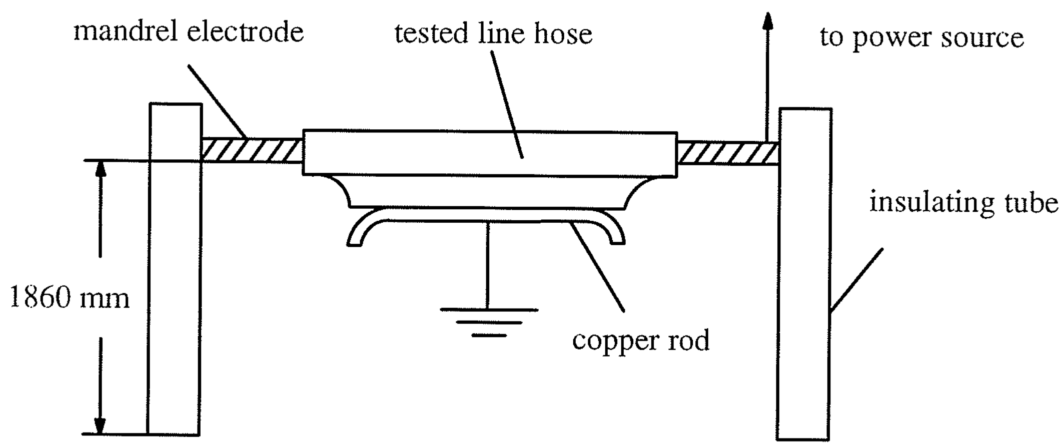


5BL

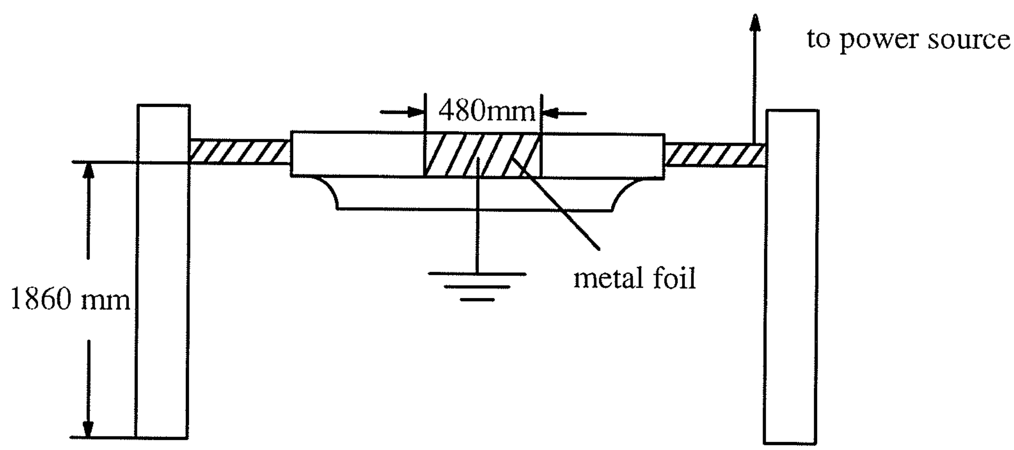


5BR

Figure 3.1 Eight Electrode Configurations (No.1A–5BR)



a) copper rod as grounded electrode



b) aluminium foil as grounded elctrode

Figure 3.2 General Test Setup for Line Hose

3.2.4 Switching Surge Test Procedure

The mandrel electrode was connected to the output of the surge generator (2.4 MV impulse generator). The switching surge waveshape recommended by the working group was 50/1000 μs. In our switching surge test, the front time of the wave forms varied from 44.4 to 48.7 μs and the wave form was shown in Figure 3.3. Unlike in the AC and the DC tests, in surge tests, a series of individual surges with crest values successively adjusted in a judicial manner must be used to establish statistically the breakdown voltage. The starting point, i.e., the crest voltage level of the first surge to be applied to a batch of similar samples, is also very important to save testing time, and to avoid unnecessary damage to the samples. Prior to starting the surge tests, the Special Test Group suggested a test procedure for the surge test of line hose, which every laboratory should follow in surge testing of line hoses. The test procedure included the following steps :

1) Mount the sample in the test set up.

2) Calculate Ve, the expected surge crest voltage,which will cause breakdown.

   $Ve=Vac \times 2 \times 1.3$

   where Vac is the power frequency breakdown level in kV rms,previously determined for similar samples. Record the value of Ve.

3) Calculate $D=0.05 \times Ve$ and $Vt=Ve-D$. Use Vt as the crest voltage for the first trial surge to be applied to the sample. Apply the first trail surge voltage.

4) The result of the first trial surge can be either breakdown or withstand of the sample. In case of breakdown of the sample, follow steps listed below under Possibility 1. In case of the withstand, follow steps listed below under Possibility 2.

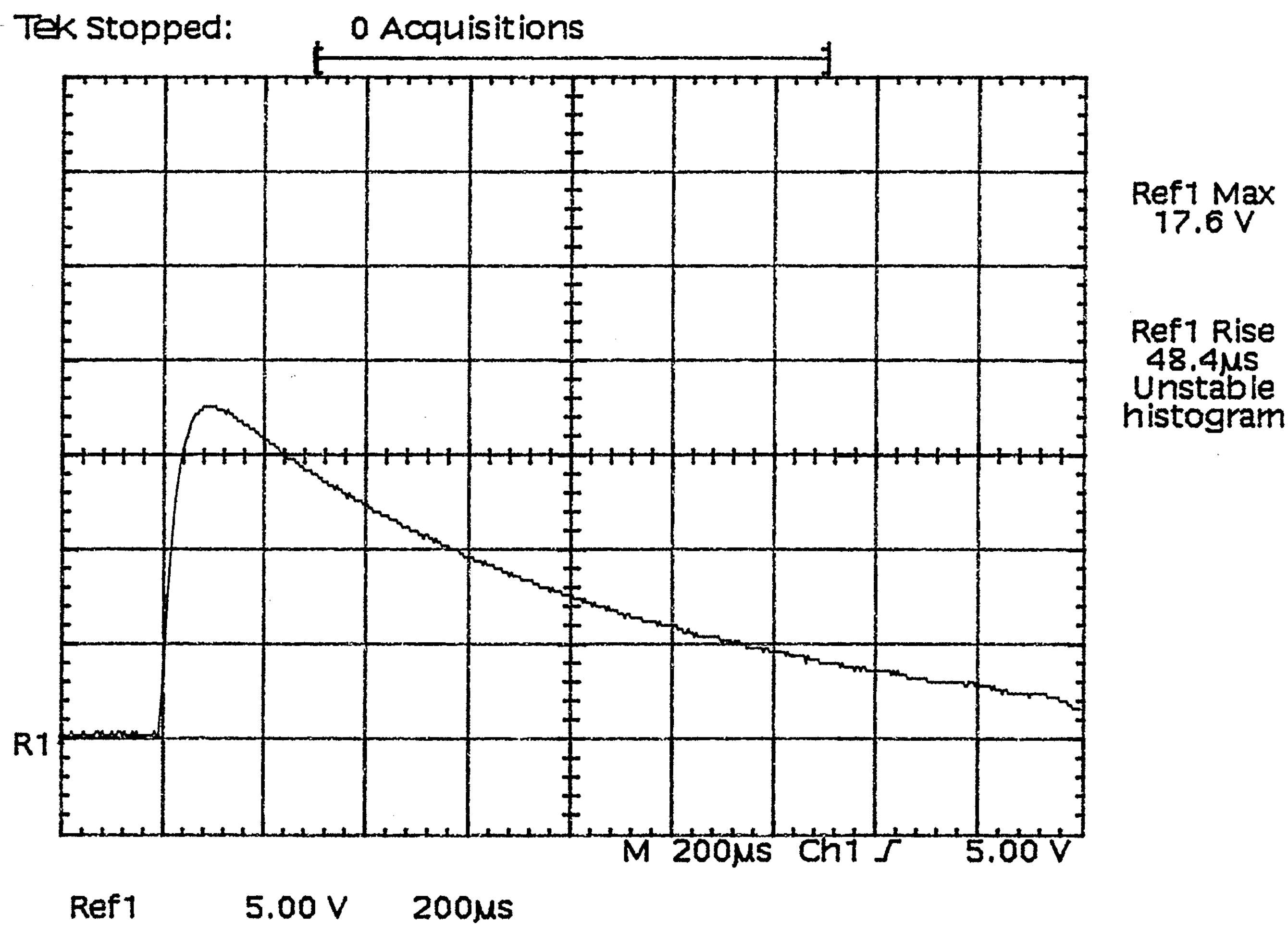


Figure 3.3 The Waveform of Switching Surge Voltage Used in Testing

Possibility 1 – Vt resulted in breakdown of the sample;

a. Decrease Vt by factor D and use crest level Vs=(Vt–D) for the second trial surge voltage. Apply the surge voltage and Record Vs, the crest voltage level of the surge used.

b. If breakdown takes place upon application of the second surge, decrease the crest of the third trial surge by factor D, apply the surge and record Vs. On the other hand, if withstand take place, do not apply the third trial surge, but proceed to step 5.

c. If the third surge results in breakdown, apply another surge with appropriately reduced surge crest level, and so on, until withstand is obtained.

Possibility 2 – Vt resulted in withstand of the sample

a. Increase Vt by factor D and use crest level Vs = (Vt+D) for the second trial surge. Apply the second trial surge and record Vs.

b If the third trial surge results in withstand, repeat the above part of the procedure until the first breakdown takes place. On the other hand, if the third trial surge results in breakdown, then stop, record Vs and proceed to step 5.

5. Up and Down Method

a. Calculate d=0.02×Vs.

b. If Vs was obtained from Possibility 1, use crest level of Vc = (Vs+d) for the first testing surge, otherwise use crest level of Vc=(Vs–d) for the first test surge.

c. If breakdown is obtained, use Vc=(Vs–d) for the next surge, otherwise use Vc=(Vs+d) for the next surge. Repeat this part of the procedure until finished.

d. Report the crest levels Vc used and the result (breakdown/withstand) corresponding to each surge. The information could be presented on a graph showing the successive surge number as the abscissa and the corresponding surge crest level as the ordinate.Breakdowns can be indicated cated by 'x' and withstand by 'o' in the graph. See Figure 3.4 for our plotting of experimental results.

3.3 Test Results and Discussion

3.3.1 Test Results

Table 3.1 presents a summary of the test results with breakdown mode for Class 2 and Class 4 line hoses under AC and swithching surge voltages. The average breakdown voltages were calculated as the arithmetic average of at least three individual breakdown voltages determined experimentally. Throughout the tests, flashover around line hoses was the only mode of the breakdown and no puncture through the line hose occurred. In the AC tests, flashover paths were along the vertical direction ofthe line hoses except for the electrode configuration of No.5 in Figure 3.1 along the horizontal direction.

Table 3.1 Breakdown Voltages of Line Hoses Under AC and Switching Surge Voltages

Electro.No.	Class 2			Class 4		
in Figure 3.1	AC kV rms	SS kV crest	Mode of Breakdown	AC kV rms	SS kV crest	Mode of Breakdown
1A	23.34	48.95	FO	25.81	52.03	FO
1B	32.18	69.80		47.38	71.41	
2	28.82	64.20		49.50	73.43	
3	30.76	68.95		53.04	139.58	
4	35.36	76.65		45.26	91.03	
5A	35.00	77.82		41.73	91.46	
5BL	33.95	65.31		41.02	85.00	
5BR	34.30	70.91		43.85	84.93	

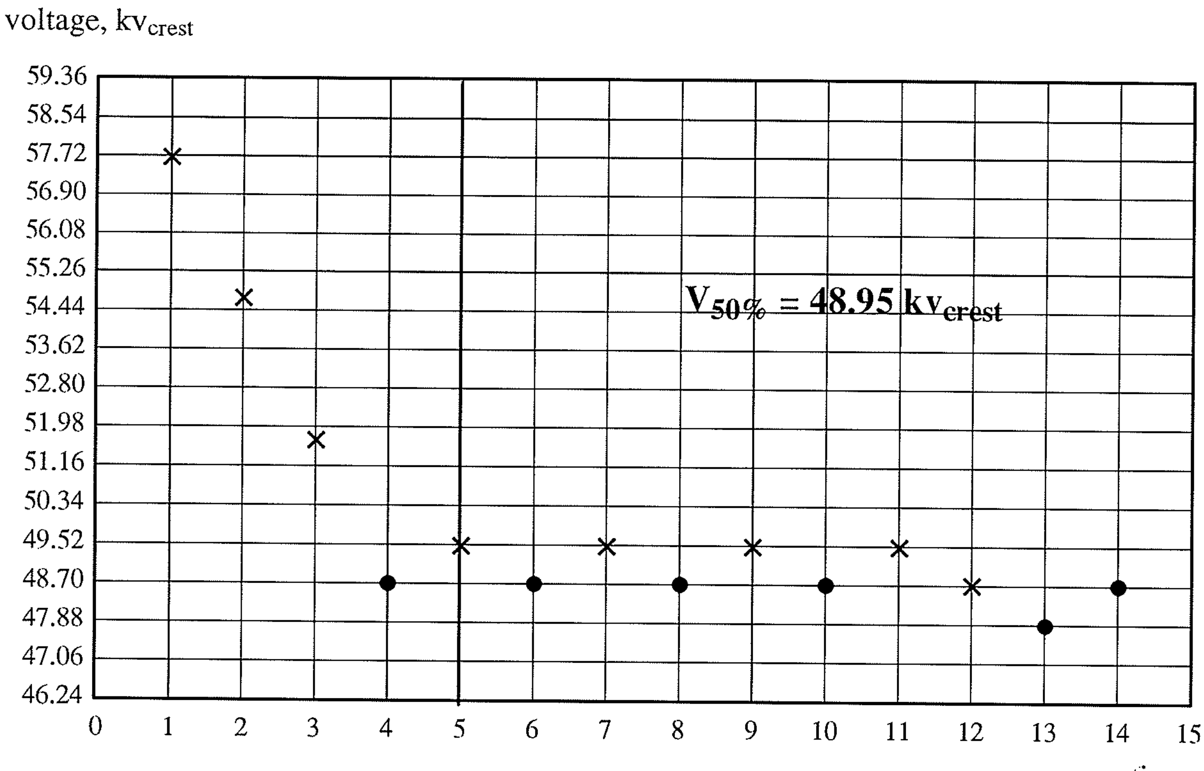


Figure 3.4.1 Results for No.1A's Electrode Configuration Obtained By Up and Down Method

× – Breakdown ● – Withstand

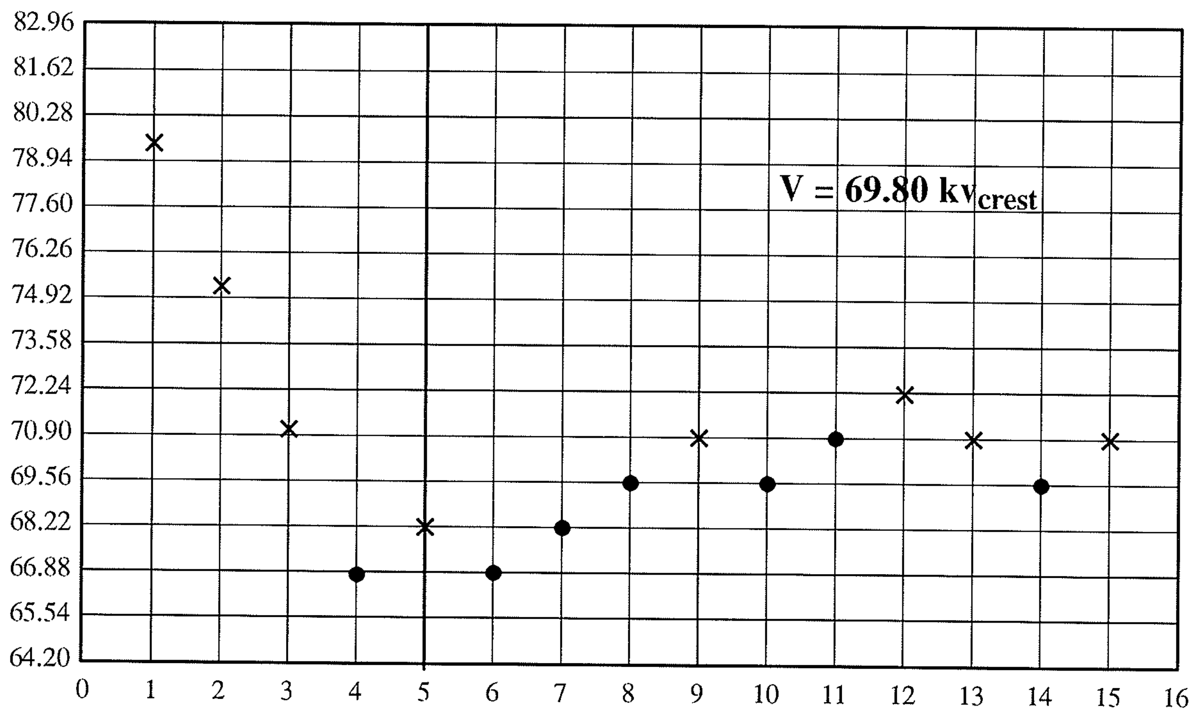


Figure 3.4.2 Results for No.1B's Electrode Configuration Obtained By Up and Down Method

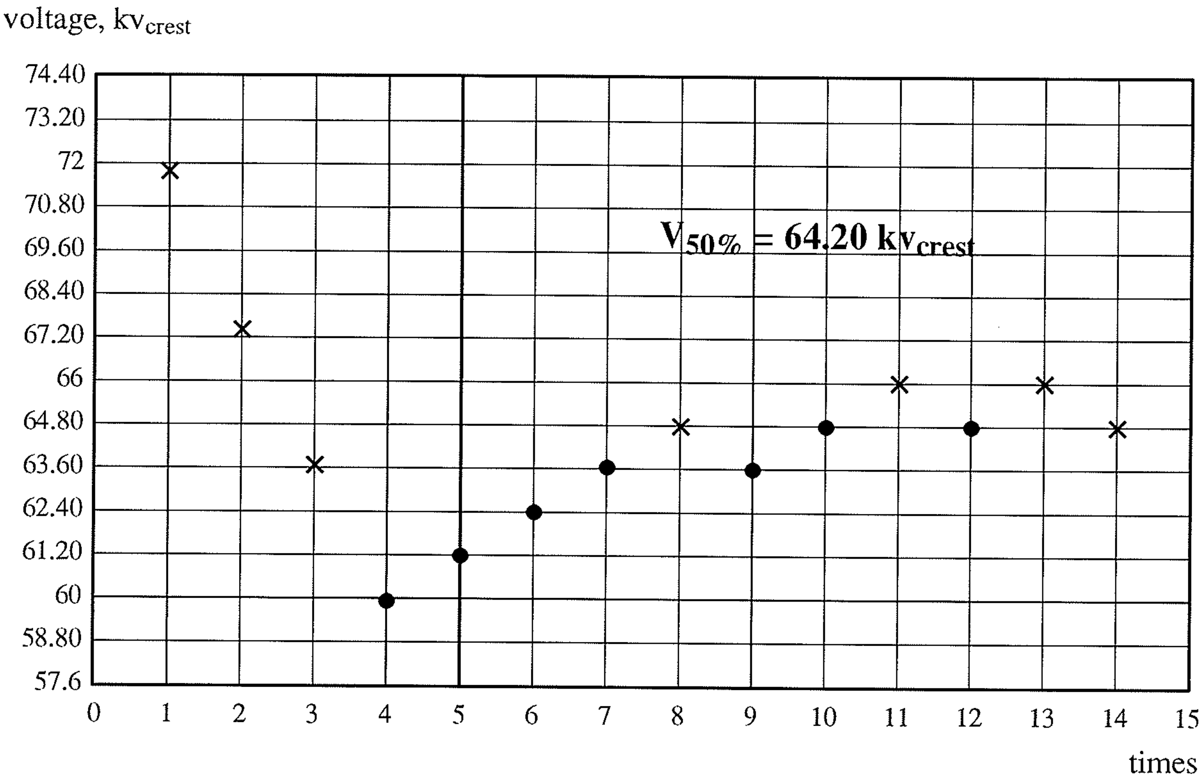


Figure 3.4.3 Results for No.2' s Electrode Configuration Obtained by Up and Down Method

× – Breakdown ● – Withstand

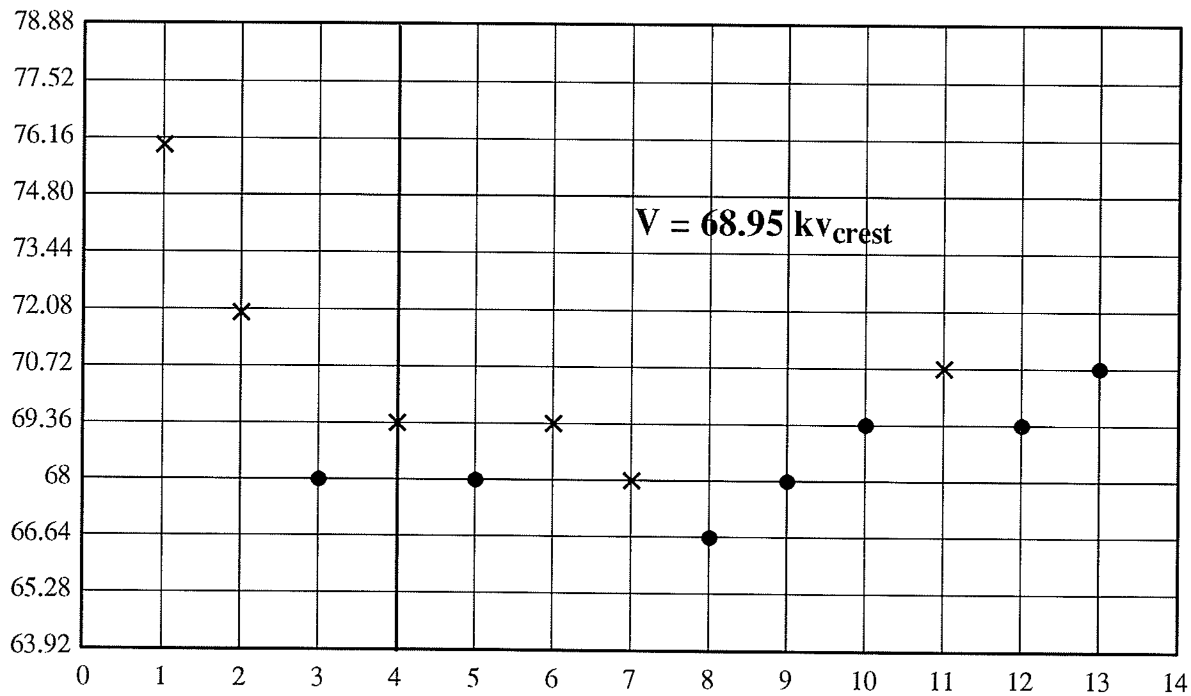


Figure 3.4.4 Results for No.3' s Electrode Configuration Obtained by Up and Down Method

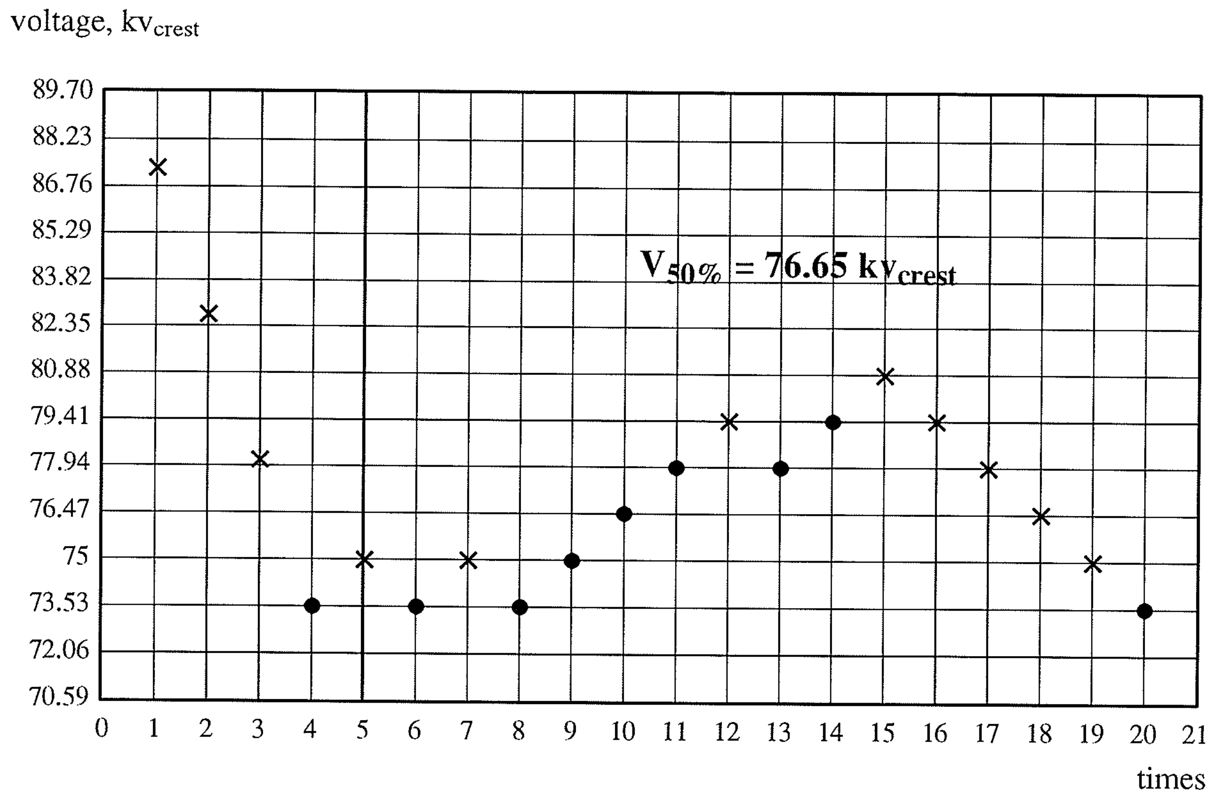


Figure 3.4.5 Results for No.4' s Electrode Configuration Obtained by Up and Down Method

× – Breakdown ● – Withstand

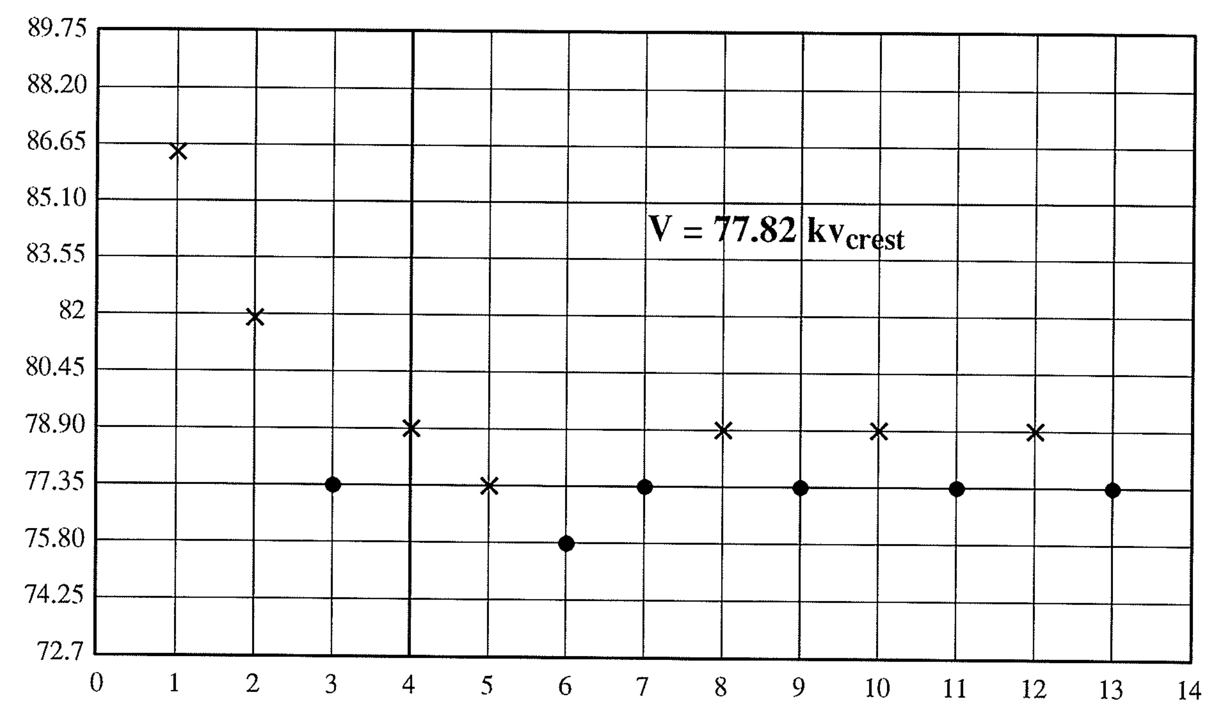


Figure 3.4.6 Results for No.5A' s Electrode Configuration Obtained by Up and Down Method

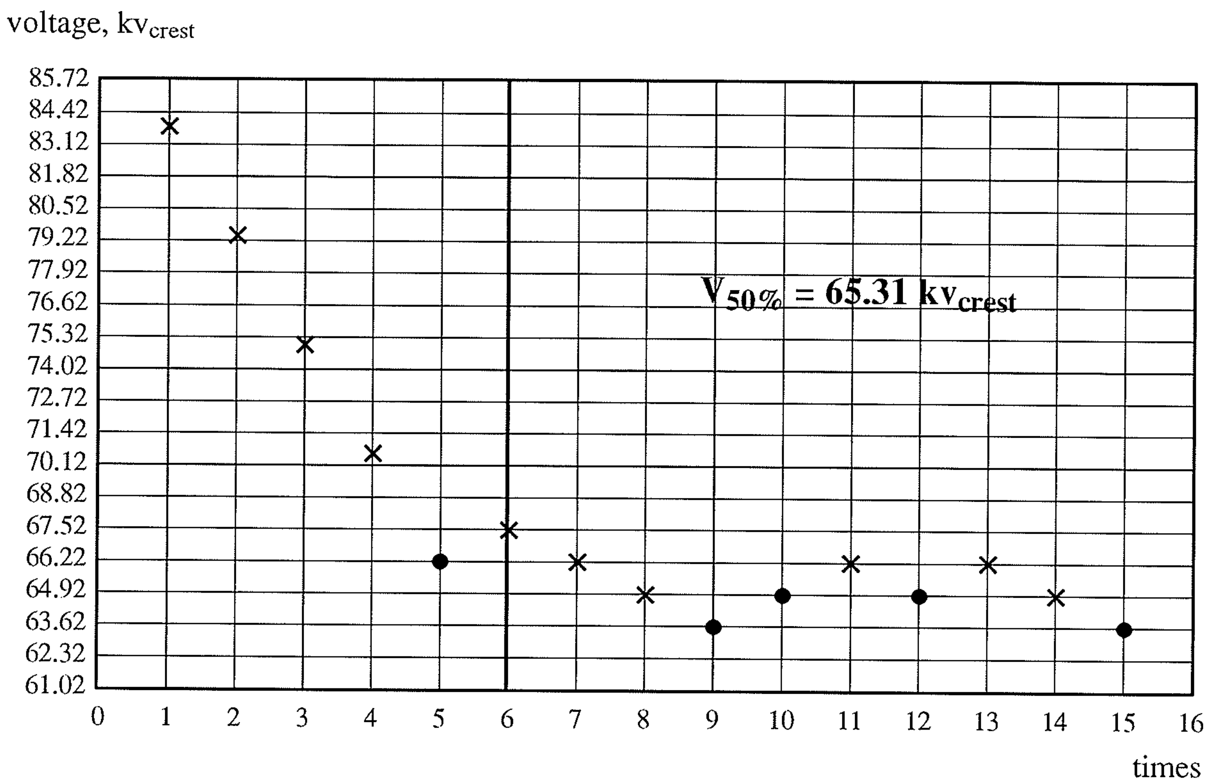


Figure 3.4.7 Results for No.5BL' s Electrode Configuration Obtained by Up and Down Method

× – Breakdown ● – Withstand

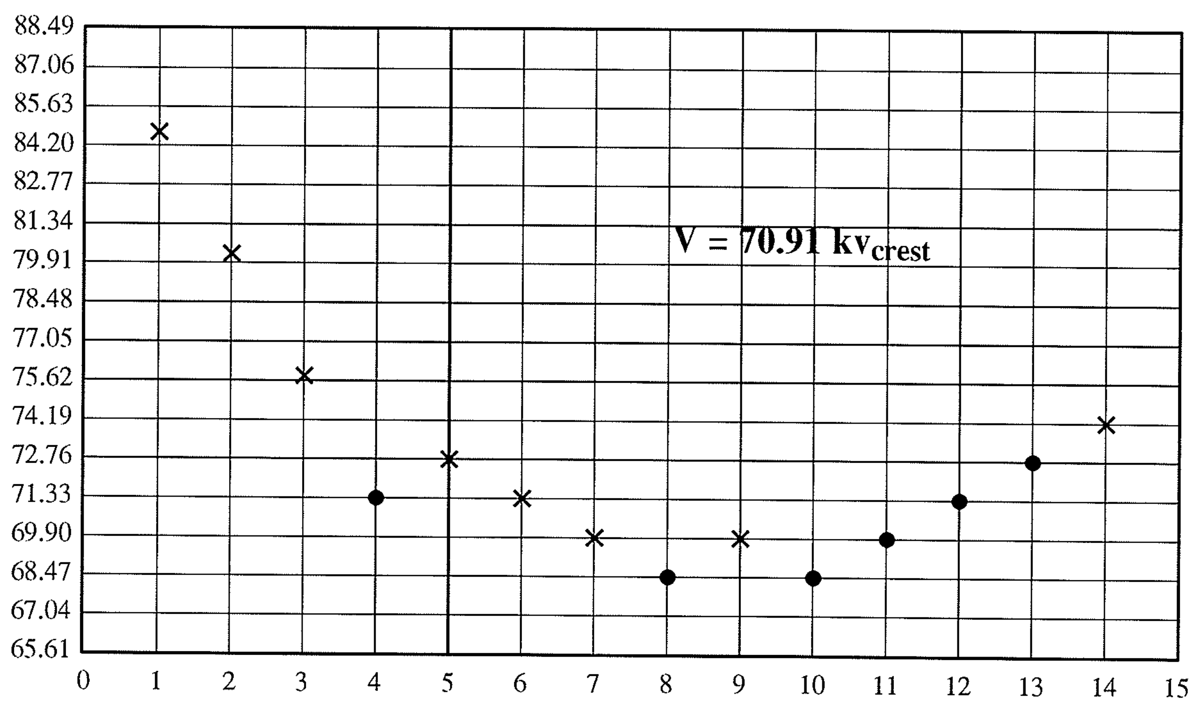


Figure 3.4.8 Results for No.5BR' s Electrode Configuration Obtained by Up and Down Method

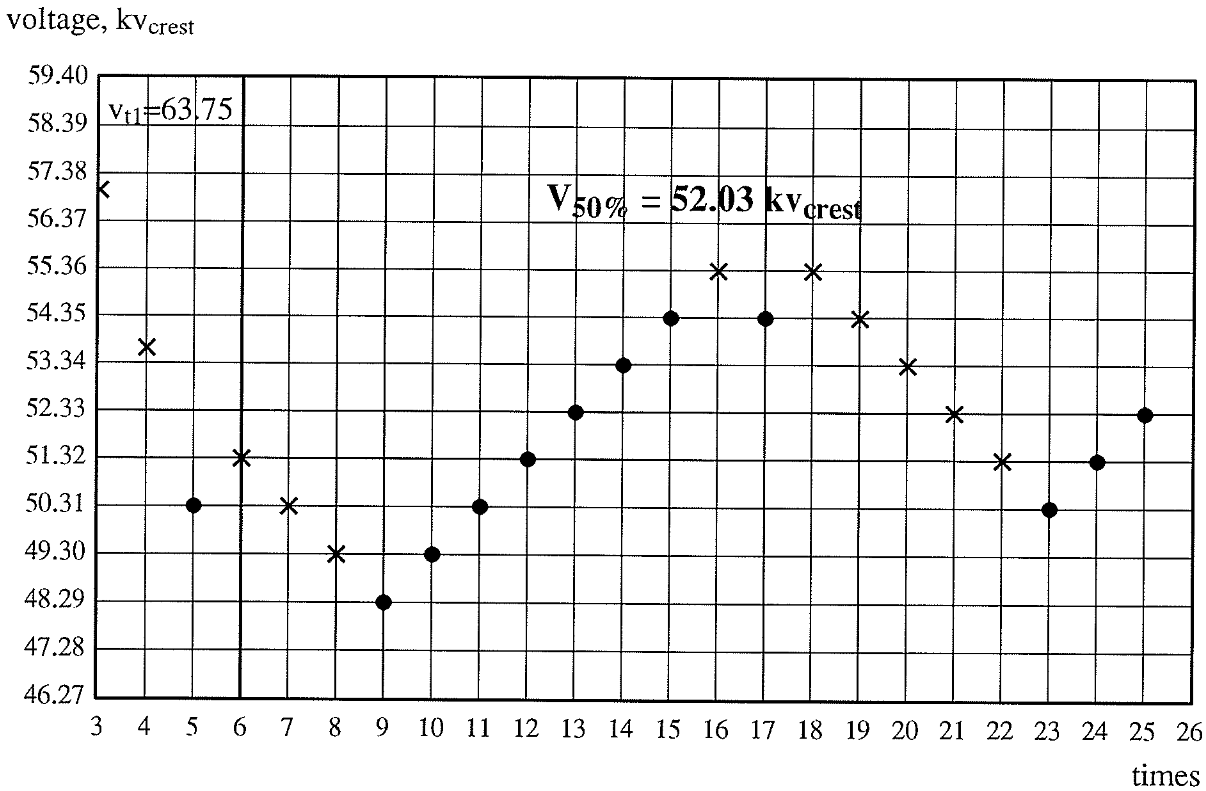


Figure 3.4.9 Results for No.1A's Electrode Configuration Obtained By Up and Down Method

✖ – Breakdown ● – Withstand

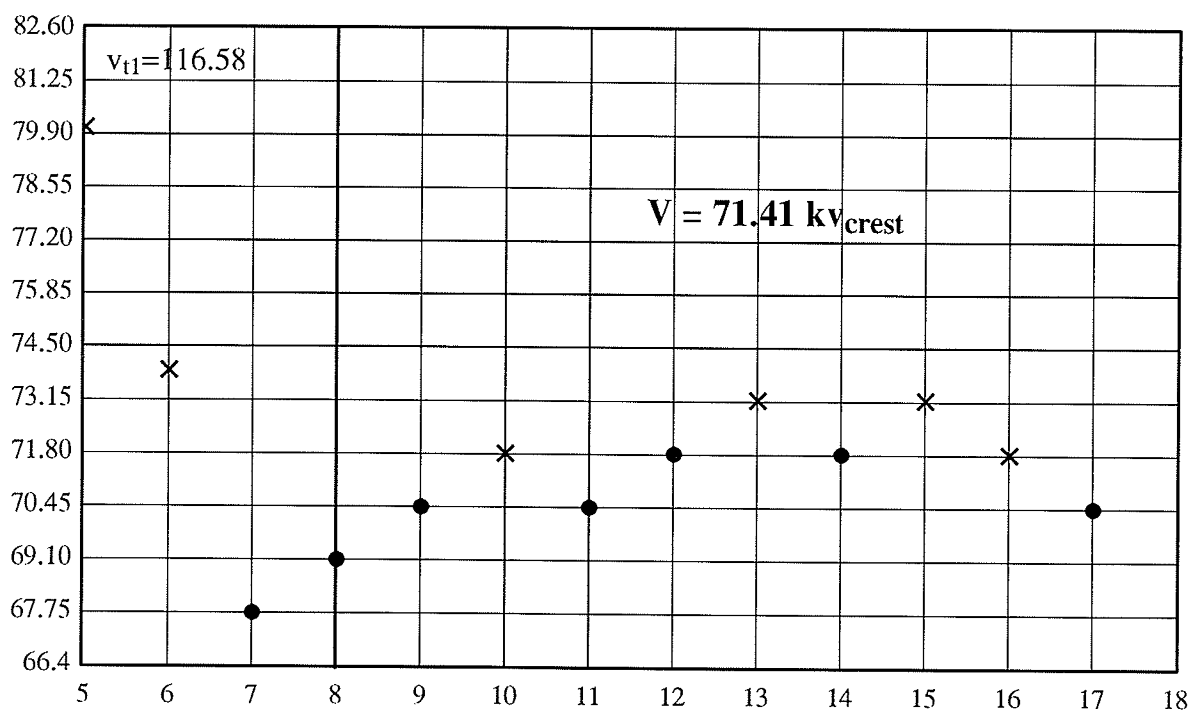


Figure 3.4.10 Results for No.1B's Electrode Configuration Obtained By Up and Down Method

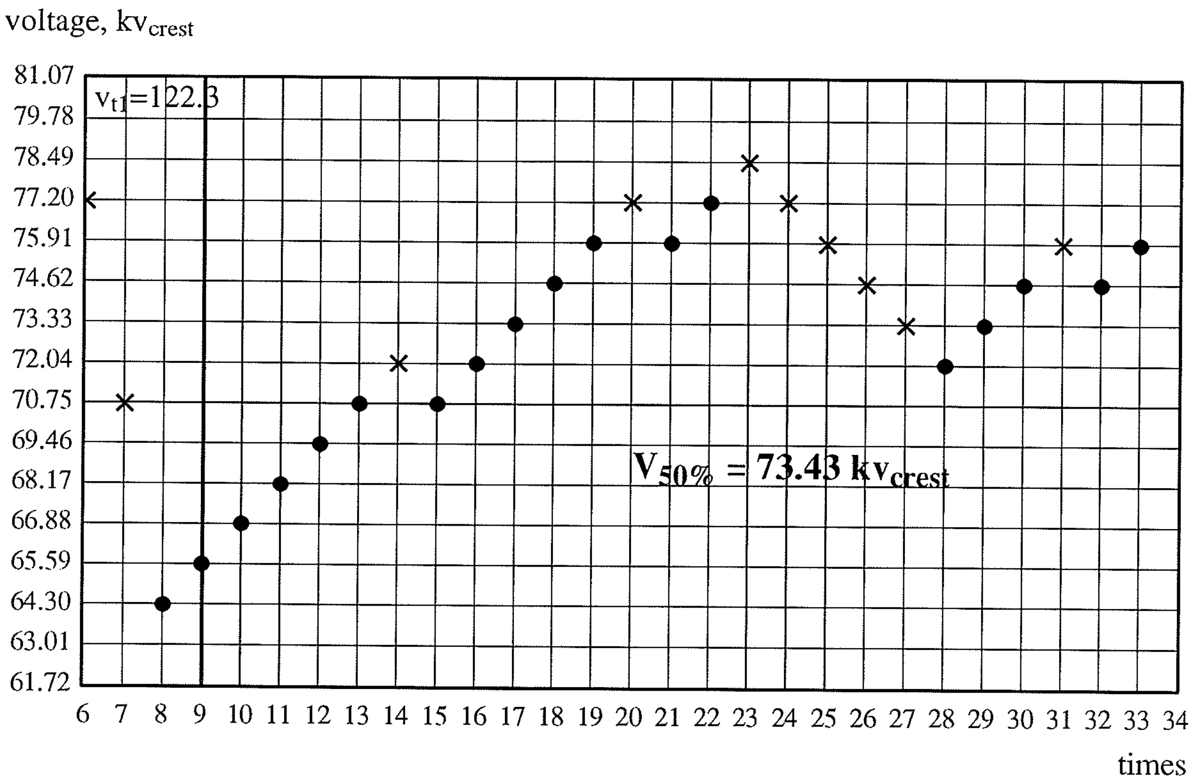


Figure 3.4.11 Results for No.2' s Electrode Configuration Obtained by Up and Down Method

× – Breakdown ● – Withstand

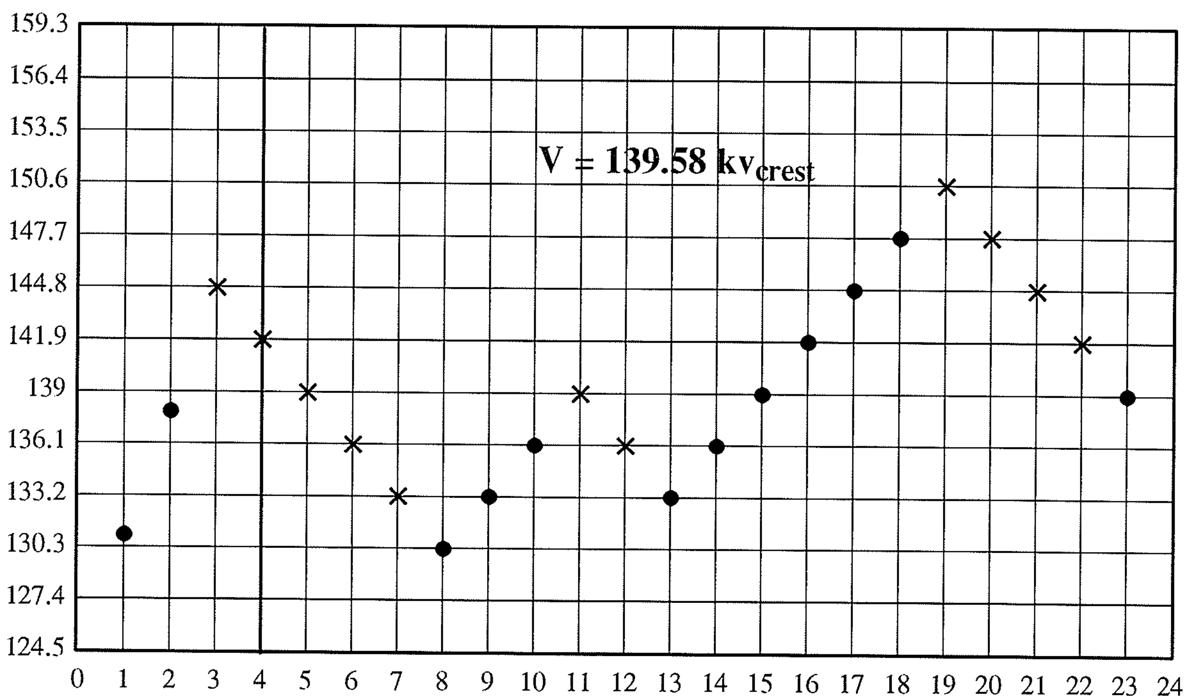


Figure 3.4.12 Results for No.3' s Electrode Configuration Obtained by Up and Down Method

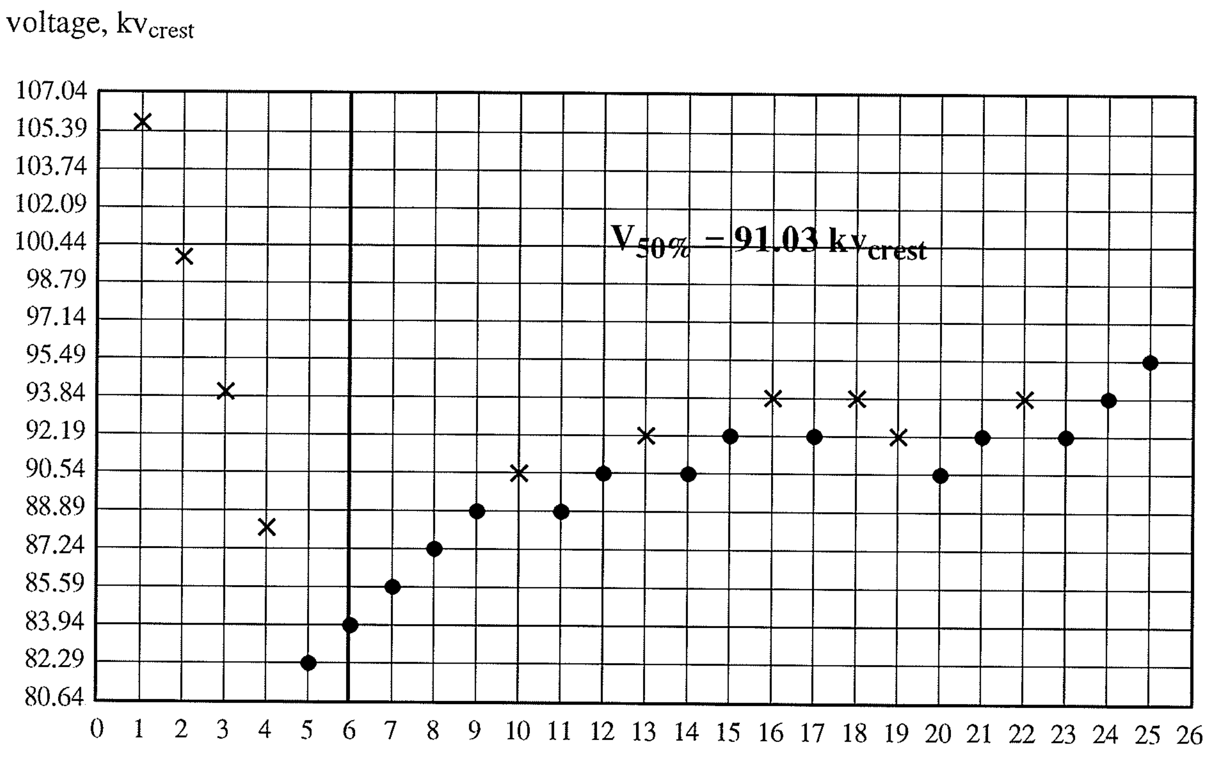


Figure 3.4.13 Results for No.4' s Electrode Configuration Obtained by Up and Down Method

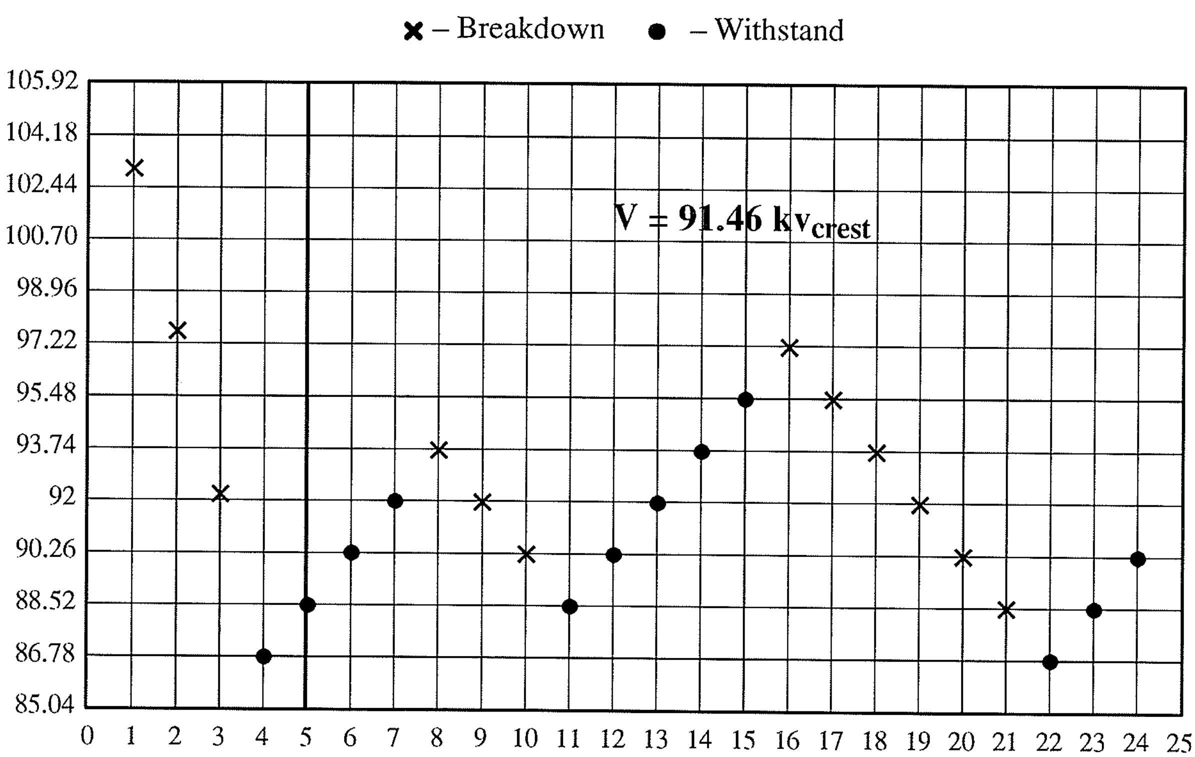


Figure 3.4.14 Results for No.5A' s Electrode Configuration Obtained by Up and Down Method

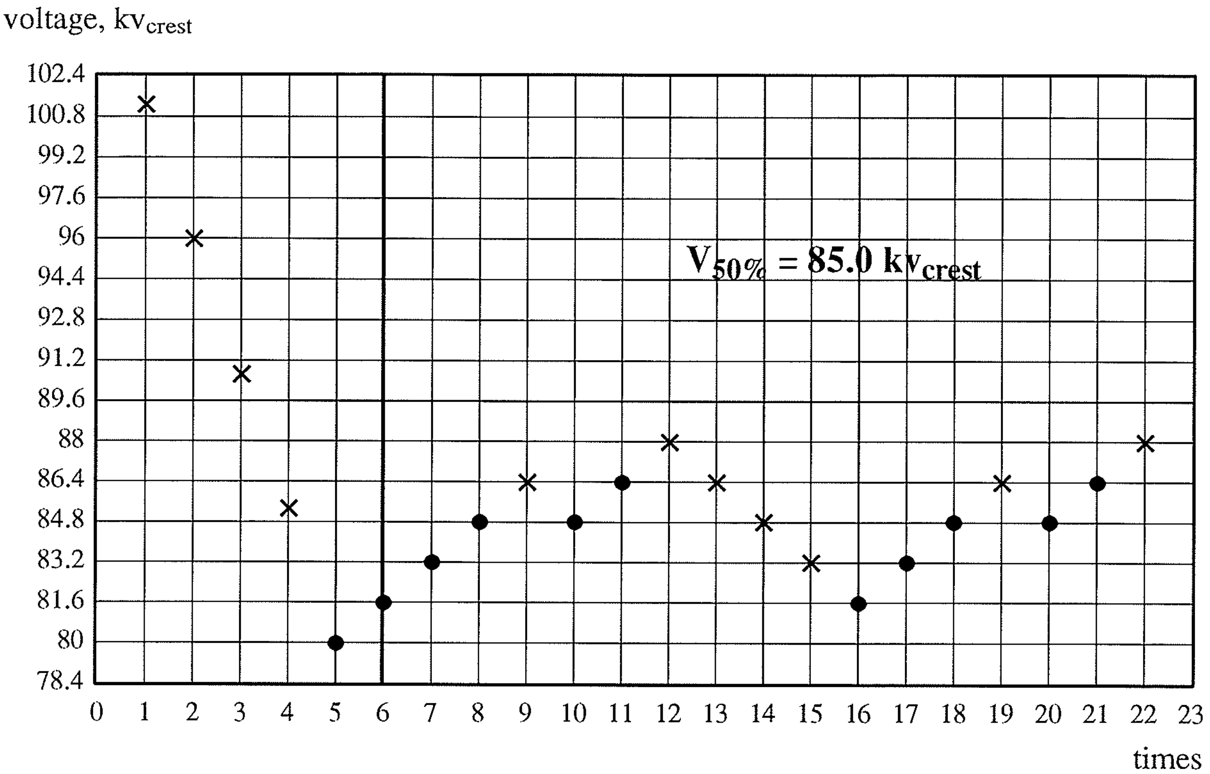


Figure 3.4.15 Results for No.5BL' s Electrode Configuration Obtained by Up and Down Method

✖ – Breakdown ● – Withstand

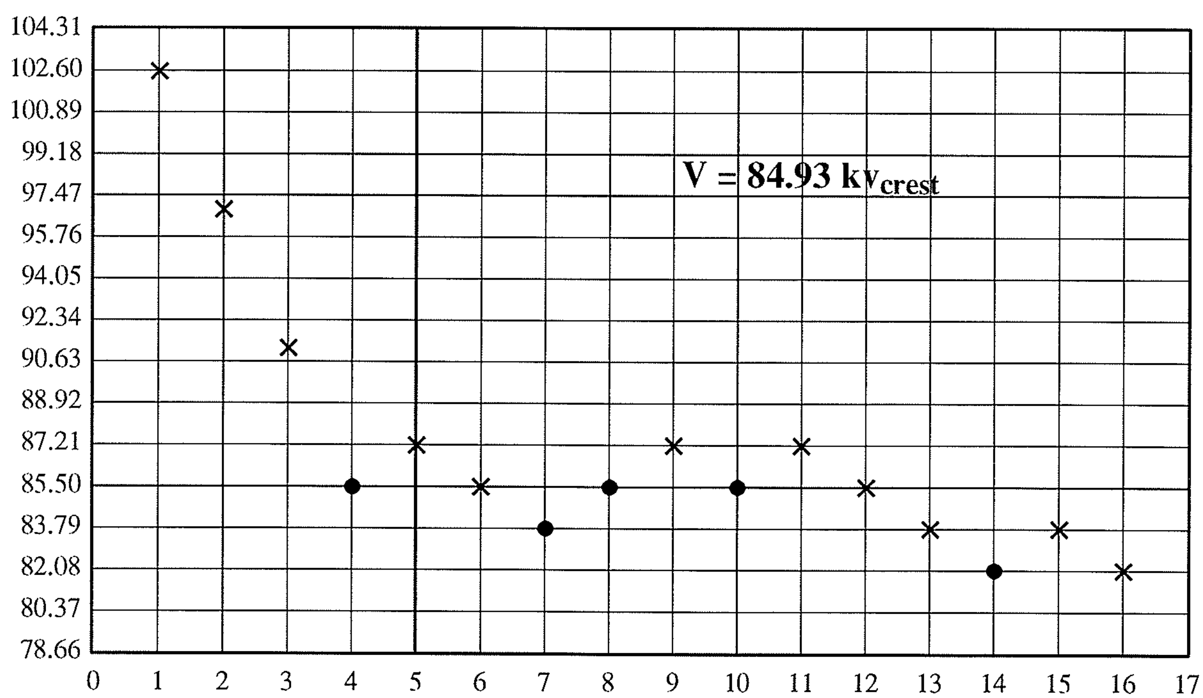


Figure 3.4.16 Results for No.5BL' s Electrode Configuration Obtained by Up and Down Method

In the switching surge tests, flashover paths were along the vertical direction of the line hoses but for the electrode configuration of No.5 in Figure 3.1, some flashover paths took place along the horizontal direction. In the switching surge tests, the breakdown occurred mostly in the front time of wave forms. For the switching surge test, the results obtained by up and down method are also presented in the form of the graph for the distribution analysis of the test data as shown in Figure 3.4, in which Figures 3.4.1–8 present the results for Class 2 line hoses and Figures 3.4.9–16 for Class 4. The graphs of the test data in Figure 3.4 show that the switching surge breakdown voltages of Class 4 hoses have a larger spread than the ones of Class 2 hoses.

3.3.2 Characteristic Ratios

In order to find a correlation between power frequency AC and switching surge overvoltages for line hoses under the given different electrode configurations, the ratio of switching surge to AC breakdown voltage was calculated and the results are listed in Table 3.2. The values in the table show that the ratios for Class 4 hose have a larger spread than the ones of Class 2.

Table 3.2 Ratios of Switching Surge to AC Breakdown Voltages

Electrode No. in Figure 3.1	Class 2	Class 4
1A	2.10	2.02
1B	2.17	1.51
2	2.23	1.48
3	2.24	2.63
4	2.17	2.01
5A	2.24	2.19
5BL	1.92	2.07
5BR	2.07	1.94

3.3.3 Discussion

From the test results, it can be seen that different electrode configurations did give the different breakdown values, with the lowest breakdowns being observed in No.1A electrode configuration. Comparing the results obtained with electrode No.1B and No.2, we notice that the use of a round foil end increased the breakdown values for Class 4 hose but did not for Class 2 hose. In the three electrode configurations of No.5, the arrangement No.5BL gave the lowest breakdown values for both Class 2 and Class 4 hoses, and the arrangement No.5A gave the highest breakdown values.

In the previous chapter, based on the recommendation of the IEC TC–78 Committee that switching surge for 69 kV and below could be assumed to be 3 p.u. of the maximum voltage used, the withstand level for 36 kV blanket was discussed and it was suggested that the present AC withstand test voltage could be decreased or remain the same, whereas the DC withstand test voltages would need to be increased. Using the same approach, the AC withstand levels for Class 2 and Class 4 or 17.0 kV and 36.0 kV level line hoses were discussed. Table 3.3 lists the suggested withstand levels for 17 and 36 kV level line hoses. In the calculations, the ratios in brackets were the minimum and maximum values of switching surge to AC breakdown voltages in Table 3.2. Comparing the data in Table 3.3 and Table 1.1 for 17 and 36 kV power lines, it can be seen that the AC withstand levels given in the Standard are higher than the ones in Table 3.3. As in the previous chapter, the result shows that the present AC withstand test voltages could be lowered.

Table 3.3 Implications of AC Withstand Levels for 17 and 36 kV Power Lines

17 kV Power Line	36 kV Power Line
$(3 \times 17 / \sqrt{3} \times \sqrt{2}) / [\sqrt{2} \times (1.92 \text{ to } 2.24)]$ = (13.3 to 15.3), kVrms	$(3 \times 36 / \sqrt{3} \times \sqrt{2}) / [\sqrt{2} \times (1.48 \text{ to } 2.63)]$ = (23.7 to 42.1), kVrms

The ASTM Standard D1050–85 specified the proof–test voltages and the nominal maximum use voltages for line hoses, which are listed in Table 1.1 (see Class 2 and Class 4). The breakdown voltages in Table 3.1 were used to calculate the ratios of AC breakdown voltage to proof test and AC breakdown voltage to maximum use voltage for each electrode configuration. The calculated results are given in Table 3.4. The values in column 2 and 4 were calculated by dividing AC breakdown voltages by the proof–test voltages shown in Table 1.1 and the values in column 3 and 5 by dividing AC breakdown voltages by the maximum use voltages in Table 1.1. Table 3.4 shows that the ratios for Class 4 hoses are smaller than the ones for Class 2. This point will lead us to think whether the selection of insulation levels for each Class FIPE in present Standard is reasonable ?

Table 3.4 Ratios of AC Breakdown Voltage to Proof–Test and Maximum Use Voltages

Eletrode No.	Class 2		Class 4	
in Figure 3.1	AC/proof–test	AC/max. use	AC/proof–test	AC/max. use
1A	1.17	1.37	0.65	0.72
1B	1.61	1.89	1.19	1.32
2	1.44	1.70	1.24	1.38
3	1.54	1.81	1.33	1.47
4	1.77	2.08	1.13	1.26
5A	1.75	2.05	1.04	1.16
5BL	1.70	2.00	1.03	1.14
5BR	1.72	2.02	1.10	1.22

3.3.4 SUGGESTIONS

1) For the tests of lower class line hoses (Class 0–2), No.1B 's electrode configuration is suggested. If metal foil is used as one of the electrodes, the edge of metal foil should be folded up to avoid sharp edges. The distances from the metal foil edges to the lip edge and the end of line hoses should be defined. For the tests of higher class line hoses (Class 3–4), No.2 's electrode configuration is suggested. The length and diameter of a metal rod should be defined.

2) For higher class line hoses, it has been suggested that the test under impulse voltage stress will be added to present Standard. That the wave form of switching surge voltage is 50/1000 μs or other values needs to be investigated further.

3) In the switching surge test, the procedure of up and down method was outlined. The formula $V_e = V_{AC} \times 2 \times 1.3$ was suggested for estimating test voltage. For Class 2 line hose, the formula worked well. For Class 4, a closer agreement would be obtained if the factor of 1.1 was used instead of 1.3.

4) In the training program for maintenance workers, the worker 's position around the line hoses should be taught. According to the test results from No.5 's electrode configurations, No.5BR appears suitable.

5) In the tests, the effects of the environmental conditions, e.g., temperature, moisture, rain and snow were not considered. The test results would be more practical and useful for live–line maintenance service if those factors were considered because the test results of air composite insulation systems are influenced by the environmental conditions. At present, no Standard discusses the

effects of the environment conditions in testing of line hoses or other insulating protective equipments.

6) The insulation levels for line hoses or other insulating protective equipments in the present Standard need to be reconsidered.

Chapter Four

INVESTIGATION OF THE ELECTRICAL INSULATING QUALITIES OF FRP LINE TOOLS USED IN LIVE LINE MAINTENANCE

4.1 Introduction

Live line tools, made of fiberglass reinforced plastic (FRP) tubes, have been in use since the early 50's. Historically these insulated tools have a remarkable safety record. Outside of accidents from carelessness or improper use of live line tools there have been few, if any, injuries or fatalities resulting from the degradations of the electrical insulating qualities of the tools. Therefore, the regular inspection of line tools is necessary for checking electrical insulating qualities of line tools.

Many users inspect their line tools before use and periodically test these electrically, some users give little thought to the need for the periodic testing of their tools. Others recognize the need to inspect and test but there is little experience in checking the electrical insulating qualities of FRP line tools. In 1982, IEEE ESMOL Working Group drafted a guide for In Service Electrical Testing of Live Line

Tools, which was divided into two main areas: Part I. Job Site Inspection & Testing and Part II. Shop or Laboratory Inspection & Test Procedures.

The IEEE and ASTM Standards relating to methods for checking the electrical insulating qualities of FRP line tools can be classified into : Dielectric Current (Leakage Current) and Dielectric Loss (Watts Loss) evaluations. In the Dielectric Loss Method, the entire length of the tool is used. In Dielectric Current Method, an entire length or piece samples of line tools are used. Using the entire length of a line tool, there is a disadvantage that the leakage current inside of tube wall can not be measured properly because the test electrodes are attached to the outside of the tube wall. Using piece samples can solve this problem but piece samples will make test procedure complicated because the samples need to be cut from line tools. In our tests, we used Dielectric Current Method with piece samples and the test procedure followed ASTM F711–89 . The leakage currents of new and used FRP line tools were measured. The tests were conducted in both dry and moist conditions. The details are described in the next sections.

The aim of this test program is to help electrical utilities to better understand the electrical insulating qualities and electrical testing techniques for FRP live line tools.

4.2 Testing Setup and Procedure

In this test program, the leakage currents of the samples, cut from new and used FRP line tools, were measured in both dry and moist conditions under the AC voltage of 100 kV applied for 1 minute. The AC voltage was derived from a 230 kV transformer. The tests were conducted in High Voltage and Power Transmission Research Laboratory of The University of Manitoba.

4.2.1 Test Samples and Preparation

The test samples were 12 in long, cut from FRP line tools which were supplied by Manitoba Hydro. According to the diameters of the supplied FRP line tools, these were divided into two groups. One was 31.8 mm in diameter and the other 38.1 mm. The details and conditions of two groups of FRP line tools are listed in Table 4.1.

Table 4.1 The Conditions of the Supplied Line Tools

31.8 mm diameter line tools			38.1 mm diameter line tools	
new	25 years old used	used	15 years old never used	20 years old used

Before testing, the samples must meet the requirements of dry and moist conditioning. All dielectric current tests must be made before and after exposure to moisture , as specified in the section of 4.2.2, using 60 Hz voltage. The conditioning procedure of the testing samples was as follows :

1. Prior to the initial leakage current tests, the samples was cleaned with a suitable solvent. In our case, Manitoba Hydro supplied us with cleaning kit manufactured by A.B. Chance.The cleaning kid included four parts : Moisture Eater, Abrasive Cleaning Pads, Gloss Restore kit and Hot Stick Wiping Cloths. The details are give in Appendix. The working efficiency of the cleaning kit is discussed later.

2. Before measuring the leakage current – after initial cleaning 1, the samples were kept in the ambient atmosphere of the test for at least 24 hrs.

3. Upon completion of the leakage current test (I_1) in the dry condition, the samples were then placed into a fog chamber and were subjected to the following moisture conditioning prior to measuring the leakage current test (I_2).

4. Moisture Conditioning in the Fog Chamber

   The requirements of moisture conditioning include the use of Relative Humidity: 93 % or greater ; Temperature: 23 ± 2° C; Time: 168 h (7 days). In our case, trays of heated water were placed in the sealed chamber to generate a high moisture environment. The lowest relative humidity obtained in this way was 90 %.

4.2.2 Test Setup

Fig.4.1 shows the test setup for measuring the leakage currents of FRP line tools. Details of the dimensions and materials of the test setup are given in Appendix. According to the Standard, the measuring equipment should not be less than 1.8 m from the high voltage electrode. The assembly of connection for the measuring equipment should be shielded and grounded. The vertically mounted test samples were at lest 0.9 m above the floor placed on an insulting support. From the safety point, the voltage across a known–value resistor connected in series with test sample was measured instead of leakage currents passing through samples. The testing procedure was as follows:

1. Mount the sample in the test setup.

2. Apply the power frequency voltage between the electrodes, according to Test Method D14, increasing the voltage at a rate of 300 V/m, to 100 kVrms.

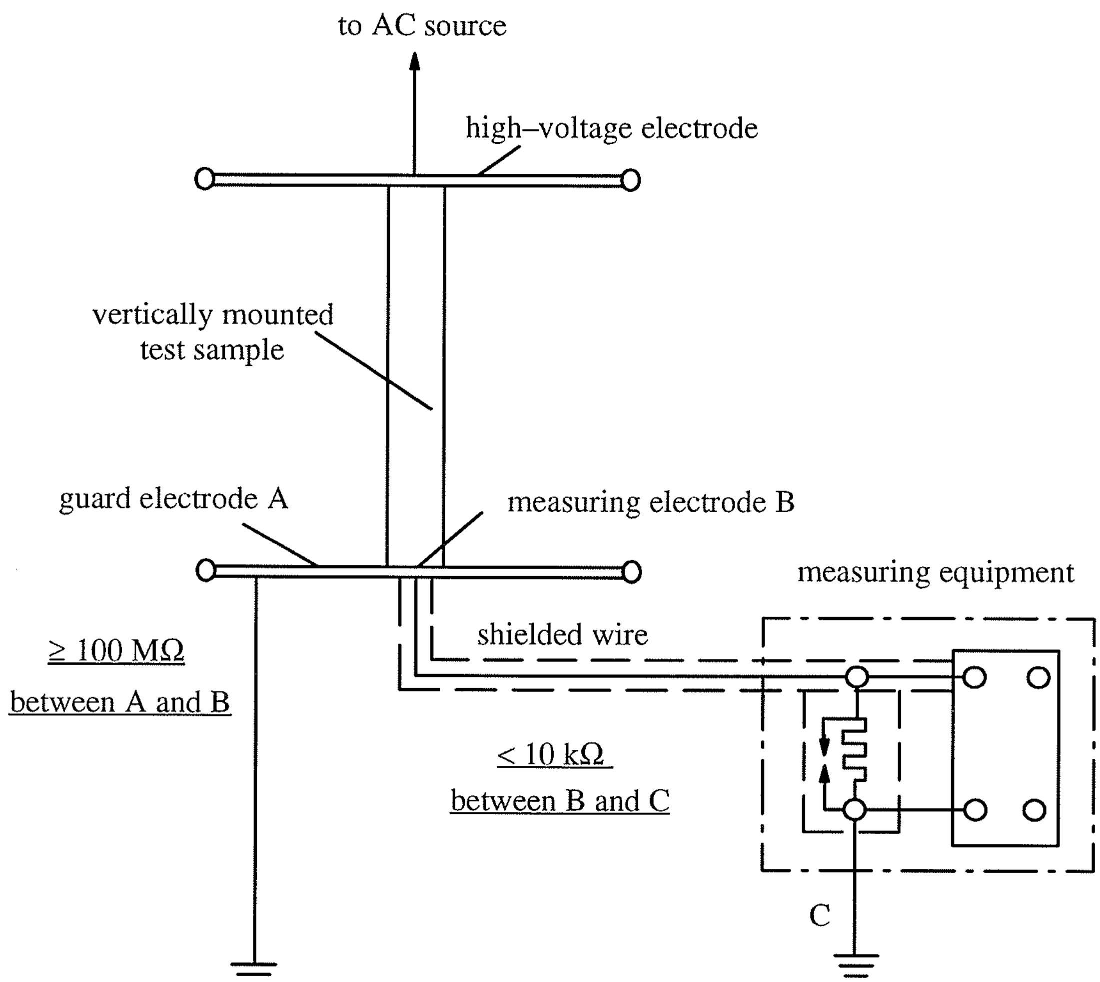


Figure 4.1 Test Setup for Measuring Leakage Current

3. Measure the voltage across the resistor , in our case, the resistance was 9.94 kΩ, after applying the voltage for 1 min. and according to I=V/R, then the leakage current I_1 passing through the testing samples was obtained. The measured current I_1 must be less than the values in Table 1.3, otherwise the sample is disqualified.

4. Place the sample tested to be into the fog chamber for the moist conditioning as specified in section of 4.2.1.

5. After moisture conditioning and a light wiping with a dry towel, the leakage current I_2 was measured under the same condition as I_1. The difference between I_2 and I_1 should be less than 20 μA.

6. Repeat the same testing steps with the next sample. At least three samples should be tested for each average leakage current value.

4.3 Test Results and Discussion

Fig. 4.2 shows the graph of the measured leakage currents for a new 31.8 mm diameter FRP line tools before and after exposure to moisture. In the graph, the Standard leakage current requirement for 31.8 mm FRP line tool is also included, see the continuous line. Each point on the graph represents the arithmetic average of at least three individual leakage current readings, see Table 4.2 for measured data. From the experimental results, it can be seen that the leakage currents through the test samples vary with the time of exposure to moisture. The leakage current I_1 measured prior to exposure to moisture was 7.1 μA and after exposure to moisture for 7 days, the measured current I_2 increased to 9.3 μA. On the 5th day during the 14 days of exposure to moisture, the leakage current reached the maximum value (10.9 μA). After the maximum value, the leakage current droped slightly to a stable value around 9 μA. Compared with the standard requirement in Table 1.3, the measured leakage current I_1 (7.1 μA) before exposure to moisture was 1.1 μA larger than the permitted value (6 μA) and the difference between I_2 and I_1 is 2.2 μA, which is nearly twenty times less than the permitted difference value (20 μA). From this test, it can be concluded that the electrical insulation quality of new 31.8 mm diameter FRP line tools is acceptable.

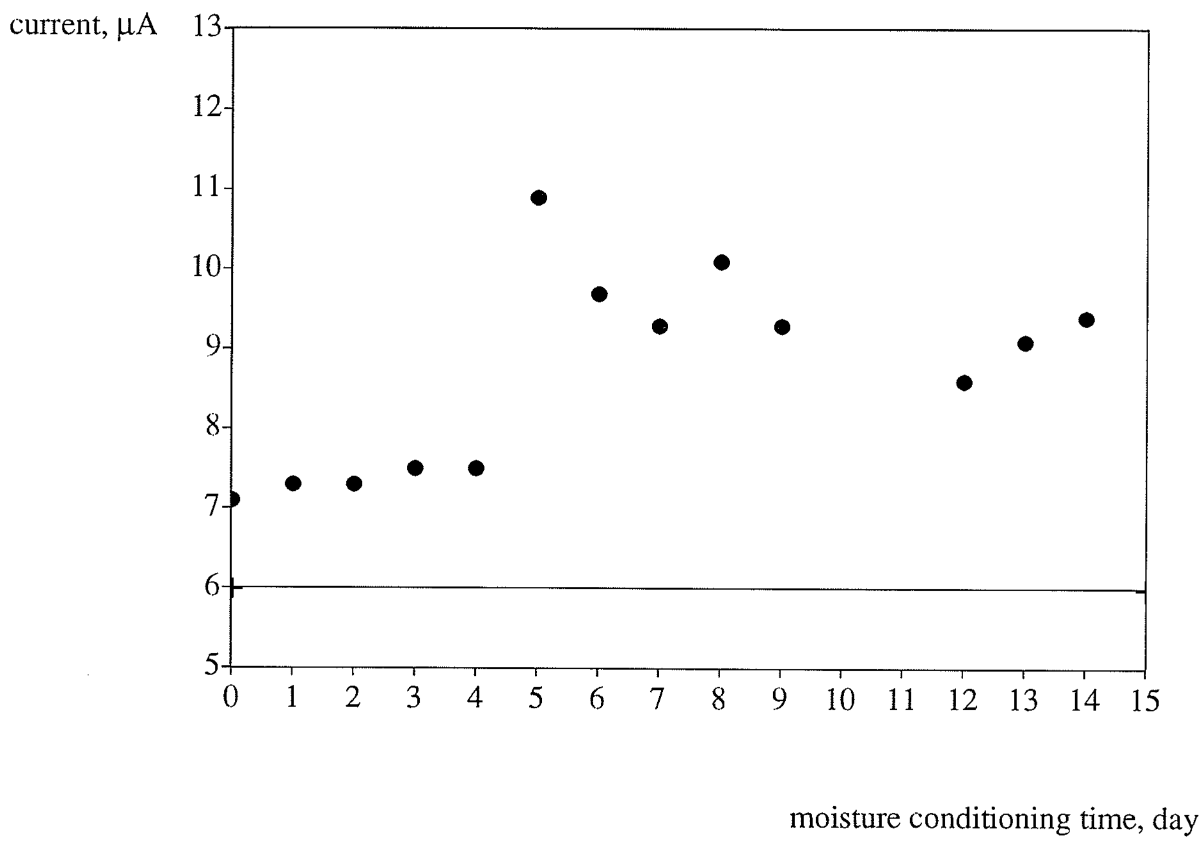


Fig. 4.2 Experimental Leakage Current vs Moisture Conditioning Time

Table 4.2 Test Results for New 31.8 mm Dia. FRP Tube Exposed to Moisture For Different Times

(Leakage Current = Average Voltage / 9.94 kΩ)

Moisture Time Day	Measured Voltage mV	Average Voltage mV	Leakage Current μA
0	70	70.73	7.1
	71		
	71.2		
1	73	72.3	7.3
	69		
	75		
2	73.9	72.73	7.3
	70.6		
	73.7		
3	76.0	74.7	7.5
	75.8		
	71.4		
4	79.0	74.15	7.5
	71.0		
	71.3		
	74.3		
5	95.5	108.6	10.9
	107.8		
	89.8		
	141.3		
6	108.7	96.65	9.7
	98.0		
	89.1		
	90.8		
7	89.0	92.35	9.3
	90.0		
	96.0		
	94.4		

8	96.6	100.08	10.1
	107.2		
	94.0		
	102.5		
9	88.3	92.53	9.3
	94.3		
	89.2		
	98.3		
12	89.2	85.8	8.6
	80.2		
	81.7		
	92.1		
13	87.2	90.58	9.1
	95.5		
	92.3		
	87.3		
14	87.1	93.7	9.4
	92.4		
	102.0		
	93.3		

For checking the electrical insulation qualities of used FRP line tools, the leakage currents of line tools that were in service for 15, 20 (38.1 mm in diameter) and 25 years (31.8 mm in diameter) were measured. In the FRP line tool used for 25 years, there were two screw holes through the tube. In the test, this situation was specially considered for checking the difference between samples with and without holes on the tubes. Table 4.3 gives the experimental results for a 25 years old line tool. It can be seen that, in the dry tests, the leakage currents for the samples both with and without screw holes are the same (8.1 μA) and are 2.1 μA larger than the permitted value, whereas in the moist tests, the leakage currents for the samples with and without screw holes are different, and the current for the sample with holes is seven times larger than the one without holes.

Table 4.3 Experimental Leakage Currents of a 31.8 mm Diameter FRP Tool Used For 25 Years

Standard Required Level	Leakage Current (I_1) Before–Moisture Conditioning	
	without screw holes	with screw holes
$I_1 < 6\ \mu A$	8.1 μA	8.1 μA
	Leakage Current (I_2) After–Moisture Conditioning	
$I_2 - I_1 < 20\ \mu A$	10.6 μA	18.1 μA

The relationship between experimental leakage currents and the time of exposure to the moisture for the 25 years old tube is listed in Table 4.4. Figure 4.3 shows the results graphically. It can be seen that the presence of two screw holes through the tube has an influence on the electrical insulation quality of FRP line tool in the moist condition but not in the dry condition. Therefore, it is suggested that the holes should not be made on the FRP line tools.

Table 4.5 lists the experimental results for 38.1 mm diameter line tools used for 15 and 20 years. The leakage currents measured for the 15 and 20 years old FRP tools before exposure to moisture were 9.0 and 9.2μA, larger than the permitted value. Tests conducted on samples subjected to the moisture conditioning showed heavy corona and the tests were, therefore, terminated.

Table 4.4 Test Results for 31.8 mm Diameter FRP Tube Used for 25 Years Exposed to Moisture For Different Time

a) Without Holes In The Samples

Moisture Time Day	Measured Voltage mV	Average Voltage mV	Leakage Current μA
0	79.6	80.1	8.06
	80.0		
	80.6		
	80.2		
1	108.0	113	11.37
	112.8		
	118.2		
2	110.6	110.5	11.12
	101.1		
	119.8		
3	98.7	103.4	10.4
	105.6		
	105.9		
4	129.0	119.8	12.06
	116.5		
	114.0		
5	126.8	120.3	12.1
	118.1		
	116.0		
6	104.3	112.3	11.3
	109.5		
	123.2		
7	103.8	105.7	10.64
	96.2		
	117.2		

b) With Four Screw Holes In The Sample

Moisture Time Day	Measured Voltage mV	Leakage Current μA
0	80.0	8.05
1	12.60	12.68
2	12.59	12.67
3	12.60	12.68
4	12.15	12.22
5	12.36	12.44
6	12.32	12.39
7	18.0	18.11

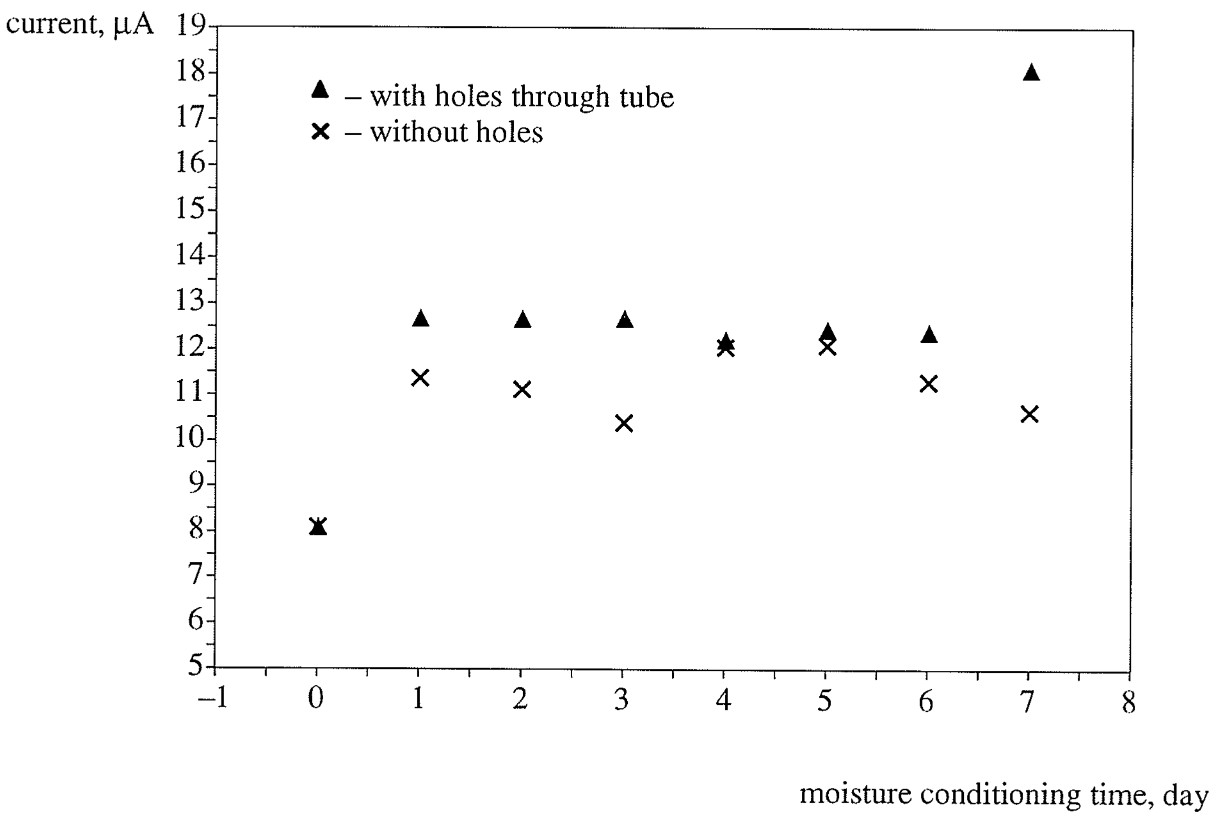


Fig. 4.3 Experimental Leakage Current vs Moisture Conditioning Time

Table 4.5 Experimental Leakage Currents for 38.1 mm Diameter FRP Tools Used For 15 & 20 Years

(Maximum leakage current permitted in the Standard is 8 μA)

Conditioning	15 Years Old , Never Used	20 Years Old, Used
Before–Moisture	9.0 μA	9.2 μA
After–7–Day–Moisture	heavy corona observed during tests	

To evaluate the efficiency of cleaning FRP line tools with the cleaning kid used by Manitoba Hydro, the leakage currents were measured. Wet cloth cleaning was also included in the test . The experimental results corresponding to different cleaning methods are given in Table 4.6, which were plotted in Fig. 4.4. From the results, it can be seen that the cleaning efficiency of moisture eater is most effective and the wet cloth is least effective. After measuring the leakage current of FRP tool cleaned with wet cloth, the sample was placed into an oven at 40° C for 3 hrs. The leakage current decreased only 0.3 μA by the drying process. Cleaning with both moisture eater and silicon cloth gave the same results as with moisture eater only.

Table 4.6 Leakage Currents for (Used) 31.8mm Diameter Tools After Cleaning

No.	Cleaning Methods	Leakage Current, μA
1	wiping with towel	6.9
2	cleaning with moisture eater	6.8
3	cleaning with moisture eater and silicon cloth	6.9
4	cleaning with wet cloth	7.8
5	dried for 3 hrs in 40°C oven after 4	7.5
0 and 6	permitted in the standard	6

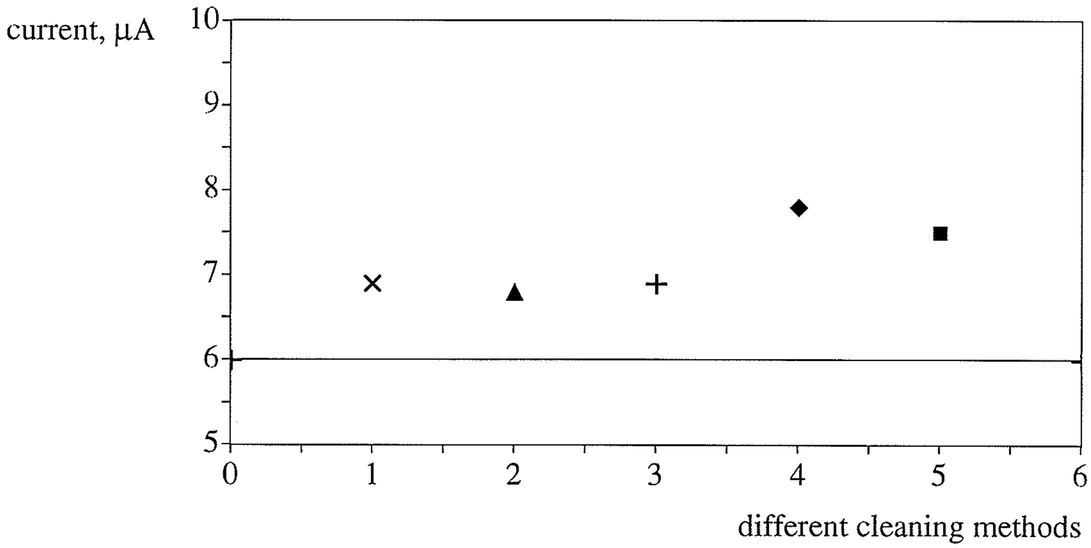


Fig. 4.4 Experimental Leakage Current Corresponding to different Cleaning Methods

The leakage current increased with increasing the applied voltage. To test the leakage current properties of FRP line tools at the voltage higher than the standard requirement (100 kV), the applied voltage was increased. When the voltage was increased to approximately 110 kV, a loud partial discharge noise was noticed in the vicinity of the electrode and then the tests were interrupted.

Chapter Five

DIELECTRIC TESTING OF INSULATING ROPES USED IN LIVE LINE MAINTENANCE

5.1 Introduction

For years, various types of ropes have been used by electrical utility linemen during maintenance or construction activities on or near energized transmission and distribution systems because of their properties of high resistance and flexibility. Although the rope was used in a variety of ways, electrical stress for most types of ropes did not present a problem even for wet ropes, since the electrical stress was low. However, it became apparent that the rope was not being used just ' in the proximity of energized line' but as a temporary insulator. The insulating properties of ropes, even when used ' in the proximity of energized transmission systems' have become a concern as the power system voltage has been increasing. Electrical testing of ropes was not part of the Standard until the wet test was adopted and included in the IEEE Standard 516–1987,Trial Use Guide for Maintenance Method on Energized Power Lines, which briefly specified the electrical inspection method and procedure for insulating ropes. In our test program, the test procedures specified in the Standard were followed. During the tests, it was found that because of the large stray capacitance currents between the electrodes , the test setup required modification.

This part of thesis presents dielectric test results for various types of ropes, which have been in service for different periods of time in Manitoba Hydro. Leakage current tests were conducted with 24 in (60 mm) long ropes with one end grounded and the other in direct contact with a single phase conductor energized with 60 Hz voltage at 30 kV line–to–ground. The tests included dirty and dry, and dirty and wet ropes.

5.2 Experimental Setup and Test Procedure

This test basically follows the previous test program, measuring details of the leakage current through the samples in order to assess the electrical insulation quality. The measuring system was described in the previous chapter. In this test program, the leakage current through a certain length of rope was measured in dry and moist conditions after the AC voltage of 30 kV was applied for 30 s. The AC voltage was obtained from a 230 kV transformer. The tests were conducted in High Voltage and Power Transmission Research Laboratory of The University of Manitoba.

5.2.1 Test Samples and Preparation

Table 5.1 lists the types of ropes tested, which were supplied by Manitoba Hydro. The measured part between the electrodes was 24 in (60 mm) long. The rope sample was tested in a vertical position. The electrodes, consisted of one wrap of AWG No 18–AWG and No 24 bare wire, were attached to the test samples. The IEEE Standard 516 was followed in the preparation of the test samples. For the wet test, the rope was immersed in a tub containing tap water by submerging it for 15 to 20 min. After soaking the sample was hanged in a vertical position to drain the excess of water. The sample was allowed to dry for 15 min before test.

Table 5.1 Ropes Tested

No.	Type	Color	Sample's History
1	solid nylon	yellow	new used once
2	solid nylon	yellow	used for 3 years
3	solid nylon	yellow	used for 8–10 years
4	solid nylon	orange	new used once
5	solid nylon	yellow & blue	used for 8–10 years
6	hollow nylon	dark blue	new
7	hollow nylon	light blue	used
8	solid hemp	brawn	used for 25 years

5.2.2 Test Setup

Figure 5.1 shows the electrode arrangement used for measuring the leakage currents of the insulating rope. The measuring system is the same as the one described in the previous chapter. For safety reasons, the voltage across a resistor connected in series with the rope was measured instead of leakage currents passing through samples. According to the Standard, the rope sample used for testing must be at least 8 ft (250 cm) long so that when the rope is held in a vertical position there will be

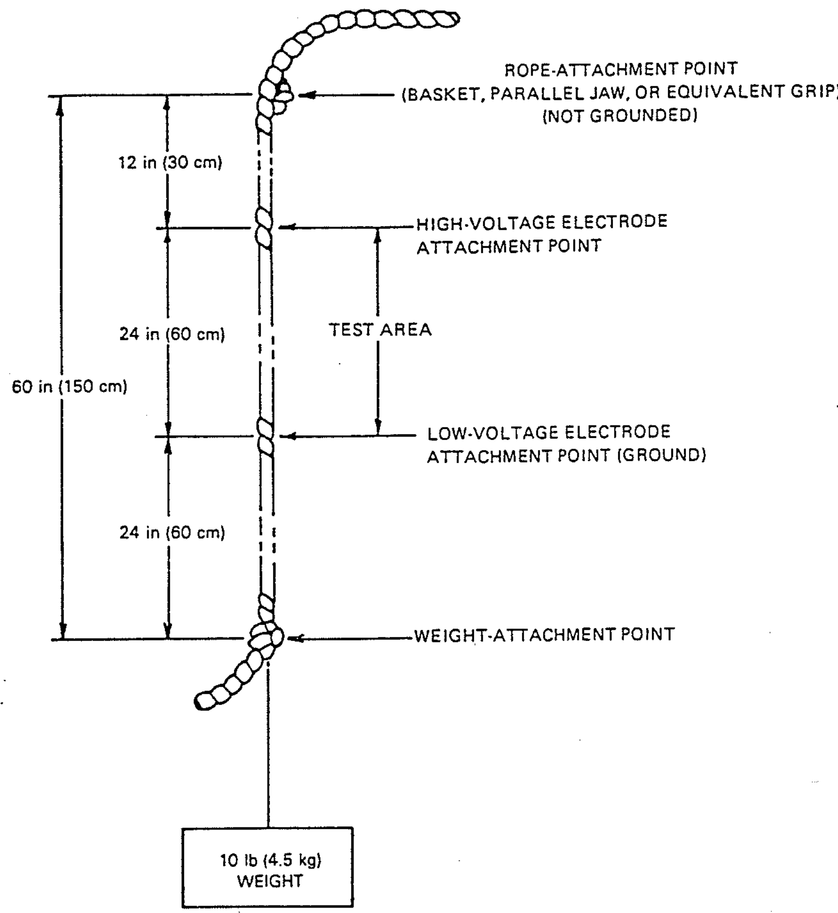


Figure 5.1 Arrangement for Dielectric Testing of Rope

5 ft (150 cm) of rope free from knots, eyes or splices. The ends should be heatsealed. When the sample is handled, it must always be hold outside the tested length (see Figure 5.1). The electrodes should be attached to the sample prior to wetting. The test procedure was as follows :

1. Mount the unconditioned sample in the test setup as described in Figure 5.1.

2. Apply the power frequency voltage between the electrodes.The voltage should be raised gradually from 0 kV to 30 kV in not less than 5 s but not more than 15 s. The voltage should be held at 30 kV for 30 s.

3. Measure the voltage across the resistor, in our case, the resistance was 9.94 kΩ.

4. At the end of the dry test, the sample is immersed in tap water. The entire rope should be kept in water for a period of 15 to 20 min.

5. The sample is taken out from the water tub and hanged in a vertical position with a weight. The sample was allowed to dry for 15 min.

6. Repeat the steps 2 and 3. The leakage current obtained over a 24 in (60 cm) test sample must not exceed 1 mA from the time of initial application of voltage until the end of the test.

7. Repeat the testing steps for the next sample.

5.3 Test Results and Discussion

Tests were conducted at 30 kV/ 2 ft for 30 seconds on dry and wet ropes. Table 5.2 gives the experimental leakage currents obtained for the test samples. The word of 'above' in the table indicates that on applying the voltage between the electrodes, the voltage across the resistor exceeded 10 V, i.e., the leakage current 10 V/ 9.94 kΩ > 1 mA. In these cases, for safety reasons, the tests were interrupted. During the test, the leakage current across the sample was very unstable with continuous fluctuations .

Table 5.2 Leakage Currents (μA) for Insulating Ropes
(refer to Table 5.1 for details of rope samples)

No. of Sample	Dry Test	Wet Test
1	5.4	43.1
2	3.8	above
3	4.0	above
4	3.7	4.0
5	4.4	above
6	3.7	above
7	4.3	above
8	4.5	above

From the experimental results, it can be seen that in dry condition, the measured leakage currents for various types of ropes were small and were approximately the same for all samples, but in the wet conditions, there were large differences observed for different types of ropes. It is clearly seen that only No.1 and No. 4 rope samples did not exceed the leakage current limits specified in the Standard. The No. 1 rope sample's leakage current exceeded No. 4 sample's by a factor of 10. Other types of ropes failed to meet the 1 mA leakage current limit. This implies that the hydrophobic properties of No. 4 's rope are the best among the various types of ropes tested.

From the tests, it can be seen that a wet test provides a proper method for checking the electrical insulating properties of ropes. Further classification and investigations are needed regarding the electrode arrangements and test voltage levels for different power system levels. In the test set in the standard, because of the arrangement of electrodes, large stray capacitance currents will flow during the tests. A guard electrode, such as the one described in Chapter 4, should be incorporated in the test arrangement to reduce the effect of capacitance current. Dry testing of ropes should also be considered as part of the standard and corresponding test criteria should be defined.

Chapter Six

CONCLUSIONS

CORRELATION OF AC, SWITCHING SURGE AND DC BREAKDOWN TEST RESULTS FOR RUBBER INSULATING BLANKETS

1) The experimental results show that the ratios of SS/ACpeak (1.9) and DC/ACpeak (2.25) are greater than one, which is now being used by the industry and in the standard.

2) The test results suggest that the AC withstand voltage specified in the standard could remain the same or be decreased, but the DC withstand test voltage needs to be increased.

3) The insulation levels for different class insulating blankets or other insulating protective equipments in the present Standard need to be reconsidered.

4) In practice, the blanket is used in air and not in oil. Therefore, it is necessary to understand the electrical insulation properties of blankets in air .

5) Comparison of experimental results obtained by 11 international laboratories shows that there exists a spread in the data but the general conclusions reached by the different investigators were similar, i.e. , the equivalence in testing between power frequency and DC voltage, and power

frequency and switching surge overvoltages now used by the industry and in the standards may be incorrect.

EFFECT OF ELECTRODE CONFIGURATIONS DURING LINE HOSE TESTS UNDER POWER FREQUENCY AC AND SWITCHING SURGE VOLTAGES

1) For the tests of the lower class line hoses (Class 0–2), No.1B 's electrode configuration is suggested. If metal foil is used as one of the electrodes, the edge of metal foil should be folded up to avoid the sharp edges. The distances from the metal foil edges to the lip edge and the end of line hoses should be defined. For the tests of the higher class line hose (Class 3–4), No.2 's electrode configuration is suggested. The length and diameter of a metal rod should be defined.

2) For higher class line hoses, it should be considered that the test under impulse voltage stress will be added to present Standard. The use of the present wave form of 50/1000 μs for switching surge voltage needs to be further investigated.

3) The ratios of SS/ACpeak obtained for eight electrode configurations shown in Fig.3.1 are larger than one. This leads to that the equivalence between the AC and switching surge stresses for line hoses used by the industry and in the Standard may be incorrect and may need to be reconsidered.

4) The AC withstand level for line hose specified in the Standard could be decreased.

5) According to the experimental results for No.5 electrode configurations, it is suitable for the lineman in operation to be represented by a position in No.5BR.

6) In the tests, the effects of the environmental conditions, e.g., temperature, moisture, rain and snow were not considered. The test results would be more practical and useful for live–line maintenance service if those effects were considered because the test results for air composite insulation systems are influenced by the environmental conditions. At present , no Standard requires the tests of line hoses or other insulating protective equipments under different environment conditions.

INVESTIGATION OF THE ELECTRICAL INSULATING QUALITIES OF FRP LINE TOOLS USED IN LIVE LINE MAINTENANCE

1) The experimental results show that, for the new 31.8 mm diameter FRP line tool, the dry condition leakage current is 7.1 μA , 1.1 μA larger than the permitted limit (6 μA) and the difference of leakage currents between the dry and moist conditions is 2.2 μA , nearly 10 times less than the standard limit (see Table 4.2). For used 31.8 mm diameter FRP tools (25 years old), the measured leakage currents (see Table 4.3) did not exceed the permitted limits in both dry and wet conditions. This means that the quality of the 31.8 mm line tool is acceptable.

2) For used 38.1 mm diameter FRP line tools (15 and 20 years old), the values of the measured leakage currents in the dry condition are not significantly larger than the standard requirement but the values in the wet condition failed to meet the requirement (see Table 4.5).

3) The screw holes through FRP tube should be avoided, otherwise the insulation property of the tube is decreased in the wet conditions.

4) When cleaning FRP line tools, a special cleaning kit such as the one manufactured by A.B.Chance should be employed, and wet cloth should never be used.

5) The quality inspection method used for FRP line tool is efficient but should not be used in the Job Side inspection because the samples need to be cut from line tools and the degree of moisture should be taken into account.

6) The degradation of FRP line tools is minimal and they can be used for long time if FRP line tools are kept clean and dry at all times .

DIELECTRIC TESTING OF INSULATING ROPES USED IN LIVE LINE MAINTENANCE

1) In dry condition tests, the measured leakage currents for various types of ropes are nearly the same but in wet condition tests, the measured leakage currents are different. It is, therefore, confirmed that the wet test is a desirable method to check the electrical insulation quality of ropes.

2) The hydrophobic properties of the No. 4 ropes were found to be the best among the various types of ropes studied.

3) The test setup recommended in the Standard needs to be reconsidered because the electrodes give rise to large stray capacitance currents during tests.

4) The rope should be kept dry and clean. Wet rope should never be allowed to contact an energized power system.

Appendix

1. EPOXIGLASS CLEANING KIT FOR FRP TUBE

2. DETAILS ABOUT ELECTRODE SIZES AND MATERIALS

1. EPOXIGLAS CLEANING KIT

The items contained in this kit are essential for the care and maintenance of Epoxiglas® tools and insulated boom sections of aerial lift trucks. The proper use of these maintenance aids will insure that maximum and useful life is obtained from Epoxiglas products. Do not use on Gel-Coat or painted boom surfaces.

The kit consists of four parts:

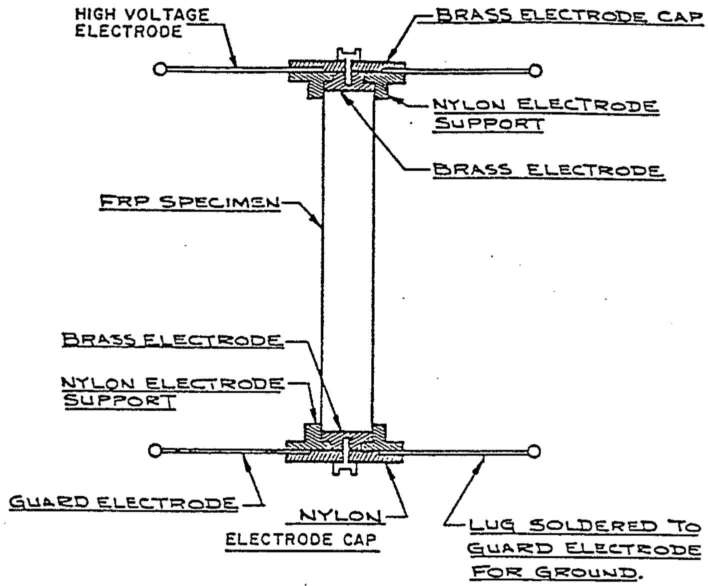
1. **Moisture Eater**™ — This cleaner should be used on contaminated Epoxiglas during general tool maintenance and in preparation for reglossing a tool's surface. Moisture Eater removes moisture and a wide variety of contaminants such as dirt, tar, grease, tree sap, light metal rubbings and old surface coatings without harming the Epoxiglas.
2. **Abrasive Cleaning Pads** — These pads are used in conjunction with Moisture Eater to remove contamination that clings to the tool or contamination ground into scars and scuffs in the tools surface. Gloss restorer should be applied after using these pads since cleaning with Moisture Eater will remove the glossy finish on the tool as well as contamination. The pads may also be used on metal parts to remove oxides and surface corrosion.
3. **Gloss Restorer Kit** — This kit consists of two parts. When mixed and applied to the surface of a cleaned Epoxiglas tool they combine to form a clear, tough coating that replaces the original gloss and protects against contamination and moisture.
4. **Hot Stick Wiping Cloths** — Silicone impregnated cloths are used to wipe down mildly contaminated Epoxiglas, removing dust and dirt, and depositing a thin protective film on the surface of the tool. They give an added measure of protection when used after recoating with gloss restorer.

TOOL CARE & STORAGE

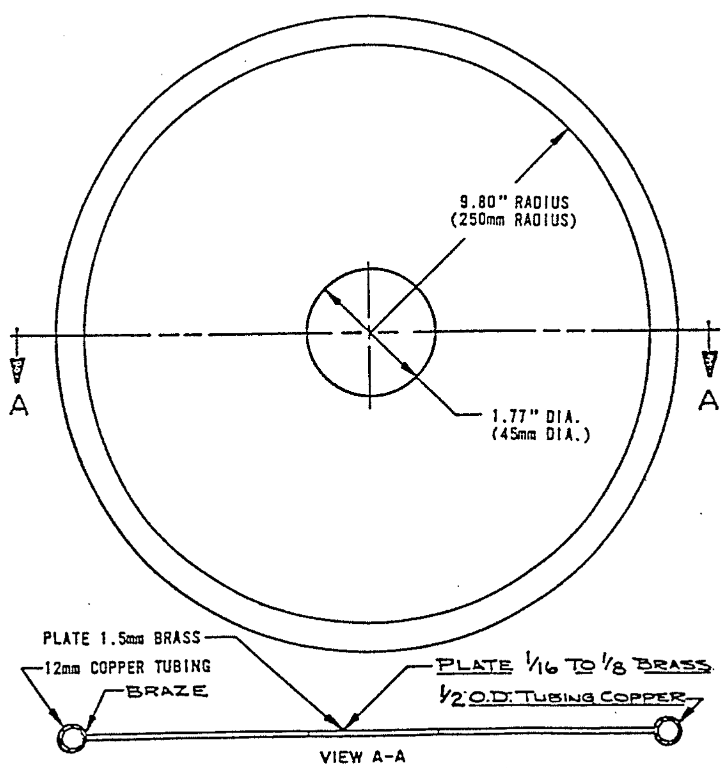
ORDERING INFORMATION

Catalog Number	Description
C400-1169	Epoxiglas cleaning kit
	The above kit consists of the following items: (Each also available separate.)
C400-1168	Moisture Eater Cleaning Solvent (1 gal.)
C400-1166	Abrasive Cleaning Pads (1 box - 20 pads per box)
C400-1520	Gloss Restorer Kit
M1904	Hot Stick Wiping Cloths

2. Detailes about Electrode Sizes and Materials

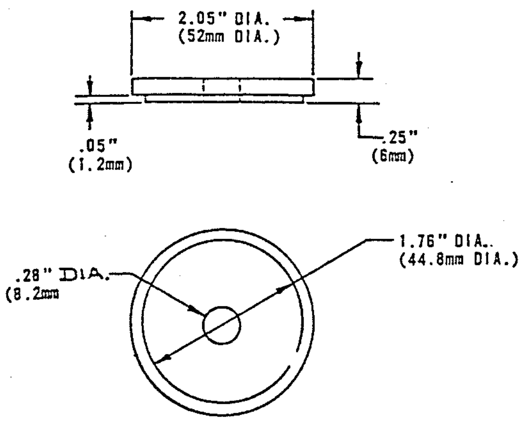


A. Assembly Detail



2 REQUIRED

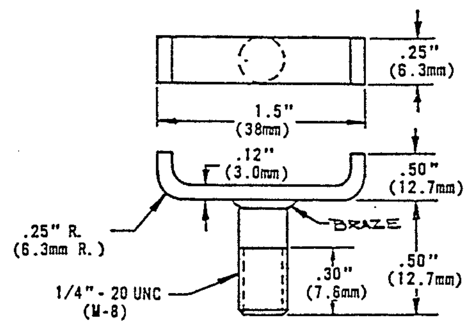
B. Electrode Detail



1 REQ'D NYLON

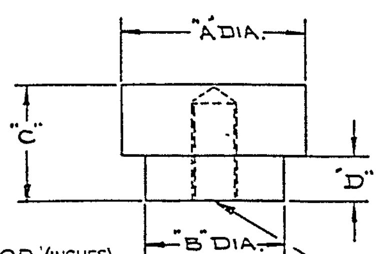
1 REQ'D BRASS

C. Electrode Cap Detail



2 REQ'D BRASS

E. Brass Screw Detail



ROD (INCHES)

DIA.	"A"	"B"	"C"	"D"
3/8	.385	.32	.37	.19
1/2	.510	.38	"	"
5/8	.635	.50	"	"
3/4	.765	.50	"	"

ROD (MM)

ROD DIA.	"A"	"B"	"C"	"D"
10	10	8	23	18
15	15	8	23	18

TUBE (INCHES)

DIA.	"A"	"B"	"C"	"D"
1	1.02	.50	.39	.19
1 1/4	1.27	"	"	"
1 1/2	1.53	"	"	"
1 3/4	1.78	"	"	"
2	2.04	"	"	"
2 1/2	2.53	"	"	"
3	3.04	"	"	"

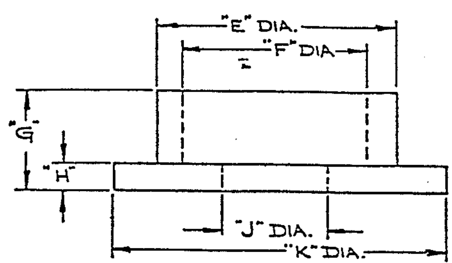
TUBE (MM)

TUBE DIA.	"A"	"B"	"C"	"D"
32	32	22	10	4.9
39	39	29	10	4.9
51	51	37	10	4.9
64	64	37	10	4.9
77	77	37	10	4.9

2 REQ'D EACH SIZE

BRASS

D. Brass Electrode Detail



ROD (INCHES)

DIA.	"E"	"F"	"G"	"H"	"J"	"K"
3/8	.80	.41	.78	.20	.34	2.05
1/2	.90	.53	"	"	.40	"
5/8	1.10	.66	"	"	.52	"
3/4	1.20	.79	"	"	.52	"

ROD (mm)

DIA.	"E"	"F"	"G"	"H"	"J"	"K"
10	20	10.04	20	5	8.2	52
15	25	15.04	20	5	8.2	52

TUBE (INCHES)

DIA.	"E"	"F"	"G"	"H"	"J"	"K"
1	1.45	1.04	.78	.20	.52	2.05
1 1/4	1.70	1.29	"	"	"	"
1 1/2	1.95	1.55	"	"	"	"
1 3/4	2.20	1.80	"	"	"	"
2	2.45	2.06	"	"	"	2.45
2 1/2	2.95	2.55	"	"	"	2.95
3	3.45	3.06	"	"	"	3.45

TUBE (mm)

DIA.	"E"	"F"	"G"	"H"	"J"	"K"
32	42	32.2	20	5	22.2	52
39	49	39.2	20	5	29.2	52
51	61	51.2	20	5	37.2	61
64	74	64.2	20	5	37.2	74
77	87	77.2	20	5	37.2	87

2 REQ'D EACH SIZE

NYLON

F. Nylon Electrode Support Detail

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