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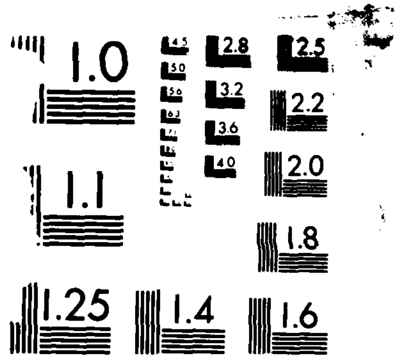


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AFWAL-TR-85-2079

# HIGH VOLTAGE PULSE TESTING SURVEY



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P.O. Box 3999
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October 1985

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## NOTICE



This technical report has been reviewed and is approved for publication.

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The purpose of this work was to lay the technical groundwork necessary to establish new guidelines for high voltage pulse testing waveform parameters, test requirements, test procedures and test limits with respect to insulation characteristics in advanced, high power airborne components. This work has been initiated via this survey which reviews government, industrial and technical society literature concerning impulse and/or pulse testing of military, commercial, and experimental equipment. The survey details the test pulse rise time, dwell time, fall time, and peak voltage applied to evaluate the insulation systems typically found in electrical/electronic aerospace components. Based on the survey findings, a complete specification for a suitable pulse testing apparatus to accomplish such tests is provided as Appendix.

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# FOREWORD

Presented herein is the Boeing Aerospace Company's Final Report covering work accomplished on Contract F33615-81-C-2013, Task 917 for the period of October 1, 1984 through July 31, 1985. This contract is being performed for the San Jose State University Foundation, San Jose, California. The program is under the direction of Dr. J. D. Pinson, SJSUF.

W. G. Dunbar is the technical leader of this work for the Boeing Aerospace Company. This work was sponsored within AFWAL Project 3145, Task No. 32 under the title "High Voltage Pulse Testing." The author would like to thank Daniel L. Schweickart of the Aero Propulsion Laboratory at Wright-Patterson AFB for his technical input and guidance during the program.

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# I PROGRAM OBJECTIVES

The Pulse Test Survey summarizes government, industry, and technical reports on high voltage pulse testing of commercial and experimental equipment. The survey details peak voltage and test pulse rise time and fall time as they are applied to evaluate electrical insulation between electrical and electronic system components. Survey findings could be used to specify a pulse test set for certain aerospace systems. Electromagnetic pulse data, where applicable, will be included in the survey.

## II SCOPE

The major tasks reported in the high voltage pulse survey are:

- A survey of technical literature on the impulse testing of electrical insulating materials, components, and systems.
- Specifications for the development of a high voltage pulse generating test set.
- A comparison of pulse testing and partial discharge and dielectric-withstanding voltage testing.

## III BACKGROUND

Specifications and tests for eight components used in high voltage power equipment and systems were prepared in contract F33615-77-C-2054, "High Voltage and High Power Specifications and Tests," and reported in Air Force document AFAPL-TR-2024, "High Voltage Specifications and Tests." In these documents a pulse test was specified with parameters to be determined. From 1979 through 1981 several test articles were "pulse tested" in contract F33615-79-C-2067, "High Voltage Testing." These data were reported in "High Voltage Testing," AFWAL-TR-82-2057, in five volumes entitled: Vol. I; "Test Program Report", Vol. II; "Specifications and Test Procedures", Vol. III; "Generator Test Procedure", Vol. IV; "High Voltage Design Guide: Aircraft", and Vol. V; "High Voltage Design Guide: Spacecraft." Each test article was pulse tested using an IEEE standard number 4, double exponential wave shape; that is, a 1.2 $\mu$s rise time to 90% peak voltage and a 50 $\mu$s decay to 50% peak voltage. Pulse generators used to evaluate commercial power system equipment use this waveform.

Some of the recent aerospace vehicle designs use graphite-epoxy structures instead of conventional metal-clad structures. The peak p-static discharges on graphite-epoxy structures have been measured to exceed 10 kV peak with much faster rise and fall times than the discharges on metal-clad structures. In addition, graphite-epoxy structures are capable of many more discharges per second than the metal-clad structures. New space and airborne high-voltage components and equipment, therefore, must be able to withstand high pulse repetition rates with much faster rise and fall times than those specified by IEEE Std. 1 No. 4. It is necessary to determine how component and system electrical insulation will respond to these higher frequencies with respect to life, maximum voltage stress, and voltage distribution within the insulation.

## IV PULSE PARAMETERS

The main objective of the program was to determine the life of electrical insulation used in the construction of components and transmission lines and for the isolation of high voltage parts and components within the system. Two parameters required by the survey were the pulse shape and the voltage.

### A. Pulse Time Parameters

Several pulse shapes have been investigated for different electrode configurations in gaseous, liquid, and solid insulations. This report will be limited to those pulse shapes used in high-voltage electronic equipment and generated by the pulse-forming networks for radars, lasers, and scientific equipment. Pulses generated by switching transients and induced by lightning are also relevant to this investigation. The variables pulse rise time ($t_1$), dwell time ($t_c$), and fall time ($t_2$), for equipment-generated, lightning-induced, and switching pulses are shown in Table 1. Electromagnetic pulses have rise times of less than one nanosecond and are considered only for shielding and induced cases.

Table 1. Pulse Duration Variables

| Pulse Shapes | Rise time ($t_1$) | Dwell time continuously variable ($t_c$) | Fall time ($t_2$) |
|---|---|---|---|
| 1 | 10 ns | * | 100 ns |
| 2 | 50 ns | 100-300 ns | 50 ns |
| 3 | 250 ns | 0.5-1.5 μs | 250 ns |
| 4 | 0.9 μs | 5-20 μs | 0.9 μs |
| 5 | 1.2 μs | * | 50 μs |
| 6 | 100 μs | * | 2500 μs |
| 7 | 500 μs | * | 2500 μs |

* denotes double exponential waveform

## B. Voltage Parameters

Pulse voltage magnitude may vary from a few volts, as induced into a well-shielded low-voltage circuit, to several megavolts generated by a Marx generator. Of interest to this study is a comparison of pulses and electrical insulation integrity at voltages applicable to equipment used in present and future airplanes and spacecraft. These voltages range from a few hundred volts, used by small radar and laser systems on present aircraft and in scientific experiments and flash tubes on present spacecraft, to multi-hundred kilovolt systems planned for future aircraft and spacecraft applications.

## V INSULATION EVALUATION

Aerospace electrical and electronic systems must be lightweight, small in volume, and very reliable for the life of the system. To meet the system design constraints, electrical insulation must be designed to avoid tree initiation in solids and breakdown in liquids and gases. When associated with the component characteristics, arcovers may occur in some gas and vacuum applications.

### A. Pulse Shapes

In engineering applications the electrical withstanding voltages and breakdown or arcover voltages and their statistical variations are complex for very high voltages between widely separated electrodes. Overvoltages usually occur in pulses or arcs resulting from transients within the system. The waveshape generally associated with these surges is approximated by the double exponential waveshape produced by a Marx generator. This waveshape is obtained by:

$$V = A_1 \left[ \exp \left\{ -(A_2 - A_3)t \right\} - \exp \left\{ -(A_1 + A_2)t \right\} \right]$$

where $A_1$, $A_2$, and $A_3$ are constants and t is time, usually in microseconds.

The impulse shape is defined in British Standard 923:1972[2] and IEEE Standard 4-1978 in terms of two time values, $T_1$ and $T_2$, that define the rise time and fall time. A $T_1/T_2$ impulse shape has a rise time increasing from 30% to 90% of its maximum value in 0.6 $T_1$ and a fall time decreasing to 50% voltage amplitude in a time $T_2$, as shown in Figure 1.

A chopped impulse is suddenly interrupted by a disruptive discharge, causing the voltage to decrease rapidly to near zero value. The chopping action may take place any place on the waveform. A delayed chopped waveform is shown in Figure 2.

Many other waveshapes, such as lightning, electromagnetic pulses, and transients, have been simulated and tested in laboratory experiments. The data presented in this paper, however, refer to double exponential unless otherwise stated.

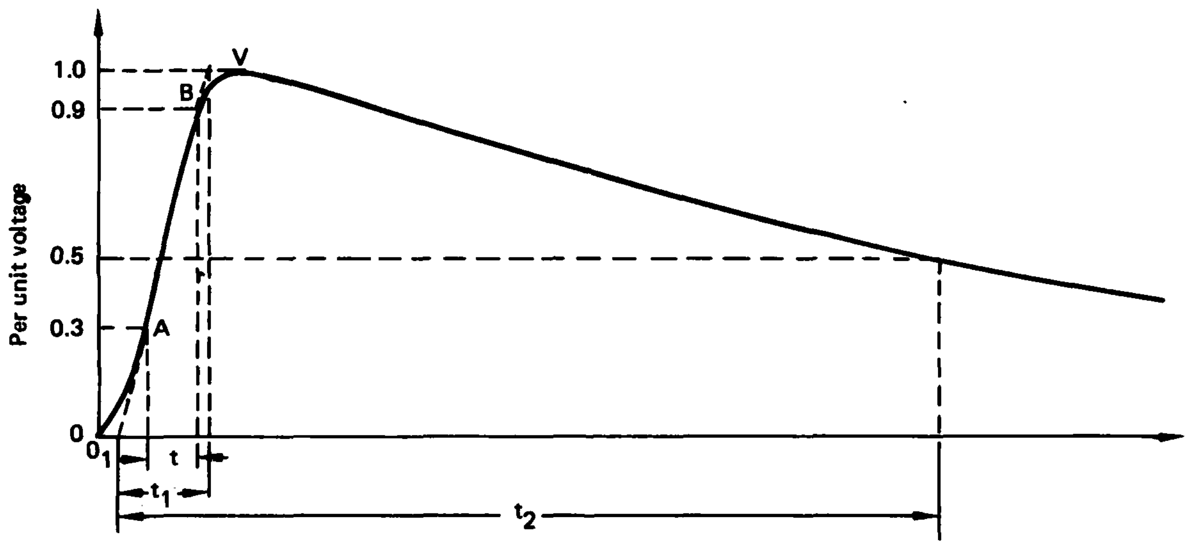
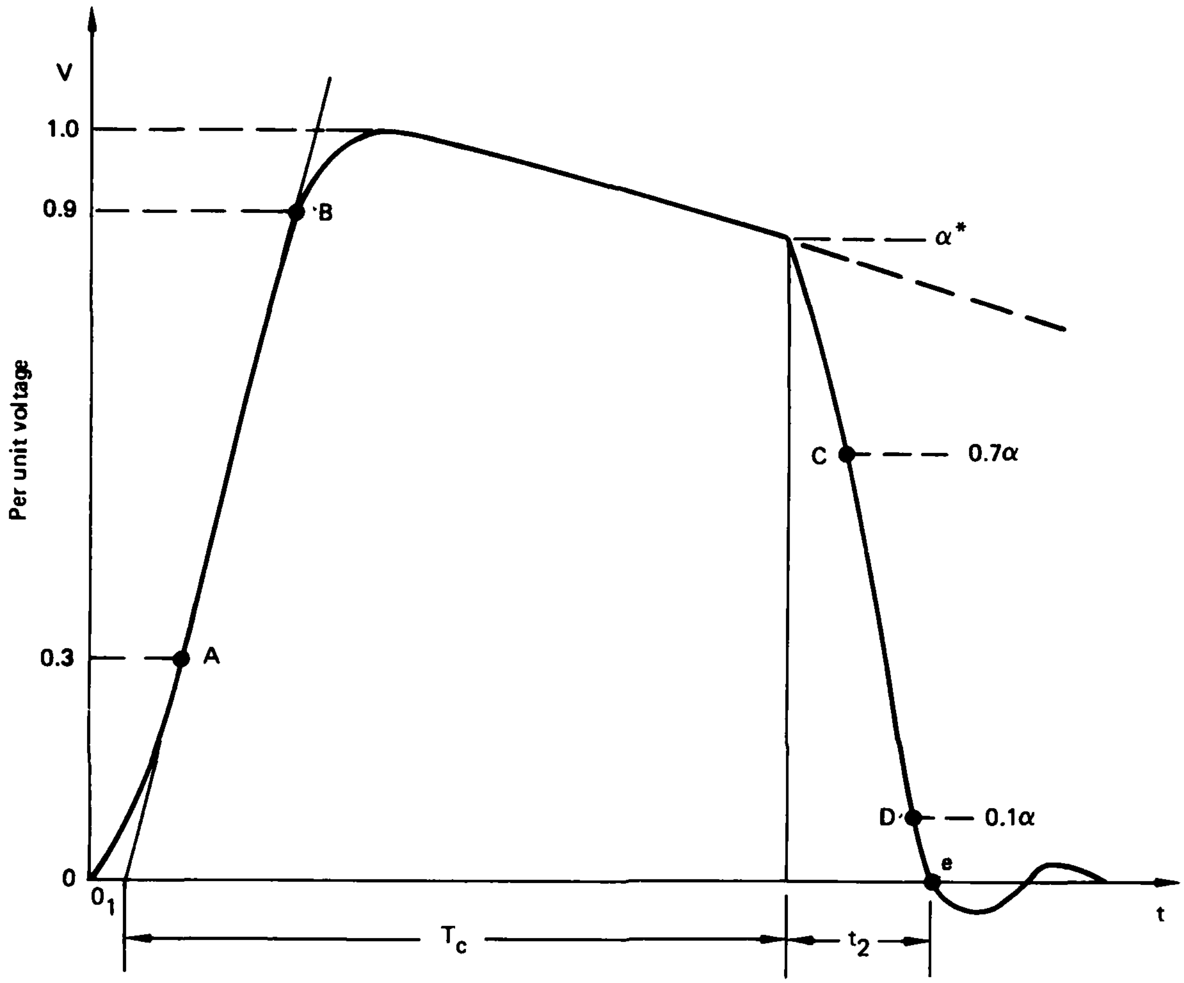



*Figure 1. Double Exponential Pulse*




*α ⩾0.9 PU voltage

*Figure 2. Chopped Pulse*

B. Gases

Lightning strikes were simulated in early impulse analyses and experimentation, and are still of major concern to scientists and engineers. Initial work used air as the insulating gas. Today pressurized electronegative and other stable gases such as sulfur hexafluoride and the fluorocarbons have replaced air in high voltage impulse insulation for switch gear transformers and Marx generators.

1. Air

The breakdown or sparkover voltages in air between round rods with tapered ends and between a taper-ended rod and a grounded plane are shown in Figures 3, 4, and 5. These data show there is a critical relationship between pulse rise time and breakdown voltage.[3,4] The critical rise time (minimum voltage) occurs at 150 to 250 $\mu$s, as shown in Figure 6. In negatively pulsed rods with impulse rise times shorter than 1 $\mu$s, the breakdown voltage increases significantly, as shown in Figure 7. Moreover, the critical (minimum voltage) rise time for negative pulses occurs at 10 to 25 $\mu$s.

(a) Waveshape Effects

Changing the waveshape from a double exponential, where voltage v varies as a function of t as

$$v = V\left(e^{-at} - e^{-bt}\right)$$

and V, a, and b are constants to a damped oscillatory waveshape, has little or no effect on the characteristic of the waveform. Both waveshapes show a minimum at about the same rise time and have the same breakdown voltage as a function of spacing with all other parameters constant.

(b) Bias Voltage

Experimental data indicate that having a bias voltage of dc or ac lowers the breakdown voltage less than 3% for short gaps (between 1 and 5 cm) between rods or between a rod and a positive or negative ground plane. For longer air gaps (1m to 2m)

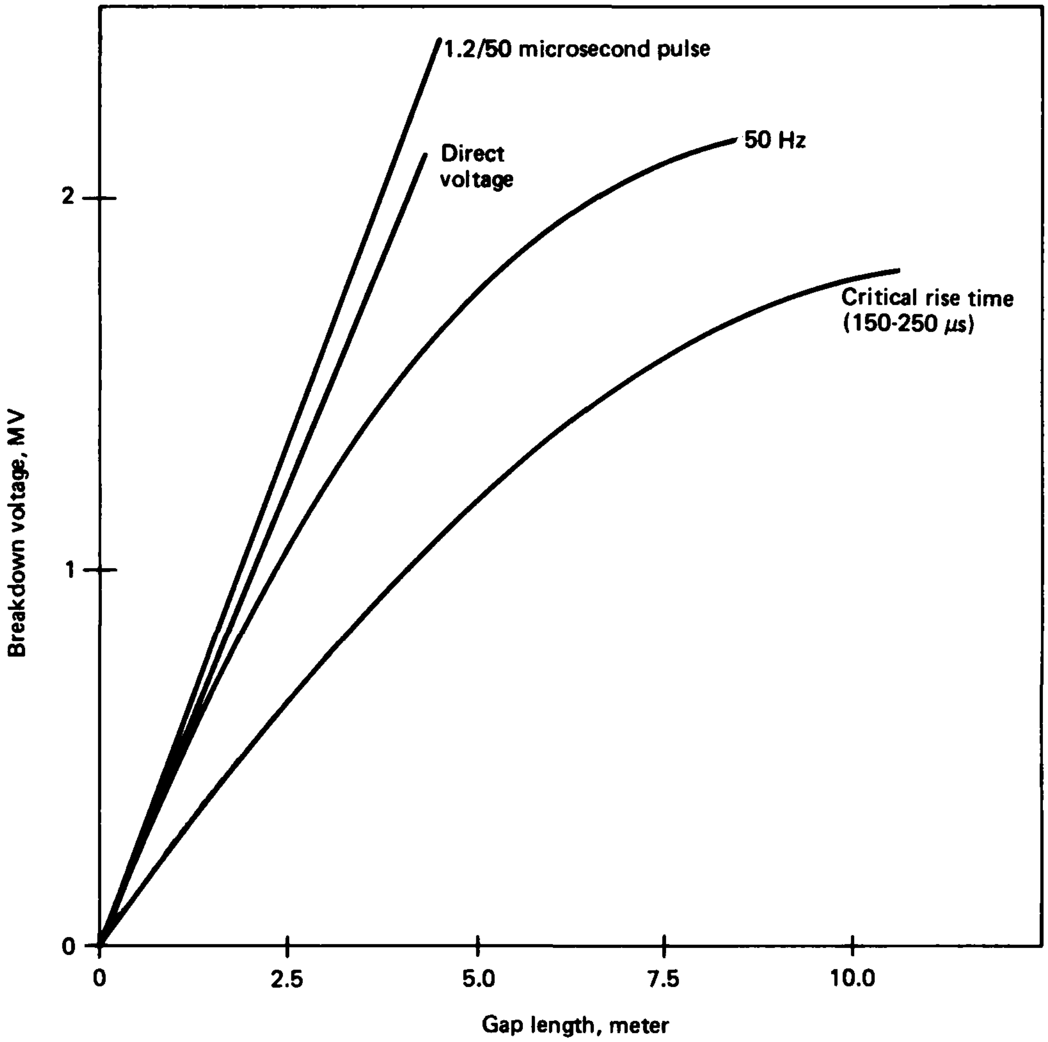



*Figure 3. Positive Impulse Breakdown Voltages for Rod-Plane Gaps in Air*

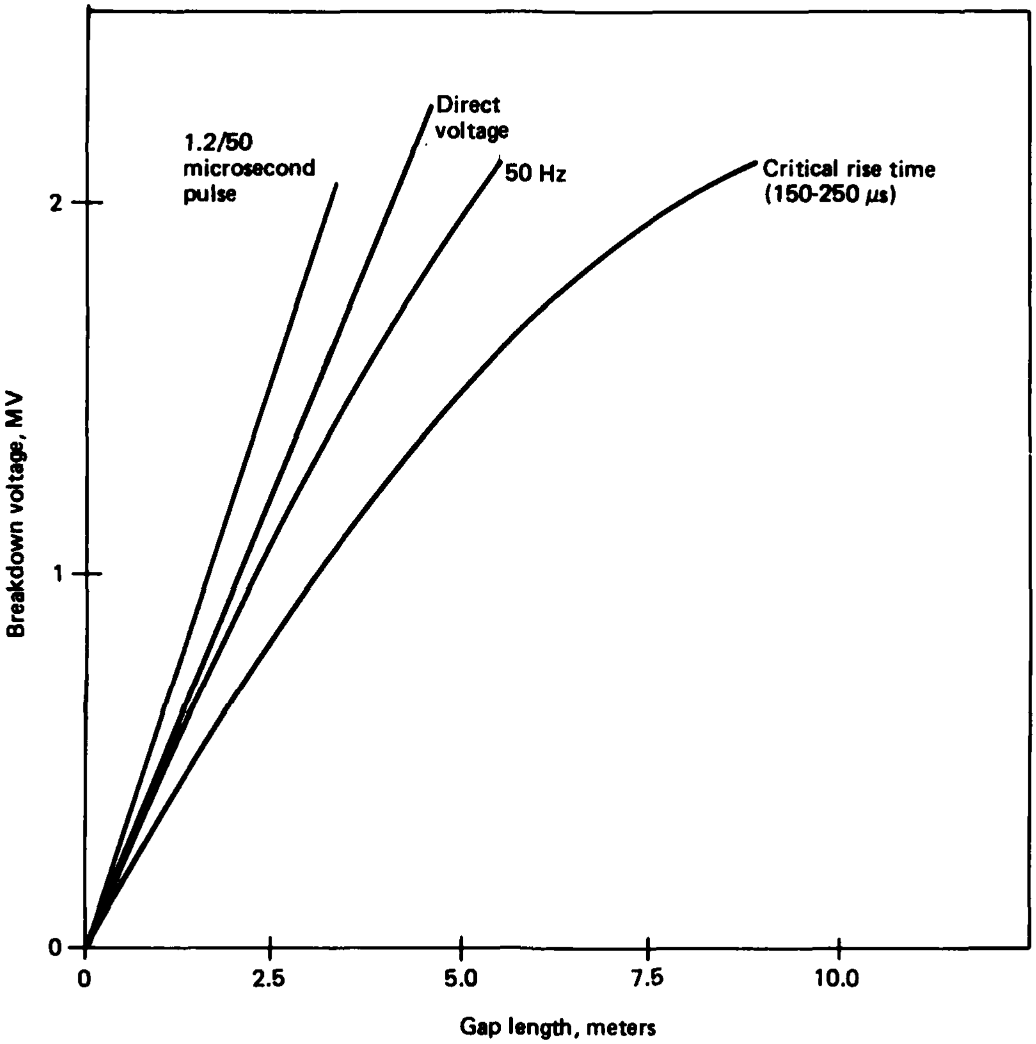



*Figure 4. Positive Impulse Breakdown Voltage for Rod-Rod Gaps in Air*

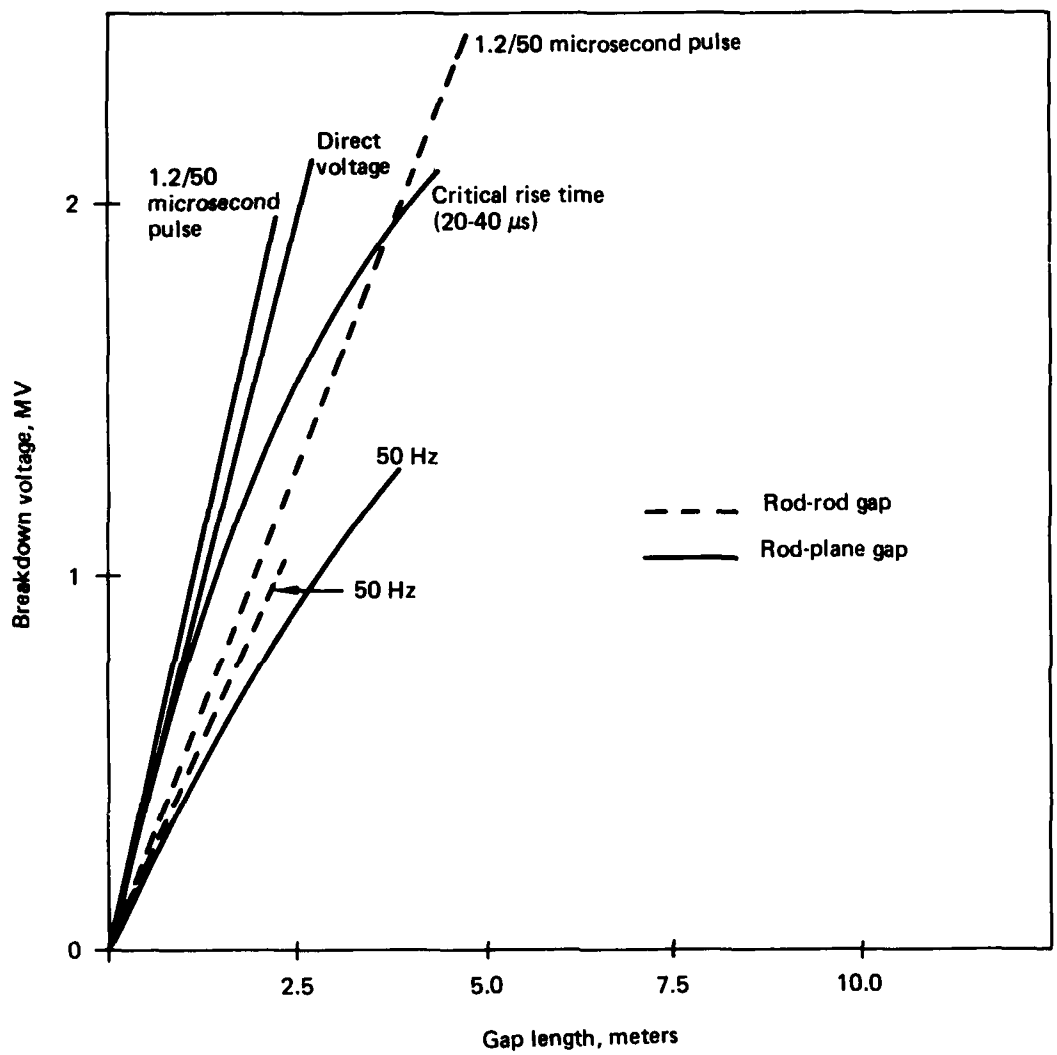



*Figure 5. Negative Impulse Breakdown Voltage for Rod-Rod and Rod-to-Plane Gaps in Air*

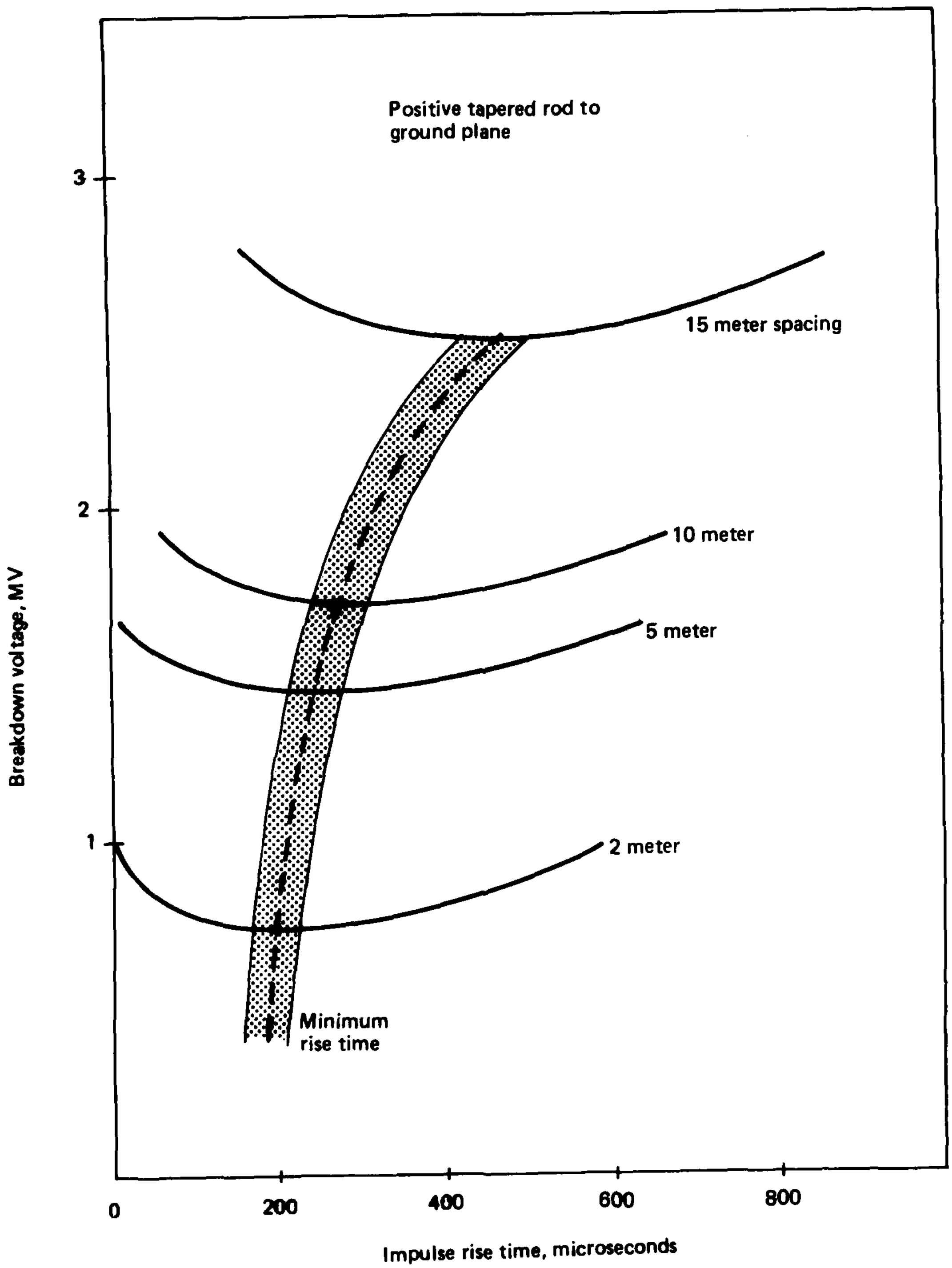



*Figure 6. Breakdown Voltage as a Function of Impulse Rise Time in Air*

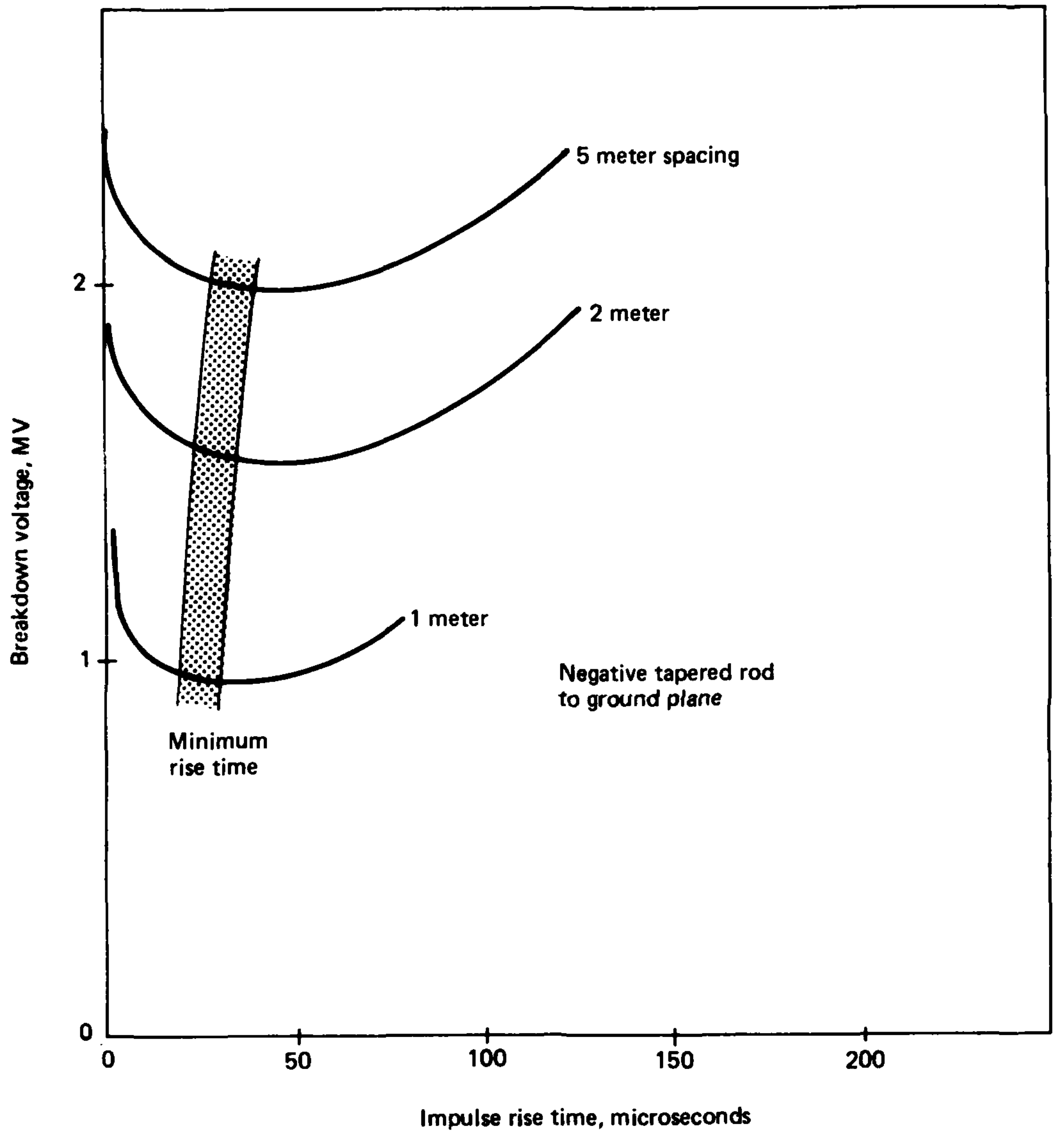



*Figure 7. Breakdown Voltage as a Function of Impulse Rise Time in Air*

the bias voltage will lower the breakdown voltage as much as 8% or 10% for either positive or negative ac or dc bias with respect to the impulse polarity.

(c) Humidity

Relative humidity to 90% has little effect on the breakdown voltage. But when fog or polluted fog containing minute suspended water droplets was used in the experiments, the breakdown voltage was decreased by 5% to 12%.

2. Sulfur Hexafluoride

Sulfur hexafluoride is used as an insulating gas because it is relatively inexpensive, plentiful, easy to handle and has desirable dielectric properties. Sulfur hexafluroide is an electronegative gas; that is, when an electron comes into the vicinity of an atom, there is a finite probability that the electron will be captured to form a stable negative ion by one of several possible processes. These processes effectively remove a light mobile electron from the swarm and replace it with a relatively heavy, slow-moving ion, influencing the growth of ionization and breakdown. The process, in other words, serves as a quenching action to the initiated electron streamers.

Rod-to-plane breakdown voltage has been reported by Fujinami, et al.[5] Their, data summarized in Figure 8, show that $SF_6$ has high breakdown voltage for both positive and negative polarities. In addition, the standard breakdown deviation for 10 separate discharges is less than 7%, whereas in air it may be as great as 20%.

C. Vacuum

1. Direct Current Source

Vacuum breakdown voltage as a function of spacing for very small spacings is shown in Figure 9.[3] This is an accumulation of data, including scatter, for electrodes made of steel, aluminum, copper, and lead. Lead and copper have the lower breakdown characteristic, and steel and aluminum, the higher values. All data were taken at pressures less than $10^{-2}$ Pa at $23(\pm 10)^{o}C$.

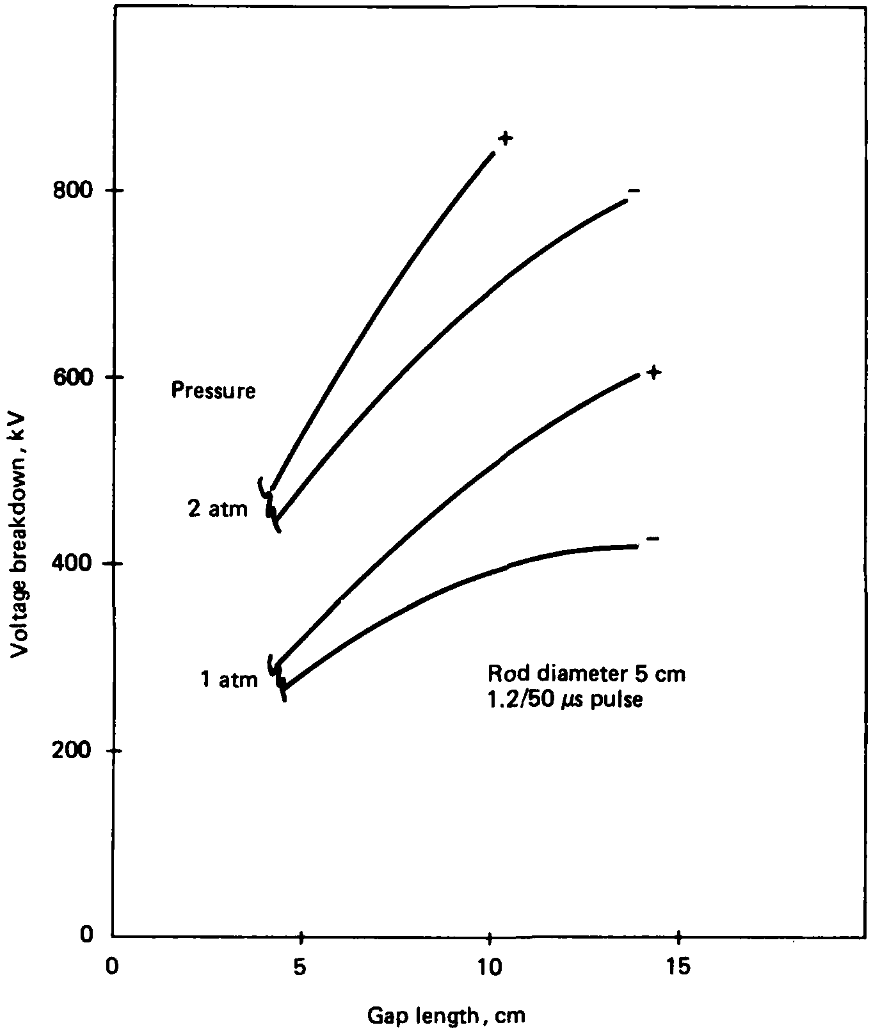



*Figure 8. Breakdown Voltage of $SF_6$ as a Function of Spacing*

2. Pulse

Fast rise time pulses of 20 to 50 ns have much higher breakdown voltages than the steady state devices shown in Figure 9. The breakdown voltages for 1 and 2 mm gaps between brass electrodes are[6]:

| Gap Length | Breakdown Voltage |
| --- | --- |
| 1 mm | 32 kV |
| 2 mm | 60 kV |

As the voltage is increased above breakdown initiation, the current rises at a rate of approximately 100 A/kV.

Impulse voltage measurements were made between the CuBiAg contacts of a vacuum interrupter, spaced 12 mm apart using 1.5/40 μs double exponential pulses[7]. The test results show that the breakdown initiation voltage has a minimum of about 60 kV, as do the 2 mm-spaced electrodes above. These data show the significance of pulse rise time on the pulse withstand voltage.

3. Insulator Flashover

Flashover along insulating surfaces is less than it is along a parallel plate vacuum gap of similar dimensions.

(a) Alumina

High-density alumina rods (1.25 cm diameter by 1.25 cm long) were impulse-tested with 1.50 μs pulses. The rods were placed between either aluminum or steel electrodes and tested for flashover using a negative or a positive dc bias voltage[8]. The vacuum was held at a pressure between $10^{-4}$ and $10^{-3}$ Pa for more than 1 hour before each test to complete outgassing of the chamber and test samples. Test results are shown in Figure 10. When the electrodes were preconditioned, the voltage reduced to 0 in about 1 μs. Without preconditioning, the flashover voltage decreased exponentially to that of an unstressed test sample in about 60 μs.

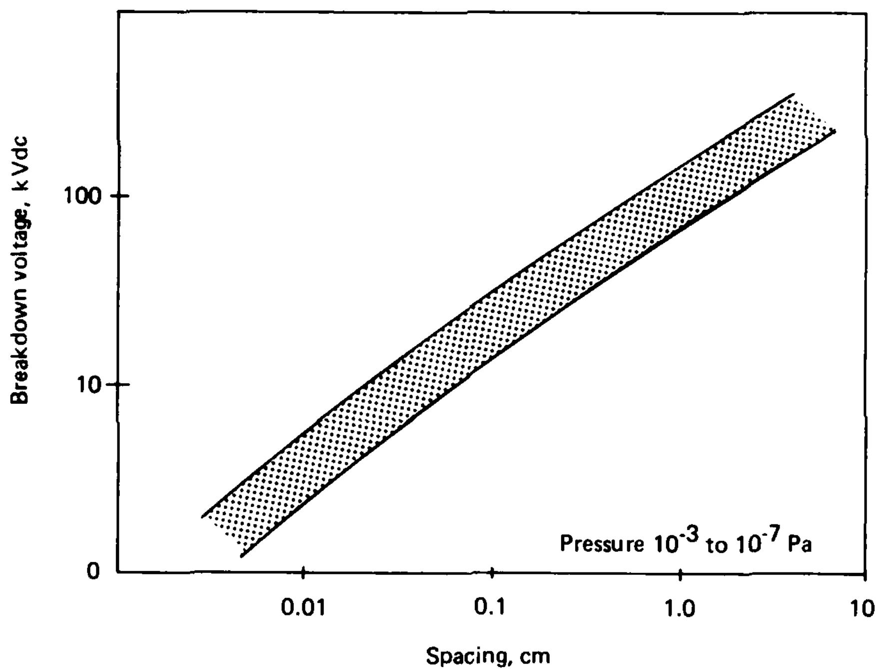



*Figure 9. Vacuum Breakdown Voltage as a Function of Spacing for Steel, Copper, and Aluminum Electrodes*

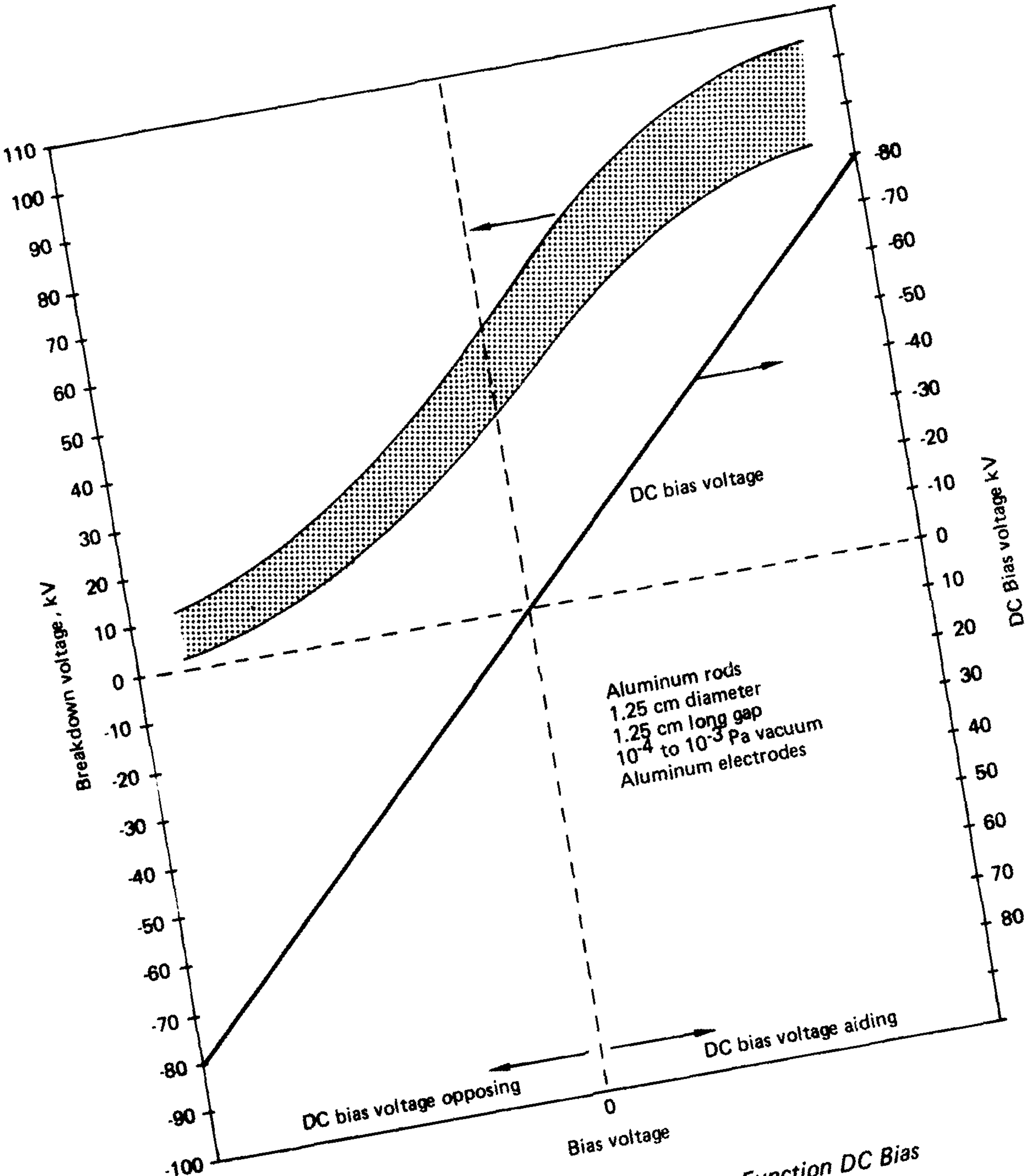



*Figure 10. Impulse Flashover Voltage as a Function DC Bias*

(b) Organic Materials

Several organic materials have been impulse-tested for flashover[9,10], including polycarbonate (Lexan*), methylmethacrylate (Lucite*), acetal (Delvin*), plexiglass teflon polyethylene, polymethylmethacrylate, and blue nylon. Most of the tests were made using specimens 1 cm long and 6.35 cm in diameter in a vacuum of $10^{-4}$ Pa, as shown in Figure 11. Metallization of the electrodes with a thin silver layer decreased the flashover voltage to about 65% of the value for the nonmetallized condition when other parameters were held constant. Metallization does give a better contact with the test fixture electrode, but it coats the surface of each electrode with a thin layer of metal that appears as a sharp emitting group of minute points at the ends of the specimen and reduces its flashover capability.

The initial flashover voltages for several materials are shown in Table 2. Subsequent testing of four materials was done with and without radiation. These results show that acetal and methylmethacrylate each had significantly improved flashover voltage equal to or greater than 161 kV -- an improvement of more than 165% for over 8000 pulses. Blue nylon had lower flashover voltage after being irradiated. Polycarbonate was 167% better for the first three pulses but degraded to the performance of a nonradiated material thereafter. Irradiated acetal and methylmethacrylate should both be considered preferable materials for high-voltage pulse applications.

D. Cryogenic

Short-term and long-term breakdown characteristics of Nomex, Tyvex, and PPLP immersed in $LN_2$ at 77.3°K were investigated at 1.2/50 and 250/2500 μs pulses[11]. PPLP Type 1 is made of cellular paper, polypropylene film, and cellulose paper, PPLP Type 2 is a composite of cellulose paper, extruded polyproplylene film, and oriented polypropylene. The breakdown for the materials is shown in Table 3. The porosity of each material significantly affects its breakdown characteristic.

When partial discharges are generated during the front of an impulse, bubbles are produced in the $LN_2$. When the voltage across the bubbles changes during the time the wavetail exceeds the discharge inception value, additional discharges may initiate.

*Registered trademark.

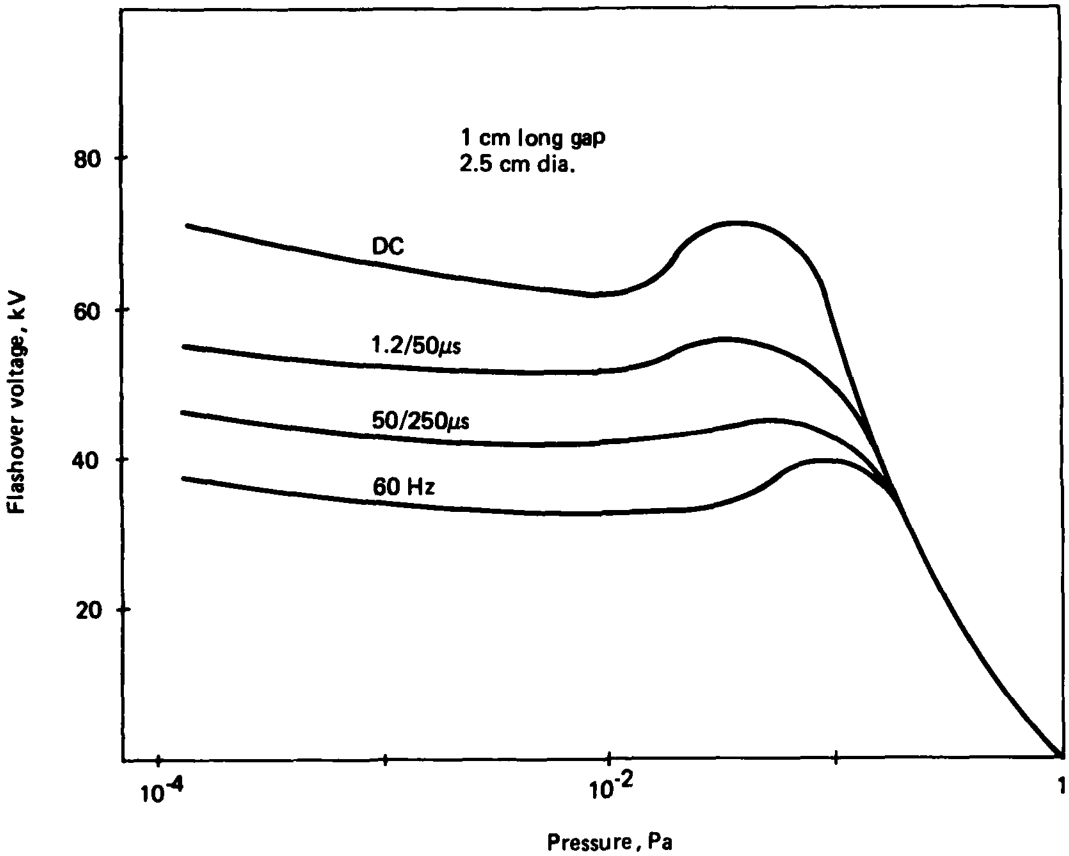



*Figure 11. Flashover as a Function of Pressure in Vacuum for Nonmetallic Polymethylmethocryolate specimen*

Table 2. Initial Flashover Voltage for 1 cm Length Specimen

| Specimen Material | Flashover Voltage kV DC | AC | 1.2/50 | 50/250 | 5/135 |
|---|---|---|---|---|---|
| Polymethylmethacrylate | | | | | |
| nonmetallized | 68 | 35 | 55 | 45 | |
| metallized | | 30 | | | |
| Plexiglass | 73 | 50 | 90 | | |
| Teflon | 70 | 40 | 85 | | |
| Polyethylene | 62 | 37 | 83 | | |
| Acetal | | | | | 85 |
| Blue nylon | | | | | 110 |
| Polycarbonate | | | | | 75 |
| Methylmethacrylate | | | | | 50-95 |

Table 3. Impulse Breakdwon of Materials in $LN_2$ at $77.3^oK$ and 1.2/50 $\mu s$ Pulses

| Material | | Breakdown | Stress | Pressure |
|---|---|---|---|---|
| Type | Thickness mm | kV | kV/mm | MPA |
| PPLP Type 1 | 0.2 | 234 | 1060 | 0.4 |
| Tyvex | 0.75 | 93 | 124 | 0.2 |
| Nomex | 0.375 | 120 | 320 | 0.2 |

The initial bubbles thus cause concentration of discharges to preferred sites resulting in greater deterioration and leading to lower breakdown voltages. The lifetime of the bubbles decreases, however, with increasing pressure applied to the $LN_2$. Some of the bubbles formed by discharges during the wavefront of the longer 250/2500  s impulses may collapse before more discharges initiate at random as the wavetail voltage decreases, causing deterioration to be less concentrated and resulting in higher breakdown voltages.

E. Liquids

After an investigation of the dielectric impulse-withstand voltage for silicone oils[12] and mineral oils[13], some important features of liquid dielectrics under impulse stresses are --

a. Steamers and electron avalanches are the principal mechanisms for impulse breakdowns.
b. The electrons in avalanches are exponential and depend on the applied field.
c. The velocity of propagation of an avalanche is much less than that of a streamer -- $10^{-3}$ to $10^{-6}$ cm/s for avalanches versus $10^{-6}$ to $10^{-8}$ cm/s for streamers.
d. Streamer formation takes place at the head of the avalanche after it has reached critical state.

This research suggests that nanosecond impulse breakdowns are caused by streamer formation rather than avalanche formation and that lower breakdown can be expected between electrodes of dc and power system frequencies.

Arcs cause damage to insulation oils by overheating the oil in the path of the spark. Heat causes a chemical breakdown, leading to the formation of hydrogen methane, carbon dioxide, and carbon monoxide in silicon oil (polydimethylsiloxane  PDMS). In addition, a gelatinous substance, which is polymerized PDMS, forms on the electrodes. Both the gas bubbles and the gelatin alter the breakdown of the oil and must be removed to obtain stable breakdown results. A comparison of the impulse and power frequency breakdown strengths of PDMS between brass electrodes is shown in Figure 12.

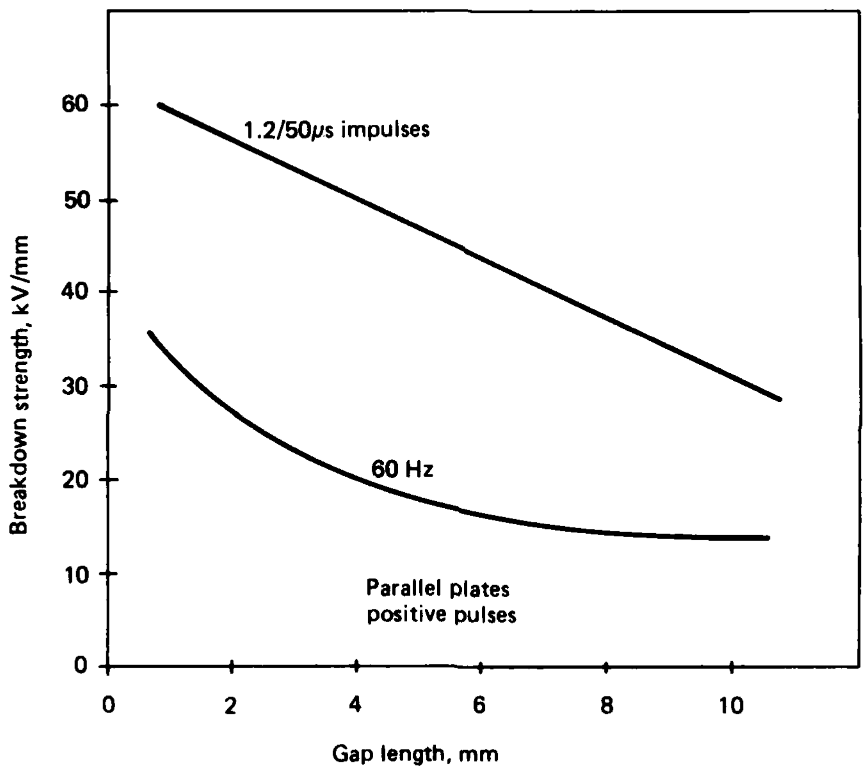



*Figure 12. Breakdown Strength of Silicone Oil Under Power Frequency and Impulse Voltages*

Many surfaces in practical systems are covered with an electrical insulation. An insulation system of silicone oil on a XLPE (cross-linked polyethylene) spacer tends to lower the impulse breakdown by approximately 10 percent.

The negative impulse breakdown of paraffinic and naphthenic oils between needle points and a sphere, spaced 2.54 cm apart at 20°C, is 48 kV/cm with a standard deviation of 5% to 10%. General 1.2/50 microsecond impulses were used to obtain these data. Experimental results show that the impulse breakdown characteristic was little influenced by the quantity of oil, the radius of curvature of the needle point, or the addition of a small quantity of water[13]. Positive point to sphere has a much lower breakdown of only 34 kV/cm.

48 kV/cm for negative points
34 kV/cm for positive points

Test experience shows the following characteristics for paraffinic and naphthenic oils:

a. Impurities in the oils have little effect on the impulse breakdown strength.
b. Negative breakdown is considerably higher than positive breakdown.
c. Both oils have similar impulse hours withstand voltage.
d. After thermal aging for 1000 hours, the negative impulse withstand voltage is lowered 20%.

F. Solids

The impulse breakdown voltage and corona initiation voltage for polytheylene, polyimide, and polymethylmethacrylate (PMMA) have been investigated. Corona evaluation experiments were made using samples with artificial cavities with controlled parameters.

1. Polyethylene

Partial discharges in gas-filled cavities within an insulation system have been investigated[14]. The cavities were made by punching a small hole 0.5 to 3.8 mm in diameter in a sample 0.08 to 0.3 mm thick. Another sample of the same thickness was sandwiched next to the one with the cavity, the edges were sealed to prevent slippage, and the entire sandwich, approximately 5 mm thick, was situated between the test electrodes.

Two rise times were used for the experiment: 1/50 μs impulses and 500/3000 μs impulses. Each sample was subjected to 50 pulses at a rate of one pulse every 2 to 20 sec. The repetition rate had little or no effect on the inception voltage. The parameters that did affect the initiation and extinction voltages were the cavity depth and time lag. Partial discharge initiation and extinction for various cavity depths were close to the calculated values for a cavity in series with a solid dielectric.

Peak partial discharge magnitudes varied from 115 to 600 pC, with the highest peaks occurring at time lags of 2 to 5 μs. The lower peaks occurred at time lags greater than 40 μs. In every test, the initial discharge was very large in comparison to the secondary discharges for each impulse observed. Whenever a new sample was tested, the reverse discharges were numerous and of small magnitude. The number of discharges was proportional to the cavity diameter.

Prestressed polyethylene[15] with the same polarity and opposing square pulses is shown in Figure 13. Prestress is the dc bias voltage. These data represent the 95% confidence level and may be used for design data, if the electrical stress is decreased for operating time degradation.

2. Cross-Linked Polyethylene (XLPE)

A 15-kV, XLPE-insulated cable was tested by Densley for breakdown at 25° and 90°C under both wet and dry conditions[16]. Test results are shown in Table 4.

Table 4. Breakdown Strength of XLPE Cables

| Temperature | Breakdown Stress kV/mm | Test Condition Wet | Test Condition Dry |
|---|---|---|---|
| 25°C | 31.3 | X | |
| 25°C | 59.2 | | X |
| 90°C | 23.7 | X | |
| 90°C | 28.6 | | X |

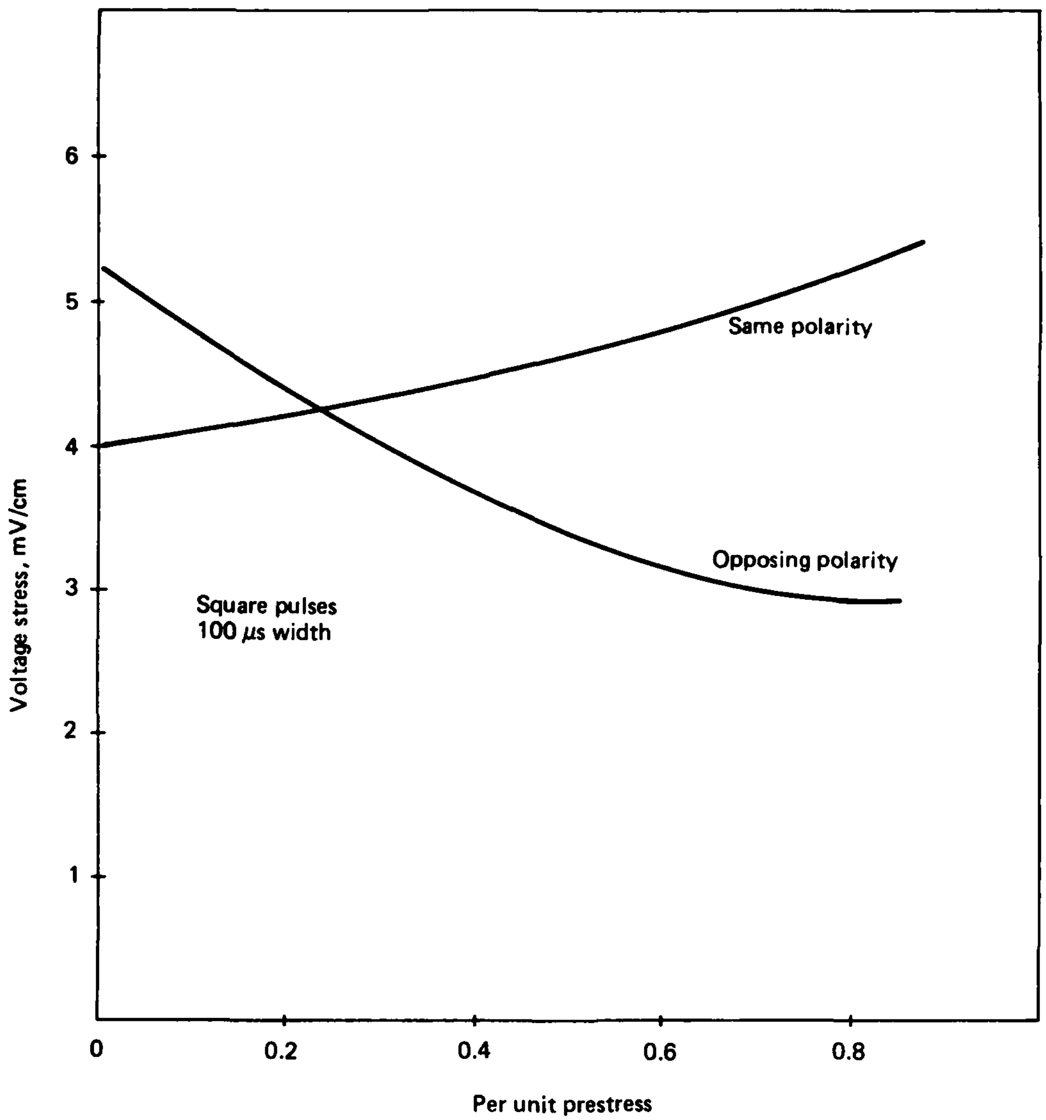



*Figure 13. Breakdown as a Function of Percent Prestress With Polyethylene Film*

The dry condition was created by passing a current through the center conductor and heating the cable to 90°C for at least 2 days prior to testing. The cable was wetted by pouring water into the strands for at least 2 days prior to testing.

3. Polyimide and Polyvinylchloride (PVC)

The short life durations of polyimide and PVC films were measured by subjecting the two films to partial discharges at sine wave frequencies of 1 kHz to 60 kHz, with 10 $\mu$s duration square pulses at a repetition rate of 15.625 kHz by the Ahmed's.[17] The square waves were generated by a TV horizontal flyback transformer with variable voltage inputs and outputs.

Pulse breakdown voltage for PVC and polyimide films is shown as a function of time in Figure 14. These data show that polyimide has higher pulse breakdown strength than PVC. In the life-to-voltage breakdown acceleration formula,

$$L = V^{-n},$$

L is the average lifetime, V is an average applied voltage, and n is a constant. Life as a function of voltage has an n value of approximately 1.4 for polymide and 1.9 for PVC for time greater than 3 min, both materials have a break point of about 3 min. For lifetime to breakdown less than 3 minutes, the n value is approximately 1.1 for both materials.

The break point in the life curve can be attributed to the two characteristic breakdown mechanisms. For time less than 3 min high-voltage intrinsic breakdown occurs. For lifetime greater than 3 min, breakdown occurs after progressive deterioration from partial discharges.

When operated continuously, electrical insulation heats up, rapidly accelerating its demise. Figure 15 shows the frequency acceleration characteristics of PVC and polyimide as a function of time and operating voltage. The time chosen for the curves shown in the plotted data is 10 hr. The results assume that there is ample cooling to prevent temperatures exceeding 25°C.

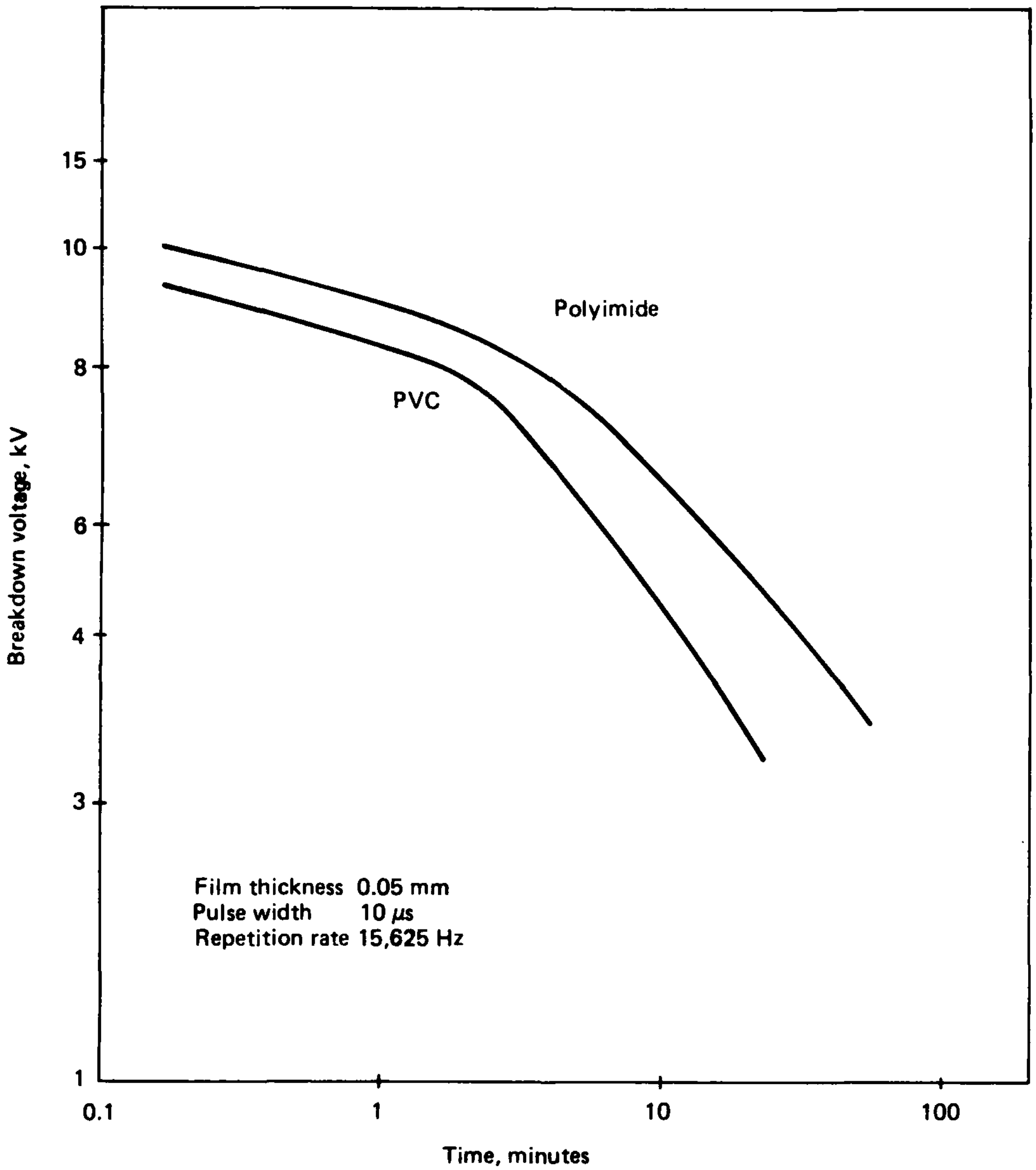



*Figure 14. Pulsed Voltage Life Characteristics of Insulating Films*

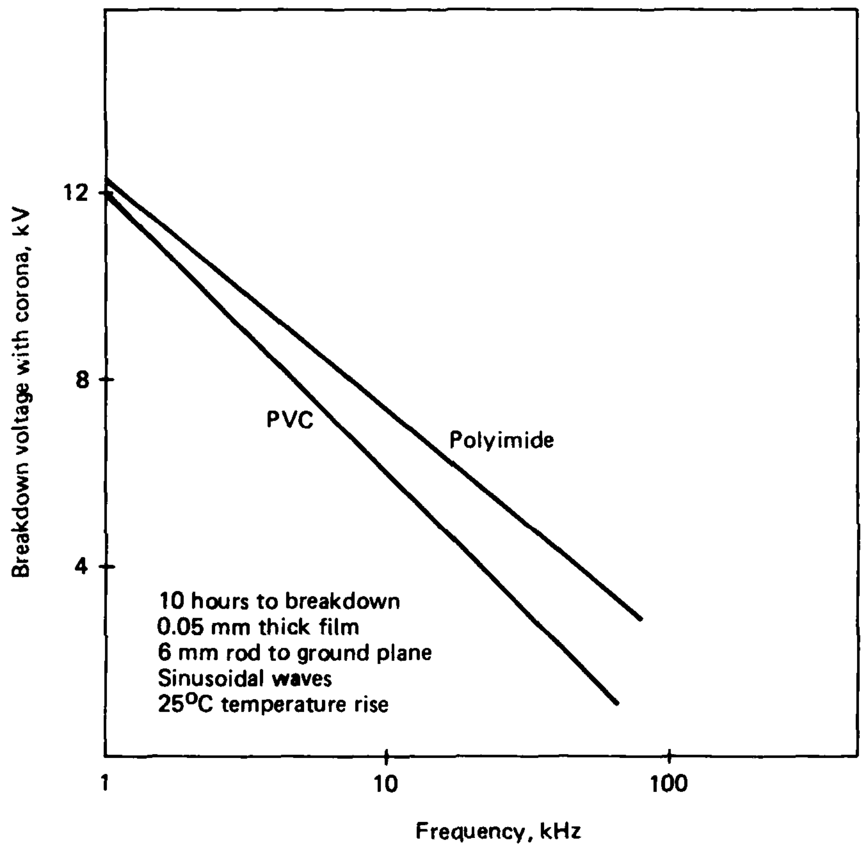



*Figure 15. Sine Wave Voltage Breakdown Caused by Corona Deterioration*

## VI BENEFITS

A test program is used to qualify electrical and electronic equipment. To confirm the qualification program, the tests must prove that the operating characteristics of the system are achievable but do not deteriorate the life or operating characteristics of the parts or the system.

### A. Materials

A high steady-state electric field maintained for a long time will not degrade an electrical insulation that has been correctly assembled and processed. This implies that no partial discharges or arcs occur at the surface or inside the insulation. The quality of the dielectric remains unchanged even if the electric stress is applied continuously for several years. Only under partial discharges or overstress does the material in the vicinity of the partial discharges begin to decompose and change in structure. Partial discharges also raise the temperature of the material in their vicinity, increasing the rate of decomposition.

### B. Program

The survey results and the former pulse test results show several program benefits.

1. Pulse rise and fall time effect the insulation life.
2. Pulse polarity affects the insulation life and the maximum voltage stress characteristics of the insulation.
3. The electric field stress versus insulation life should be evaluated by test for operation at the critical pulse rise time and for shorter and longer pulse rise times.
4. An evaluation of electrical insulation for long life capacitors should include the probability of partial discharge generation between the plate(s) and film.
5. Work should be initiated to evaluate creepage and flashover of structural insulating materials and potting materials when immersed in pressurized air and other insulating gases.

## VII REFERENCES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# VIII PULSE TEST SET

The general requirements for a high voltage pulse test set are contained in Appendix A. The pulse test set will be used to test and evaluate high voltage parts and components applicable to aerospace power systems.

APPENDIX

# ITEM DESCRIPTION FOR HIGH VOLTAGE PULSE TEST SET

## Table of Contents

## SPECIFICATION FOR A HIGH-VOLTAGE PULSE TEST SET

### 1. SCOPE

1.1 General - This specification covers the general requirements for a high-voltage pulse generator facility which shall have the capability of producing and transmitting a high-voltage pulse to the terminals of a unit under test. The facility includes the high-voltage pulse generator, the high voltage line and terminations, calibrating and measuring instrumentation, and grounding leads.

1.2 Classification

1.2.1 Family - Equipment which converts alternating current into high-voltage pulse power.

1.2.2 Type - Non-regulated: Equipment which converts and supplies pulse power with the voltage regulation dependent on the inherent characteristics of the equipment components and the unit under test.

### 2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on date of invitation for bids or request for proposal, shall be used as guidelines or references to the extent specified herein.

SPECIFICATIONS

FEDERAL

| | | |
|---|---|---|
| L-P | - | Plastic Sheet, Laminated, Thermosetting, Paper-Base, Phenolic Resin. |
| QQ-S-571 | - | Solder, Tin Alloy; Tin-Lead Alloy; and Lead Alloy. |
| PPP-B-566 | - | Boxes, Folding, Paperboard. |
| PPP-B-601 | - | Boxes, Wood, Cleated-Plywood. |
| PPP-B-621 | - | Boxes, Wood, Nailed and Lock-Corner. |
| PPP-B-636 | - | Boxes, Shipping, Fiberboard. |
| PPP-B-640 | - | Boxes, Fiberboard, Corrugated, Triple-Wall. |

| | | |
|---|---|---|
| PPP-B-676 | - | Boxes, Setup. |
| PPP-T-60 | - | Tape, Packaging, Waterproof. |
| PPP-T-76 | - | Tape, Pressure-Sensitive Adhesive Paper, (for Carton Sealing). |

MILITARY

| | | |
|---|---|---|
| MIL-I-10 | - | Insulating Materials, Electrical, Ceramic, Class L. |
| MIL-M-14 | - | Molding Plastics and Molded Plastic Parts, Thermosetting. |
| MIL-W-76 | - | Wire and Cable, Hookup, Electrical, Insulated. |
| MIL-P-997 | - | Plastic Material, Laminated, Thermosetting, Electrical Insulation: Sheets, Glass Cloth, Silicone Resin. |
| MIL-F-14256 | - | Flux, Soldering, Liquid (Rosin Base). |
| MIL-P-15037 | - | Plastic Sheet, Laminated, Thermosetting, Class-Cloth, Melamine-Resin. |
| MIL-P-15047 | - | Plastic-Material, Laminated Thermosetting, Sheets, Nylon Fabric Base, Phenolic-Resin. |
| MIL-W-16876 | - | Wire, Electrical, Insulated, High Temperature. |
| MIL-P-18177 | - | Plastic Sheet, Laminated, Thermosetting, Glass Fiber-Base, Epoxy Resin. |
| MIL-C-45662 | - | Calibration System Requirements. |

STANDARDS

MILITARY

| | | |
|---|---|---|
| MIL-STD-129 | - | Marking for Shipment and Storage. |
| MIL-STD-147 | - | Palletized Unit Loads on 40" x 48" Pallets. |
| MIL-STD-202 | - | Test Methods for Electronic and Electrical Component Parts. |
| MIL-STD-446 | - | Environmental Requirements for Electronic Component Parts. |
| MIL-STD-454 | - | Standard, General Requirements for Electronic Equipment. |
| MIL-STD-831 | - | Test Reports, Preparation of. |
| MIL-STD-810 | - | Environmental Test Methods. |
| MIL-STD-1285 | - | Marking of Electrical and Electronic Parts. |
| MIL-HDBK-251 | - | Military Handbook, Reliability/Design Thermal Applications, 19 January 1978. |
| MS33586 | - | Metals, Definition of Dissimilar. |

2.2 <u>Other Publications</u>. The following documents shall be used as guidelines to the extent specified herein. Unless otherwise indicated, the issue in effect on date of invitation for bids or request for proposal shall apply.

| | |
|---|---|
| ASTM-D 3426 | - Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials Using Impulse Waves. |
| American National Standard | - C57.12.00-1973 - General Requirements for Distribution, Power, and Regulating Transformers. |
| AFWAL-TR-82-2057, Vol. 4 | - High Voltage Design Guide: Aircraft. |

<u>NATIONAL BUREAU OF STANDARDS</u>

| | |
|---|---|
| Handbook H28 | - Screw-Thread Standards for Federal Services. |

(Application for copies should be addressed to the Superintendent of Documents, Government Printing Office, Washington, D.C., 20402.)

INSTITUTE OF ELECTRIC AND ELECTRONIC ENGINEERS

IEEE STD-4-1978 IEEE Standard Techniques for High Voltage Testing
IEEE STD-28-1975 Surge Arresters for Alternating Current Power Circuits
IEEE STD-82-1971 Impulse Voltage Tests on Insulated Conductors
IEEE STD-142-1982 Recommended Practice for Grounding of Industrial and Commercial Power Systems
IEEE STD-181-1977 Pulse Measurement and Analysis by Objective Techniques
IEEE STD-271-1966 Extra-High Voltage Switches, Switching Surge Testing of
IEEE STD-376-1975 Measurement of Impulse Strength and Impulse Bandwidth
IEEE STD-472-1974 Surge Withstand Capability Tests, Guide for

3. REQUIREMENTS

3.1 Qualification - The HV pulse test facility furnished under this specification shall be a product which has been tested and has passed the qualification tests specified herein.

3.2 Non-Compliance with Specifications - The equipment is to be supplied in accordance with this specification. Proposed deviations from applicable codes, standards, procedures, and requirements of this specification shall be originated by the manufacturer by a Deviations Request included in the bid package. Any such deviation must be approved by the Air Force using agency before proceeding, and as such, could provide grounds for rejection of the bid. In the event the manufacturer determines that any requirement of this specification will not be met as equipment is built and tested, a Nonconformance Report shall be completed by the manufacturer and submitted to the Air Force using agency for approval or rejection prior to performing the work required under this specification.

3.2.1 First Article - When specified, the supplier shall furnish a complete HV pulse test set for first article inspection and approval. Unless otherwise specified, the first article shall consist of one complete HV pulse test set including auxiliary calibration and measuring equipment.

3.2.2 Information to be furnished with first article - The applicable information outlined in 4.5 shall be furnished with the first article, together with any other pertinent information as required by the Government.

3.3 Materials, parts, and processes

3.3.1 Selection of materials, parts, and processes - Materials, parts, and processes shall conform to applicable Government specifications. Materials conforming to contractor's specifications may be used, with government approval, provided the specifications contain provisions for adequate tests. The use of contractor's specifications will not constitute waiver of Government inspection.

3.3.1.1 Flammable materials - Insofar as practicable, materials used in the construction of the HV pulse set shall be nonflammable and nonexplosive.

3.3.1.2 Corrosive materials - Corrosive materials used in any of the manufacturing processes shall be removed or neutralized so that no corrosion will result from such use. Insofar as practicable, materials used in the construction of HV pulse facilities shall be noncorrosive.

3.3.1.3 Thermal and sound insulating material - Unless otherwise specified, the thermal and sound insulating material shall conform to the following requirements:

a. Noncapillary, nonhygroscopic, and free from perceptible odors.
b. Resistant to attack by vermin and mildew.
c. Fire retardant, unaffected by battery electrolyte or petroleum derivatives.
d. Capable of maintaining its shape, position, and consistency inherently or by suitable retaining methods.
e. Resistant to or protected from abrasion, if exposed, and shall be replaceable, and bondable to metal.

3.3.2 Electrical insulating materials - Electrical insulating materials used, including plastics, fabrics, and protective finishes, shall be moisture resistant and shall not support fungus growth. The nonmetals shall not support combustion.

3.3.2.1 Laminated phenolic - Laminated phenolic materials shall conform to the applicable ASTM Standards. When electrical characteristics are involved, only natural uncolored materials shall be used.

3.3.2.2 Molded phenolic or melamine - Molded phenolic or melamine materials shall conform to the applicable ASTM Standards.

3.3.2.3 Ceramic (external use) - Ceramic materials shall conform to the applicable ASTM Standards.

3.3.2.4 Laminated plastic sheet - Laminated plastic sheet, epoxy, shall conform to the applicable ASTM Standards.

3.3.2.5 Insulating fluids - Insulating fluids shall be free of particles. Samples shall be evaluated to assure the virgin fluid is free of particles. Provisions shall be provided to check purity of fluid and for replacement of fluid. No PCB additives shall be used. Insulating fluids will only be permitted in components.

3.3.2.6 Insulating gases - Insulating gases may be either pure or a mixture. The major subassemblies shall be gas insulated to allow for ease of maintenance and/or circuit reconfiguration.

3.3.2.6.1 Gas-filled units - When the unit is gas filled it shall be as specified in 4.9.1.1, and the leak rate shall not exceed $10^{-3}$ Pascal-cubic centimeter per second.

3.3.2.6.2 Pressure-vacuum transducer - A pressure-vacuum transducer shall be furnished for each pressurized sealed-tank and/or gas-oil-seal construction.

3.3.2.6.3 Pressure-vacuum bleeder - A pressure-vacuum bleeder device shall be set to operate at the maximum operating pressure (positive and negative) indicated on the nameplate. Effluent gases/liquids shall be ported over-board.

3.3.2.6.4 Tanks - A pressure relief device shall be provided on the cover. Maximum operating pressures (positive and negative) for which the unit is to be operated shall be indicated on the nameplate.

3.3.2.7 Materials quality - Molded, ceramic and laminated materials shall be free of flaws such as cracks, delaminations and voids. Sample lots shall be evaluated to assure flaws do not exist in the virgin material or processed materials. Bolting and clamping shall be designed to prevent delamination of parts and wiring.

3.3.3 Metals - The metal materials for each part shall be as specified. When a definite metal is not specified, a metal which will enable the part to meet the requirements of this specification shall be used. Acceptance or approval of a constituent material shall not be construed as a guarantee of the acceptance of the finished product.

3.3.3.1 Dissimilar metals - Dissimilar metals, when used in contact with each other, shall be protected against electrolytic corrosion, and shall have a low-impedance path to radio-frequency currents.

3.3.3.2 Corrosion resistance - Materials shall be of a corrosion-resisting type or suitably processed to resist corrosion. Any corrosion that causes malfunctioning of the equipment, shortening of life, impairment of use, or impairment of ease of replacement of parts shall be cause for rejection.

3.3.3.3 The following are acceptable corrosion-resisting metals as distinguished from corrosion-resisting treatments.

a. Corrosion-resisting steel which contains a minimum of 12 percent chromium.
b. Copper
c. Aluminum
d. Aluminum alloys which do not contain more than 0.4 percent copper.
e. Brass
f. Bronze
g. Beryllium-copper
h. Copper-nickel alloys
i. Nickel-copper alloys
j. Titanium
k. Inconel

3.3.3.4 Treatments - The following are corrosion-resistant treatments that will be acceptable.

a. Sherardizing
b. Galvanizing
c. Electrodepositing with cadmium, chromium, copper, nickel, silver, or zinc.
d. Aluminizing
e. Chromizing
f. Electroless nickel

3.3.3.5 Screws, nuts, bolts, and washers - All mounting and terminal screws, nuts, bolts, and washers shall be of corrosion-resistant material or shall be protected against corrosion.

3.3.3.6 Corona protection - All mounting and terminal screws, nuts, bolts, and washers near a high voltage part shall have rounded configuration to eliminate probability of corona. Screw threads shall not exist in parts subjected to high field concentration.

3.3.4 Toxic materials - Materials which are known to produce harmful toxic effects under any conditions, including fire, shall not be incorporated in the design without prior approval of the procuring activity.

3.3.5 Standard parts - Standard parts shall be used wherever they are suitable for the purpose, and shall be identified on the drawings by their standard part number or their generic part number as well as the manufacturer's part number. This applies to solid-state or passive electrical components.

3.3.6 Interchangeability - All parts having the same manufacturer's part number shall be directly and completely interchangeable with respect to installation and performance.

3.3.7 Wire - Internal wiring of the HV pulse test set is considered to be all the interconnecting wiring beyond the point where the power enters the unit enclosure and processed power leaves the unit enclosure.

3.3.7.1 Magnet wire - Magnet wire shall conform to and be of the types and sizes in accordance with the applicable NEMA Standards. Government approval shall be required when other types and sizes of magnet wire are used.

3.3.7.2 Insulated wire - When insulated wire is used as wire terminals, the wire shall be of the types and sizes in accordance with NEMA Standards.

3.3.7.3 Wire support - All wire, cable, and buses shall be supported and arranged so they withstand abrasion, flexing, and vibration. Clamping shall be such that it will not damage the insulation.

3.3.8 Fasteners

3.3.8.1 Panel Fasteners - Panels, inspection doors, and plates for all components, which are subject to frequent operation and removal, shall have corrosion-resistant fasteners.

3.3.8.2 Electrical fasteners - Each electrical fastener, and other electrical hardware shall be made of corrosion-resistant material or shall be treated to be corrosion resistant. Fasteners (bolts, screws, studs, or other fasteners) shall not generally be depended on to carry current; they shall serve merely to hold current-carrying parts (lugs, terminals) in firm contact with each other. Where flow of current through a stud cannot be avoided, the stud and all its associated hardware (nuts, locking devices, washers, or other hardware) shall be made of corrosion-resisting material. Positive means (such as pins, or square shanks) shall be provided to prevent turning of studs in their mountings when nuts are tightened or loosened; lockwashers which depend on friction or spring action will not be acceptable for this purpose. Unused length of threads on studs (or screws used as studs) shall not exceed half the diameter of the stud.

3.3.8.3 Other fasteners - Each fastener (screw, stud, bolt, pin, or other fastener) shall be equipped with a suitable locking device to prevent loosening due to vibration. Locking shall be by locknuts, castellated nuts with cotter pins, lockwashers, lock wire, or lock plates. No swedging, peening, or staking of parts subject to removal or adjustment will be permitted. Lockwashers shall be captive on nuts, machine screws, capscrews, and bolts, when the nominal size is less than 1/4-inch diameter. Fasteners and associated hardware (nuts, locking devices, washers, or other hardware) shall be made of corrosion-resistant material, or shall be provided with a corrosion-resistant treatment. Self-locking nuts may be used on removable through bolt in lieu of a lockwasher.

3.4. Design and construction - The article shall conform to the applicable specifications and standards or to the detailed specifications. All components in the system shall be operated well within manufacturer's specification, regardless of who supplies them. Suitable derating factors shall be applied where necessary to provide reliable, long-life operation consistent with industry standards.

3.4.1 Functional description - The HV pulse test set shall have the capability of producing a high-voltage waveform and transmitting it to the terminals of a test article with no more than 1000 picofarads capacitance or less than $10^6$ ohms resistance. The unit under test consists of the unit's electrical insulation, such as the insulation between transformer windings or cable insulation.

3.4.2 Performance requirements - The HV pulse test set, including the auxiliary components, shall perform as required herein. Unless otherwise specified, these requirements apply at the terminals, with a prime power input of ± 10% rated voltage.

3.4.2.1 Warm up - Warm-up time shall not exceed ten minutes.

3.4.2.2 Environment - The pulse generator shall provide reliable operation, and shall meet output voltage tolerance requirements in ambient temperatures from 60°F to 100° F, in relative humidity which varies from 20% to 95%, and with a ±10% variation of source voltage.

3.4.2.3 Input - Input power shall be from a 120/208, 3 phase, 60 Hz power source or a 277/480 volt, 60 Hz power source, as required.

3.4.2.4 Output - The pulse generator shall be capable of generating a maximum peak voltage of 400 kV at least once every 5 minutes. The voltage shall be adjustable from 5% to 100% full voltage. If required, the adjustment may be achieved with internal circuit reconfiguration. The output shall be single polarity pulses.

3.4.2.5 Pulse - The generator shall be capable of generating pulses which simulates lightning and switching pulses in accordance with IEEE STD 4. Two pulse types are shown in Figures 1 and 2. The pulse generator shall be capable of generating these pulses and derivatives thereof. Each parameter of the pulse must be variable. Figure 1 is for a double exponential waveform and Figure 2 shows a chopped waveform.

The pulse parameters are as follows:

t the time interval when the pulse is 30 percent (A) and 90 percent (B) of the peak value, V.

$O_I$ is the virtual origin, that is an extension of the rise time between 30 and 90 percent of the peak value, through 0 percent.

$t_I$ is the virtual front time by extending the line (30 percent to 90 percent of peak value) from $O_I$ to 100 percent V.

$t_2$ the time on the tail of the pulse when the value has decreased to one half of the peak value starting at the virtual origin $O_I$.

1.0V is one per unit peak value voltage.

$\alpha$ is the instant discontinuity starts.

$t_C$ is the virtual time to start of the discontinuity.

e is the time at which the voltage reaches 0-volts.

3.4.2.6 Pulse duration parameters - The pulse rise time t, dwell time $t_C$, and fall time $t_2$, variables as shown in Figures 1 and 2, shall meet the requirements of Table 1.

3.4.2.7 Tolerances - The following tolerances are acceptable for the specified values for the pulse and those actually recorded.

| | |
|---|---|
| peak voltage | ± 3% |
| rise time | ±20% |
| dwell time | ±20% |
| fall time | ±20% |

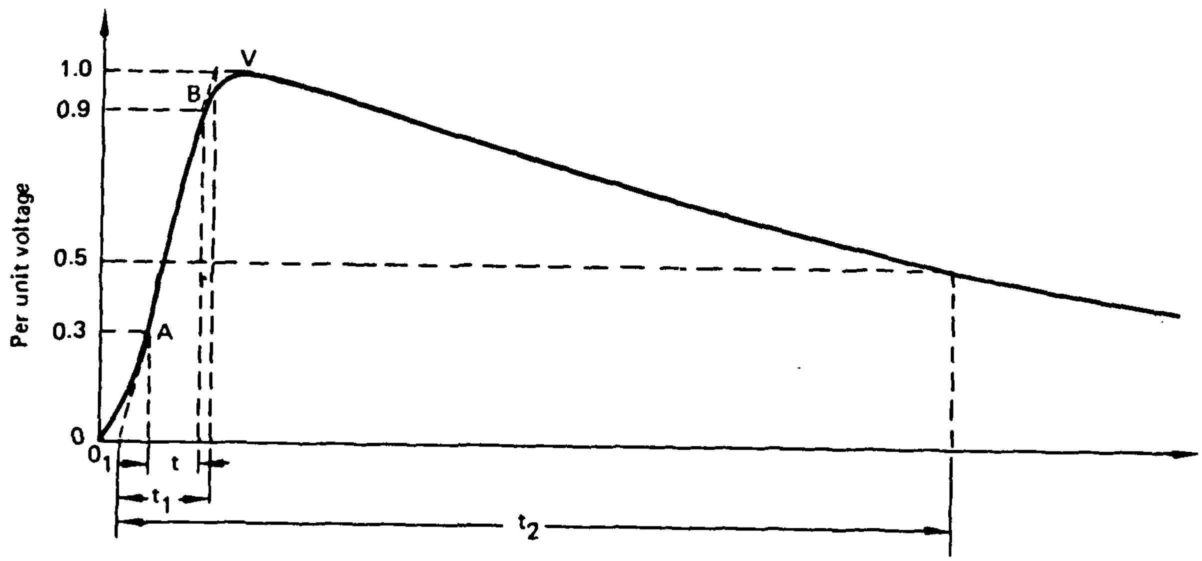


*Figure 1. Double Exponential Pulse*

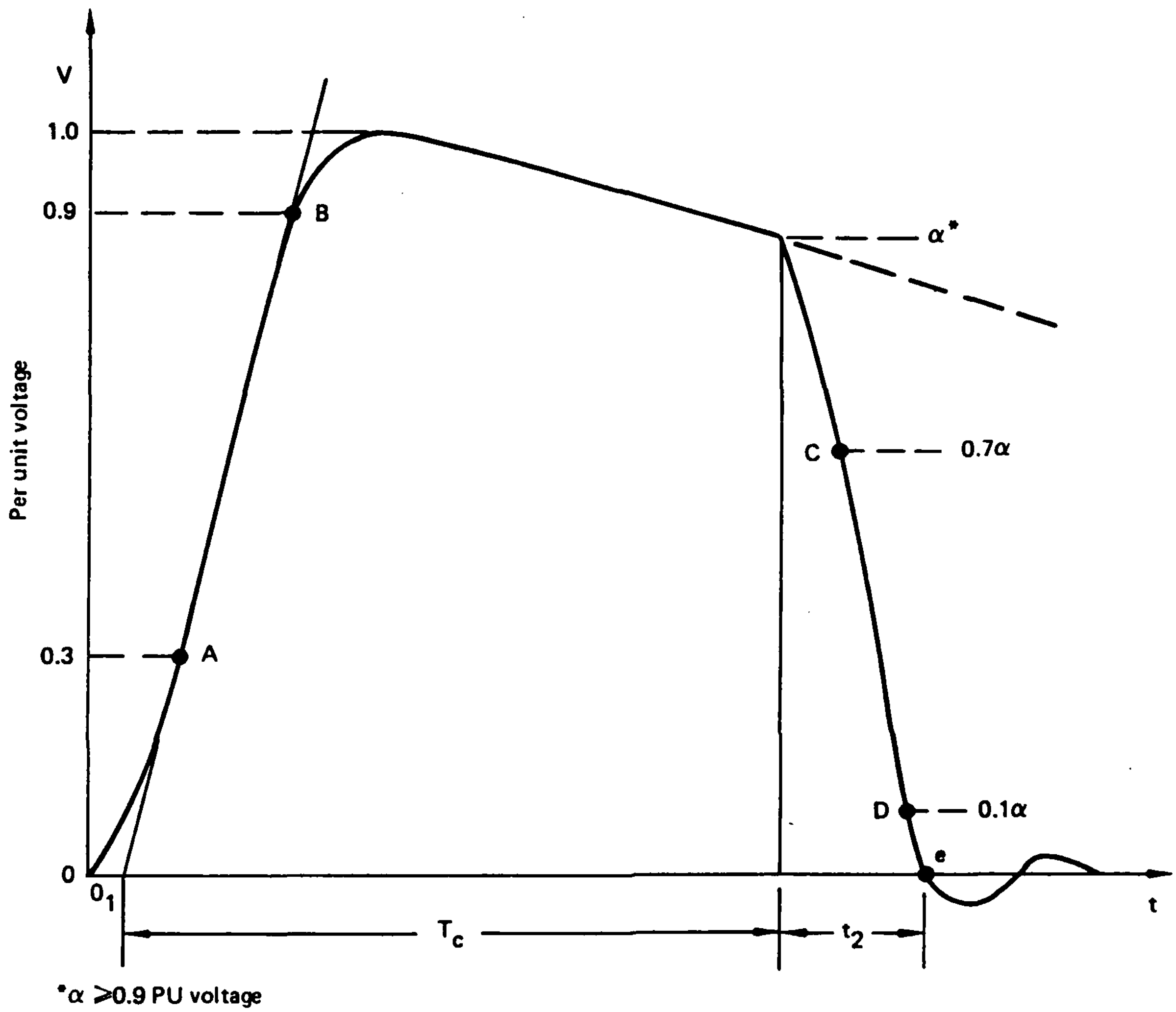


*Figure 2. Chopped Pulse*

TABLE 1. PULSE DURATION VARIABLES

| Configuration | Rise Time<br>$t$ | Dwell Time Continuously Variable<br>$t_C$ | Fall Time<br>$t_2$ |
|---|---|---|---|
| 1** | 10 ns | * | 100 ns |
| 2 | 50 ns | 100 - 300 ns | 50 ns |
| 3 | 250 ns | 0.5 - 1.5 μs | 250 ns |
| 4 | 0.9 μs | 5 - 20 μs | 0.9 μs |
| 5 | 1.2 μs | * | 50 μs |
| 6 | 100 μs | * | 2500 μs |
| 7 | 500 μs | * | 2500 μs |

* denotes double exponential waveform

** Maximum loads for 1 will be no greater than 100 picoforad. The test article will be installed in the test chamber for this test.

3.4.2.8 Life Expectancy - Life expectancy of all components should be at least 100,000 discharges at 100% voltages assuming normal maintenance and replacement of parts.

3.4.2.9 Waveform repeatability - Waveform output repeatability shall be ± 10%.

3.4.2.10 Ripple - Ripple voltage shall not exceed 10% for configurations 4 through 7 of Table 1 and 15% for configurations 1 through 3 of Table 1.

3.4.3 Measurements - Voltage measurements at the pulse test set output shall be made using a voltage divider with a matched high voltage lead or equivalent.

3.4.3.1 Voltage divider - The voltage ratio shall be 1000:1 within ±5%.

3.4.3.2 Output - BNC receptacles or equivalent shall be made available for output voltage and current monitoring with high impedance (1 megohm) analog measuring test equipment. The analog voltage output signal amplitude shall be 400 volts maximum.

3.4.3.3 Signal conditioning - The signal shall be shielded with a low impedance radio frequency path to ground and across all mechanical discontinuities. The processor shall operate following impulse spikes generated by partial discharges, momentary short circuits, and starting transients within the pulse generator electrical circuits. All signal inputs will be fiber optically connected externally to the high voltage, or shall be designed with a sufficiently low impedance path to ground to protect the signal circuits.

3.4.3.4 Display - The output of the signal processor shall be compatible with the input to a Tektronix R7633 with 7A24, 7B53A, and 7D12+M2 plugins or equivalent. The display shall be integrated into the control console. The manufacturer shall indicate in their bid whether this equipment is supplied or GFE.

3.4.3.5 Isolation - The output power lines shall be electrically isolated from the input power lines.

3.4.3.6 Current probe - The vendor shall provide an output current monitoring probe with an accuracy of at least ±5 percent. Its output shall be calibrated in volts per amperes suitable for connection to the above specified oscilloscope input.

## 3.5 Design and Construction

3.5.1 Configuration - The pulse test set shall consist of a control console, a test chamber, and a pulse generator (containing input and output power connections). The pulse generator and dc charging supply shall be contained within a single dust tight enclosure. The output shall feed through to the attached test chamber.

3.5.2 Output - The high voltage output connector shall be coaxial, horizontal, and 4 to 7 feet above the base.

3.5.3 Air supply - Factory low pressure air supply at 100 psi is available.

3.5.3.1 Pressurized gas - Other bottled dry gases are available.

3.5.4 Control console - The control console shall be located remotely (at least 75 ft) from the high voltage section. The primary AC power connections shall be made to the high voltage section. As a minimum, the following control console displays shall be shown.

a) A light to indicate primary power on.
b) Indicating control pushbuttons to open and close the circuit breakers.
c) Charge voltage meter.
d) State of charge meter.
e) Safety switches.
f) High voltage "ON".
g) Hold switch.

3.5.5 Control instruments - The control console shall provide a D.C. charging voltage and charging current indicator with an accuracy of at least ±3 percent.

3.5.7 Trigger - An auxiliary trigger pulse with a minimum width of one microsecond shall be available for instrumentation system synchronization.

3.5.8 Manual trigger - The control console shall include a manual trigger to fire the pulse generator with an auxiliary external trigger input activated by a 10 to 20 volt, 10 $\mu$ sec square wave pulse with a 50$\Omega$ input impedance.

3.5.9 Charge abort - If charging is aborted, an automatic unload circuit shall immediately disconnect the power supplies and discharge the capacitors. Upon activation of the unload circuit, capacitors shall be completely discharged in not more than 5 seconds. Unloading shall occur after the dc power supplies are turned off.

3.5.10 Interlock circuit - An interlock circuit shall be provided to prevent simultaneous operation of the unload and the firing circuits.

3.5.11 Auxiliary interlock - An auxiliary interlock input shall be provided to unload if the auxiliary interlock is opened (e.g. for a door interlock, etc.).

3.5.12 Physical Dimensions - No major subassembly shall have dimensions greater than 4' wide, 8' long, and 5' high.

3.5.13 Test Chamber - The pulse generator output shall be terminated into a 100 ±10 cubic foot test chamber. As an example, approximately 4' w X 4' h X 6'. The geometry of this test chamber shall be configured to enhance the fast rise time of the output pulse. A door for test article connection shall be no smaller than 3' X 3'. The chamber shall be capable of containing insulating gas if required for high-voltage design considerations.

3.5.14 Mounting and terminal screws - All screws shall be English dimensional units and be NC or NF standard threads. Non-conductive screws shall be utilized where required for high-voltage design considerations.

3.5.15 Terminals

3.5.15.1 Solder terminals - Solder terminals may be of any shape and shall be capable of complying with ASTM/NEMA solderability requirements.

3.5.15.2 Case as terminal - When the case is used as a terminal, any protective coating applied to the mounting surfaces shall be such as to provide a direct conducting path for an electric current from the case to the surface on which it is mounted.

3.5.15.3 Screw terminals - When specified, external screw terminals shall be supplied with two nuts, two flat washers, and one lockwasher.

3.5.15.4 Corona protected bushing insulator - When specified, terminals shall be supplied with a corona suppressor where the terminal and terminal hardware are shielded by an angle of at least 30 degrees by corona suppressor cavity. Terminal hardware shall consist of two nuts, one flat washer, and one lock washer, or shall consist of one flat washer, one lock washer and one cap screw. The terminal post shall not have external threads below the corona suppressor in the bushing. The height of the terminal assembly shall be the distance from the top of the corona suppressor to the terminal mounting surface.

3.5.16 Lifting, moving, and jacking means.

3.5.16.1 Safety factor - Lifting and jacking means shall be designed to provide a safety factor of 5. This safety factor is the ratio of the ultimate stress of the material used to the working stress. The working stress is the maximum combined stress developed in the lifting facilities by the static load of the component being lifted.

3.5.16.2 Lifting means - Lifting means shall be provided for lifting the cover separately, and also for lifting the internal assemblies from the housing using one to four lifting cables.

Lifting means shall be designed for lifting with one to four slings at a maximum angle of 30 degrees with respect to the vertical. The bearing surfaces of the enclosure shall be free from sharp edges and shall be provided with a hole having a minimum diameter of 13/16 inch (20.6 mm) for guying purposes.

3.5.16.3 Moving means - The base of the unit shall be of heavy plate or have members forming a channel that will permit rolling in the directions of the centerlines of the segments or handling with a forklift. If reasonable, enclosures may be equipped with permanent, locking style, rubber tired casters.

3.5.16.4 Jacking means - Jacking means shall be located near the extreme ends of the corners of the case.

3.5.16.5 Mounting studs - When specified, external mounting studs shall be provided with a flat washer and locknut, or with a flat washer, lockwasher, and a nut.

3.5.17 Electrical construction.

3.5.17.1 Cables - All cables between the control console and the high-voltage enclosure shall be bound into a single protective sheath. The connectors on both ends of the cables shall be quick disconnect. All cables and connectors shall have the individual conductors plainly marked in accordance with the drawings.

3.5.17.2 Internal wire leads - Internal wire leads shall be attached to the internal component terminals or case by soldering, welding, brazing, or other methods (e.g. lead-sweating or nylon-coated wires) in such a manner as to provide adequate electrical connection and mechanical strength. Where soft solder is used to provide the electrical connection, wire leads shall be anchored mechanically.

3.5.17.3 Wire bundle ties and clamps - Wire bundle plastic tie wraps shall be used as required.

3.5.17.4 Resistance to soldering heat - When the article is soldered, there shall be no damage to the insulation or loosening of windings or terminals.

3.5.17.5 Potting, filling, or encapsulating material - The amount and coverage of potting, filling, or encapsulating material used shall be essentially the same for all units of a specific design. Potting, filling, or encapsulating material shall not flow from the case of the article during any of the applicable tests.

3.5.17.6 Grounding - The article shall be grounded by bonding the case(s) to the structure. A common point ground shall be specified for bonding the power source and load in a manner to prevent circulating currents in the ground path, reduce electromagnetic interference, and prevent electrostatic discharges harmful to personnel. A ground path shall provide a path with a current-carrying capacity equal to or greater than that of the input and output conductors.

3.5.17.7 Capacitor - The high-voltage capacitors shall be fully documented and applied in accordance with the manufacturer's ratings.

3.5.17.8 Surge arresters - If required, a surge arrestor ground pad consisting of a tank ground pad, mounted near the high voltage terminals shall be available for surge protection.

3.6 High voltage design and test.

3.6.1 Insulation resistance - When measured as specified in 4.11.1, the minimum insulation resistance shall be greater than the value specified for the insulation system in the applicable specification.

3.6.2 Dielectric withstanding voltage - When tested as specified in 4.11.2, there shall be no evidence of arcing, flashover, breakdown or insulation, or damage.

3.6.3 Partial discharges - When tested as outlined in 4.11.3, the partial discharge maximum magnitudes shall not exceed the values specified.

3.7 Electromagnetic compatibility - The unit shall be designed to minimize the generation of electromagnetic interference. The design shall provide sufficient shielding to reduce the conducted/radiated electromagnetic interference to values that have no influence on the control and measuring circuits and instrumentation when operated at the maximum energy storage and discharge.

3.8 Overload - When tested as specified in 4.7.2.7, there shall be no evidence of physical damage. The pulse test set shall be capable of withstanding an inadvertent short circuit on the output, e.g. test article failure. The short circuit shall not degrade future pulse test set performance.

3.9 Visual and mechanical examination (post test) - When examined as specified in 4.6.1, the surface shall have no peeling, flaking, chipping, cracking, crazing, or other impairment of the protective coating. There shall be no leakage of the filling material, no evidence of other physical damage, such as cracks, bursting, or bulging of the case or corrosion affecting the mechanical or electrical operation of the units. All damage shall be repaired before shipment.

3.10 Marking - The HV pulse test set shall be marked with the part number, manufacturer's part number, manufacturer's code symbol, terminal identification and date code and lot symbols. Markings shall remain legible after all tests. All pieces of equipment shall be permanently and plainly marked for replacement identification in the event of failure. All test points on control and instrumentation circuit boards shall be brought out so as to be easily accessible for troubleshooting and plainly labeled in accordance with the schematics and maintenance manuals. Interconnection cables shall be similarly identified with markings protected from environmental damage.

3.10.1 Serial number - The HV pulse test set shall have a serial number. All design and test data shall be traceable to the serial number.

3.11 Manufacturer's data - The manufacturer shall submit with his bid the following engineering design information.

a) Test set circuit configuration.
b) Energy storage capacitor types, switching component types, and voltage divider ratings, output bushing geometry, and instrumentation and control nomenclature.
c) Dimensions, weight, and mounting configuration of the pulse test set and test chamber.
d) A detailed functional description of each area of the overall design including design logic, block diagram, and operational theory where appropriate.
e) A description of all tests for which the manufacturer is liable, including test procedure and where performed.
f) Estimated delivery time from contract award date.

3.12 Workmanship - The standard of workmanship that the pulse test set shall meet in terms of uniformity, freedom from defects, and appearance of the finished product shall be defined as a whole by the specifications in this document and the materials, parts, tools, and labor for fabrication and assembly of components, surface finish and testing of individual components, subassemblies, and equipment as specified by the manufacturer. Unless otherwise specified, these criteria shall be the logical basis for rejection in those cases where workmanship as determined by the Air Force is such that the pulse test set is unsuitable for the purposes intended. All details of workmanship shall be of the highest grade consistent with good commercial practice. There shall be no cracks, dents, scratches, burns, sharp edges, loose parts, foreign matter, or any other evidence of poor workmanship.

3.12.1 Safety - The equipment shall provide a safe environment to personnel in both the operating and maintenance modes. This is to be achieved by design safety features, safety placards on the equipment, and by safety cautions and instructions in the operating and maintenance procedures. Particular attention shall be directed to the hazards of high voltage and stored electrical energy.

3.13 Shorting means - A manual safety device shall be provided for short circuiting the generator output terminals to electrical ground. This shall be a backup to an automatic means for deenergizing all of the energy storage elements.

3.14 X-ray emissions - Vendor shall document x-ray emissions levels external to the enclosures. The emissions shall be in compliance with the latest OSHA requirements.

3.15 Operation and Maintenance Manuals - The manufacturer shall provide manuals to the Air Force for the pulse test set for use in the planned maintenance and support environment. Three sets of manuals shall be shipped with the equipment. A reproducible master shall be mailed to the Air Force using agency separately. The manuals shall include, but not be limited to, the following:

Safety considerations during: Installation, operation.
Description.
Theory of operation.
Storage requirements.
Installation.
Start-up procedure.
Operating instructions.
Maintenance: Preventive, corrective, periodic.
Bill of materials.
Recommended spare parts.
Manufacturer's data on purchased parts.
Generic part numbers on all semiconductor devices.
Outline drawings: Overall dimensions.
Acceptance test reports.

As built schematic diagrams of complete system and all subassemblies and circuit board cards.

As built wiring diagrams, and interconnection information with wire, terminal, and test point identification clearly shown for connection of field wiring and troubleshooting.

3.15.1 Acceptance Test Results - Any of the above documents which are larger than 8 1/2" x 11" shall be folded to that size. All documents shall be punched with holes to fit a standard 3-ring binder.

3.16 Schedule - A production schedule shall be submitted to the Air Force 30 days after award of contract. The schedule shall show completion dates of major assemblies, testing dates for subassemblies, final assembly date, final test dates, and the final delivery date. The Air Force shall be advised of any schedule revisions during the course of the contract, as soon as the necessity for the decision or change becomes apparent. It is the intent of the Air Force to operate this procurement in a total "no surprises" mode. At the discretion of the Air Force using agency, a post award, pre-design, kick off meeting will be held to review the specifications with the manufacturer under contract. A second meeting shall be conducted at WPAFB to give the Air Force an opportunity to review the design and layout of all man/machine interfaces; i.e., control panel layout, interlocks, alarms, instruments, etc. This design review meeting shall take place as early in the design phase as practically possible.

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection - Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.1.1 Test equipment and inspection facilities - Test and measuring equipment and inspection facilities of sufficient accuracy, quality, and quantity to permit performance of the required inspection shall be established and maintained by the inspection facility. The establishment and maintenance of a calibration system to control the accuracy of the measuring and test equipment shall be traceable to the National Bureau of Standards.

4.1.2 Acceptance testing - The Government shall be notified 30 days in advance to final inspection and acceptance testing. The absence of Government personnel during acceptance testing does not relinquish the manufacturer's responsibility for testing conformance compliance. The manufacturer shall submit for approval, 60 days prior to final acceptance testing, the detailed final acceptance test plan.

4.2 Classification of inspection - The inspections specified herein are classified as follows:

a. Materials inspection (see 4.3).
b. Qualification inspection (see 4.5).

4.3 Materials inspection - Materials inspection shall consist of obtaining the manufacturers certification that the materials used in fabricating the HV pulse test set are in accordance with the latest ASTM or NEMA requirements prior to such fabrication.

TABLE 2. MATERIALS INSPECTION

| MATERIALS | REQUIREMENT PARAGRAPH |
|---|---|
| Insulating Material: | |
| Laminated phenolic | 3.3.2.1 |
| Molded phenolic or melamine | 3.3.2.2 |
| Ceramic (external use) | 3.3.2.3 |
| Laminated plastic sheet | 3.3.2.4 |
| Insulating gases | 3.3.2.6 |
| Wire: | |
| Magnet wire | 3.3.7.1 |
| Insulated wire | 3.3.7.2 |
| Wire supports | 3.3.7.3 |

4.4 Inspection conditions - Unless otherwise specified herein, all inspections shall be performed in accordance with good industrial practice.

4.4.1 Test frequency - When an ac power source frequency is specified herein, the frequency used shall be within ±2 percent of the nominal value. The test frequency shall be the geometric mean of the specified frequency range or a lower value selected by the manufacturer.

4.4.2 Test voltage - When the rated output voltages are specified with a tolerance, the test voltage shall be the rated voltage (e.g. 100,000 ±3000 volts shall be tested at 100,000 ±3% volts). For dielectric withstanding voltage tests, the peak of the voltage applied shall not exceed by more than 5 percent the peak of the pure sine voltage.

4.5 Qualification inspection - The manufacturer shall have an effective program to assure the quality performance, workmanship, and reliability of all work, services, material, and equipment associated with the power supply. As a minimum, this shall include a documented QA plan for meeting these requirements and the use of competent personnel (certified when required by applicable standards). The manufacturer's QA plan and procedures shall be available for review by the Air Force if requested.

4.5.1 Test reports - The HV test set shall be accompanied with certified test reports including a statement that the unit has been subjected to the tests and comply with this specification. Reports shall be included in operations and maintenance manuals as specified in 3.14.

4.5.2 Acceptance test and/or retest qualification - A period of 60 days will be allowed for any necessary modifications, repair, and retesting required after any failure of an initial acceptance test as specified herein. Any changes required shall be fully documented in the "as built" drawings. The Air Force shall be notified 15 days prior to retest.

4.5.3 Inspection of preparation for delivery - The inspection of the preservation-packaging and interior package marking shall be in accordance with the quality conformance inspection requirements of Section 5. The inspection of the packing and marking for shipment and storage shall be in accordance with best commercial practice for high value electronic equipment. Acceptance testing will occur prior to any shipment of completed equipment.

4.6 Methods of examination and test

4.6.1 Visual and mechanical examination

4.6.1.1 External - Each module shall be examined to verify that the materials, external design and construction, physical dimensions, weight, marking, and workmanship are in accordance with the applicable requirements in Section 3.

4.6.1.2 Internal - The accessable internal parts of the modules shall be examined to verify that the materials, internal design and construction, physical dimensions, marking, and workmanship are in accordance with the applicable requirements in Section 3. Internal design, construction, and workmanship will include inspection for:

a. Dirt and debris.
b. Loose ends on wire cooling lacing and ties.

c. Rough surfaces on corona shields.

d. Correct spacing of high voltage wiring.

e. Burns, scratches, foreign deposits, and delamination of insulating boards.

f. Grease, oil, or water leaks.

4.6.1.3 Post-test - Each module shall be examined to verify that the protective coating, filling material, and case construction are in accordance with the applicable requirements (see 4.3).

4.7 Electrical performance

4.7.1 Test conditions

4.7.1.1 Altitude and temperature - The steady state output characteristics tests shall be conducted at ambient temperature of 20°C ± 10°C and ambient altitude conditions.

4.7.1.2 Warm up - Prior to each test, unless otherwise specified, the equipment shall be temperature stabilized at 23° ± 5°C for at least 15 minutes. Warmup time to operating temperature shall not exceed 10 minutes.

4.7.1.3 Input voltage - Nominal input shall be from a 120/208 ±15% volt, three phase, 60 Hz or a 277/480 ±15% volt, three-phase, 60 Hz commercial power source.

4.7.1.4 Instrumentation - Instruments used to measure transient time, voltage, wave shape, and current shall have an accuracy of ±5 percent or less. Instruments shall have been calibrated within 30 days of the date on which the tests described in paragraphs 4.8 are conducted unless the instrument history records provide sufficient evidence to support longer periods between calibration. All meter indications shall be equal to or within the tolerance range specified within this specification. All calibration instrumentation shall have calibrations traceable to the National Bureau of Standards.

4.7.1.5 Electrical measurements - Steady state electrical measurements of volts, amperes, ohms, and watts shall be made with laboratory type instruments having an accuracy of 3 percent of full scale.

All photographs of oscilloscope traces shall show the sweep time, vertical deflection sensitivity, rise time of the scope, and amplifier, where applicable, and frequency response at the 3 dB point.

All oscillograph recordings shall show a calibration trace, and the calculated values of instantaneous voltage, current, and power from the recordings shall be accurate to ±5 percent. The frequency response of all recording instruments and oscillographs used in the tests shall be included in the test data.

4.7.1.6 Temperature measurements - The accuracy of the temperature measurements shall be ±2°C.

4.7.2 Output characteristics - The ability of the facility to deliver the pulses delineated in Figures 1 and 2 and Table I shall be demonstrated. Photographs of the oscilloscope composite waveforms, using simulated load circuits of the values delineated in paragraph 3.4.1. After these runs, the test article shall be tested with output of 5%, 10%, 25%, 50%, 75%, and 100% maximum output load. The unit shall be capable of operating at each load level without altering the wave shape of Figures 1 and 2. The unit can be cooled to normal ambient conditions before the start of each test. Measurements shall be taken and recorded of the input voltage, input current, output voltage, output current, and critical component temperatures which indicate the temperature rise of the unit.

4.7.2.1 Pulse - The pulse rise time, dwell time, and fall time shall be measured and shown to conform to the values delineated in Figures 1 and 2 and Table 1. Each pulse shape shall be repeated a minimum of three times. Pulses conforming to the shapes, magnitudes, rise, dwell, and fall times delineated in paragraph 3.4.2.4 within the tolerances delineated in paragraph 3.4.2.7 shall be acceptable. In the event one pulse does not conform to the specified requirements, two more pulses shall be made. Any three pulses of the 5 pulses shall be considered acceptable performance. Loads for each pulse series shall be performed at 10% and maximum load.

4.7.2.2 Pulse rise time - The method of measurement for the pulse rise time (see Figure 1) shall be as follows:

(a) Obtain a calibrated (time and amplitude) picture of the waveform including the pulse.
(b) Draw the zero axis of the pulse.
(c) Find the peak pulse amplitude.
(d) Draw two lines parallel to the zero axis and spaced on each side of the zero axis by 90 percent and 30 percent, or other specified fraction of the peak pulse amplitude and two parallel lines spaced on each side of the zero axis by 90 percent and 30 percent, or other specified fraction of the peak pulse amplitude. The time interval between the first point of intersection of the pulse trace at the 30 percent rise line and the point of intersection of the pulse trace at the 90 percent line is the pulse rise time.

4.7.2.3 Pulse duration - The method of measurement for the pulse duration (see Figure 1) shall be as follows:

(a) Obtain a calibrated (time and amplitude) picture of the waveform including the pulse.
(b) Draw the zero axis of the pulse.
(c) Find the peak pulse amplitude.
(d) Draw two lines parallel to the zero axis spaced on each side of the zero axis at 90 percent, or other specified fraction of the peak pulse amplitude. Draw a vertical line perpendicular to the zero axis and intersecting the waveform decay breakpoint (where exponential tail has been chopped). The time interval between the virtual origin and the vertical line's intersection with the zero axis is the pulse duration.

4.7.2.4 Peak pulse amplitude - The method of measurement for the peak pulse amplitude (see Figure 1) shall be as follows:

(a) Obtain a calibrated (time and amplitude) picture of the waveform including the pulse.
(b) Draw the zero axis of the pulse.
(c) Find the maximum departure of the pulse trace from the zero axis (regardless of polarity sign). This departure is the peak pulse amplitude.

4.7.2.5 Pulse decay time - The method of measurement for the pulse decay time (see Figure 1) shall be as follows:

(a) Obtain a calibrated (time and amplitude) picture of the waveform including the pulse.
(b) Draw the zero axis of the pulse.
(c) Find the peak pulse amplitude.
(d) Draw two lines parallel to the zero axis spaced on each side of zero axis by 10 percent or other specified fraction (see 3.1), of the peak pulse amplitude. The time interval between the last point of the intersection of the pulse trace and either 90 percent line and the last point of intersection of the pulse trace and either 10 percent line is the pulse decay time.

4.7.2.6 Tolerances - The pulse parameters shall conform to the tolerances delineated in paragraph 3.4.2.7. Deviations at any voltage level pulse shape or duration shall be acceptable upon advisement by the procuring activity.

4.7.2.7 Repetition rate - A demonstration shall be made to verify a pulse repetition rate of one pulse every 5 minutes or less. The pulses shall be made with

(a) maximum voltage 400 kV,
(b) maximum rise time of 500 microseconds,
(c) maximum fall time of 2500 microseconds.

4.7.3 Signal processor - The signal processor shall demonstrate its ability to perform its instrumentation and measuring function as defined in paragraph 3.4.3.3.

4.7.4 Isolation - The input power leads shall be tested for isolation from the output power leads to demonstrate compliance with 3.4.3.5 by megger test using 2500 V dc. Isolation resistance shall exceed 10,000 megohms.

4.7.5 Control instruments - The control instruments shall demonstrate their ability to accurately select the correct pulse parameters and then control the operation of the facility. Displays and switches shall be visible to the console operators at all times during the system operation. Appropriate alarms and safety devices shall be shown to operate to warn personnel of the high voltage test, and to discharge the system in case of malfunction or incorrect procedure.

4.7.5.1 Safety control - An automatic grounding system shall be available to ground all HV modules or lines before operators are admitted into the high voltage area. An additional hand-held ground wand shall be available to ground critical HV component before the operators attempt repair or maintenance, or test article connection.

4.7.5.2 Manual trigger - The manual trigger shall be demonstrated to accurately operate the HV test facility.

4.7.5.3 Trigger pulses - The calibrated auxiliary instrumentation trigger pulse shall be tested for accuracy and operation for each pulse condition shown in paragraph 4.7.2.1. In addition, there shall be generated a firing trigger pulse with delay adjustable between 0 and 1 microsecond with a 1% resolution.

4.7.6 Interlock circuit - The interlock circuit to the facility room shall interface with the HV pulse test set. A demonstration shall be made to validate the interlock operation.

4.7.6.1 Auxiliary interlock - The operation of the auxiliary interlock system shall be demonstrated.

4.7.6.2 Charging circuit interlock - The operation of the charging circuit interlock shall be demonstrated. The operation of the unloading circuit shall be made a part of the demonstration.

4.8 Mechanical tests

4.8.1 Tank seals - Any unit or subassembly which shows evidence of leakage may be given remedial treatment. After completion of the treatment, the seal test shall be repeated as evidence that such remedial treatment is adequate. All other units in the lot which have been given similar satisfactory remedial treatment shall be acceptable.

4.8.1.1 Gas-filled units - The test article shall be tested to contain the pressuring gas.

4.8.2 Auxiliary components - Auxiliary components include pressure and temperature transducers, fans, pumps, and controls.

4.8.2.1 Transducers - Any pressure-vacuum transducer and any liquid temperature transducer shall be tested at least three times during qualification. No damage to the test assembly or sensor shall result from these tests.

4.8.2.2 Pressure vacuum bleeder - Any pressure vacuum bleeder valve shall be tested at least three times during qualification. No damage to the test assembly or sensors shall result from these tests.

4.8.2.3 Motors - Fan, pump, and control motors shall be tested for electrical continuity. Fan and pump motors shall function, without failure, during the life test.

4.8.3 Tank design proof pressure - Proof pressure cycle tests shall be conducted. The temperature of the test shall be stabilized and maintained at a temperature of 20°C ± 10°C throughout the test.

As an alternative, the test may be conducted at room temperature if the test pressure is suitably adjusted to account for temperature effects on strength and fracture toughness.

Proof pressure cycles shall consist of raising the tank internal pressure to 1.5 times the maximum operating pressure specified in the detailed specification, maintaining this pressure for 5 minutes and then decreasing the pressure to 0 psig. There shall be no evidence of leakage during the test.

At the conclusion of the test there shall be no evidence of yielding of the tank material. The volumetric change shall be determined and recorded. Permanent volumetric change shall not exceed 0.2%.

4.8.4 Cooling - This test shall be performed during the steady state conformance operating time tests of paragraph 4.7.2.1. The test shall be performed with coolant temperatures and equipment temperatures stabilized at ambient temperature of 23 ± 5°C.

4.8.5 Terminals - The article subassemblies shall be tested as specified in 4.8.5.1 through 4.8.5.3, inclusive, as applicable. After each test, the terminals shall be examined for loosending and rupturing and other mechanical damage. Unless otherwise specified, all terminals on each test sample shall be subjected to the following tests, or to a maximum of four identical terminals per sample.

4.8.5.1 Solid-wire and insulated wire lead terminals - The test article subassemblies and auxiliary components, such as sensors and motors, shall be inspected to be in accordance with best quality industrial practice.

4.8.5.2 Solder terminals - Auxiliary components shall be inspected to be in accordance with best quality industrial practice.

4.8.5.3 Flat solder terminals - Any flat solder terminals shall be inspected to be in accordance with best quality industrial practice.

4.8.6 Solderability - Solder connections for the test article shall be made and tested in accordance with best quality commercial practice.

4.9 Electrical Tests

4.9.1 Grounding and bonding - Resistance measurements shall be conducted on at least two subassembly grounds, representative of the test article. Visual inspection shall be conducted in all the test article subassembly and assembly grounds and bonds to the room structure. The bonds selected shall be tested with a direct current source. The measured impedance with current passing through the joint shall be less than 2.5 milliohms, maximum, between the test set assembly or subassembly and the structure.

4.9.2 Capacitors - Capacitors shall be tested to determine conformance with 3.5.17.7.

4.9.3 Surge arrestors - Surge arrestors shall be disconnected during dielectric withstanding voltage tests.

4.10 H.V. Evaluation tests

4.10.1 Dielectric withstanding voltage - The HV pulse test set and subassemblies shall be tested in accordance with ASTM D-149. The following details and exceptions shall apply:

a. Magnitude of test voltage shall be 100% charge voltage.
b. Nature of potential - DC, as applicable.
c. Duration of application of specified test voltage - Minimum of 30 minutes.
d. Examination during and after test - The assembly and subassemblies shall be examined for evidence of arcing, flashover, breakdown of insulation, and damage.

4.10.2 Partial discharges - When specified, the test set shall be tested for parital discharges. Partial discharges shall not exceed the following limits for a 3-minute period at 100% charge voltage.

| Voltage KV | Limit PC/KV Charge | Counts/Minute Over Limit |
|---|---|---|
| DC | 1.5 | 1 |

The partial discharge detector shall be connected to the test set high voltage charge circuit and the unit shall be tested for partial discharges. Partial discharge peak magnitudes shall be less than the values stated above with the unit supplying 100% charge voltage. The partial discharge test shall be started 30 seconds after rated voltage is stabilized. The output power shall be near zero.

4.11 Electromagnetic interference - At no load and at maximum energy storage the radiated and conducted interference shall not influence the control and measuring circuits on instrumentation during operation.

4.12 Life - The HV pulse test set shall be subjected to 100 full voltage pulses, each cycle of a value selected from Table 1. The unit shall be allowed to cool a maximum of 10 minutes between pulses. Room ambient temperature and pressure shall be maintained within the test facility during the test period. The electrical test circuit shall be devised so that an open circuit or short circuit during the 100 life pulses shall be detected and the time to failure recorded. This test may be performed at any ambient temperature provided that the maximum operating temperature is held with ±10°C and no drafts or varying air velocities are present. During the last pulse of the life test, output voltage shall be tested to demonstrate compliance with the regulation requirement of 3.4.2.7.

4.12.1 High voltage evaluation - Upon completion of the life test, the test article shall be tested for insulation resistance (see 4.7.4), and dielectric withstanding voltage (at atmospheric pressure) (see 4.10.1) using 75 percent maximum charge voltage ASTM D-149 for 30 minutes.

## 5. PREPARATION FOR DELIVERY

Components and assemblies shall be capable of being transported in a packaged condition by any standard method. Components and assemblies shall be protected and capable of withstanding strains, jars, vibrations, and other conditions normally encountered during shipping and installation. All items shall be packed and/or crated for ease of handling and in such a manner as to ensure their protection during shipment. The manufacturer shall identify to the Air Force any characteristics of the equipment which make it unsuitable for normal transportation. The equipment shall be packaged in accordance with best commercial practice for high quality electronic equipment.

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