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HIGH VOLTAGE TESTING: GENERATOR TEST PROCEDURE

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

The "High Voltage Testing: Specifications and Test Procedures" document referred to in this report pertains to high voltage/high power airborne equipment. A test plan was developed to apply the test parameters of said document to a specific high power generator prototype design. This test procedure covers the general high voltage tests required for the high voltage stator coils and assembly in this high power alternating current, three phase generator.

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FOREWORD

Presented herein is the Boeing Aerospace Company's Final Report covering work accomplished on Contract F33615-79-C-2067 for the period of September 24, 1979 through May 1, 1982. This contract is being performed for the Aero Propulsion Laboratory, Air Force Wright Aeronautical Laboratories, Air Force Systems Command, Wright-Patterson AFB, Ohio. The program is under the technical direction of Daniel Schweickart, AFWAL/POOS-2.

Personnel participating in this work for the Boeing Aerospace Company were W. G. Dunbar, the technical leader, and S. W. Silverman, the program manager.

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1.0 PROGRAM OBJECTIVES

The objectives of this program are as follows:

a. Perform high voltage tests on capacitors, cable assemblies and parts, and coils.

b. Design, fabricate, and evaluate a high voltage standard test fixture to be used for measuring the void content in various high voltage insulation systems.

c. Specify and procure a 150 kV, 400 Hz power supply for partial discharge measurements.

d. Update the Tests and Specifications Criteria Documents completed in U.S. Air Force Contract F33615-77-C-2054 to include the findings from the test article evaluations.

e. Develop a high voltage generator test procedure.

f. Update of the Airborne High Voltage Design Guide completed on U.S. Air Force contract F33615-76-C-2008.

g. Devlop a Spacecraft High Voltage Design Guide.

2.0 SCOPE

The major task reported in this volume is to:

- Develop the general high voltage test requirements for a high voltage, high power, alternating current generator.

3.0 BACKGROUND

In contract F33615-77-C-2054, a High Voltage Specifications and Tests criteria document was written for U.S. Air Force airborne power supplies and components which supply megawatts of power at tens of kilovolts to high power/high voltage systems. A generalized power source and power conditioning system is shown in Figure 3.-1 for a turboalternator driven system. However, the turboalternator can be replaced with a MHD power supply. Emphasis has been placed on minimum weight and volume airborne equipment, which imply compact systems with high density packaging.

The eight criteria documents were written in accordance with military specifications for: cables, cable assemblies, capacitors, connectors, converters, power characteristics, power sources, and transformers and inductors.

Included in each criteria document were high voltage tests and test parameters based on insulation design parameters and engineering judgment. In this program test articles were selected which represented components or component parts for the components discusssed in the criteria documents. The selected test articles were:

- Cables
- Cable Assemblies
- Connectors
- Alternator Coil (Sections)
- Alternator Coils
- Transformer Coils
- Power Transformer
- Pulse Transformers
- Capacitors

Each test article was tested for:

- Insulation Resistance
- Dielectric Withstanding Voltage
- Pulse Voltage
- Partial Discharge (Corona)

Following completion of the test program, the Test and Specification Criteria documents were updated to reflect the findings of this test program.

A generator test procedure was developed using the data from the generator coil tests in Volume 1, "Test Program Report", and the generator high voltage test procedure from Volume 2, "Specifications and Procedures", Appendix G, Power Sources. This test procedure covers the general high-voltage tests required for a high-voltage,high-power alternating current generator; one of the selected power sources for the high power system shown in Figure 3.1.

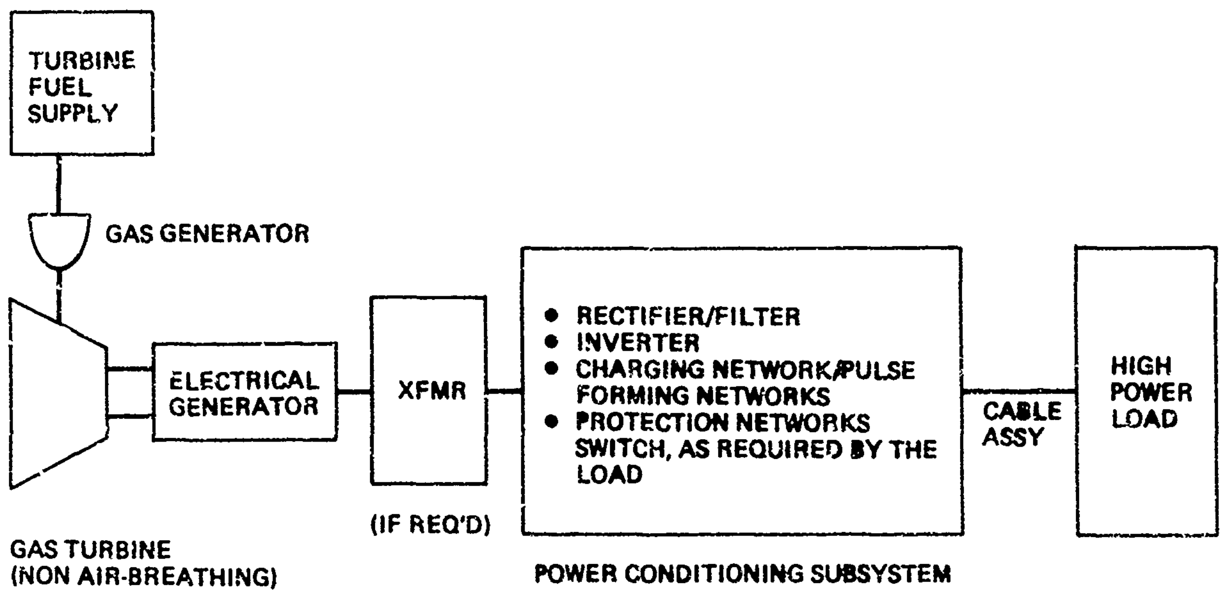

Figure 3-1: High Voltage/High Power Airborne System

4.0 INTRODUCTION

4.1 Scope. This test procedure covers the general high voltage tests required for the high voltage, high power alternating current generator described as one of the selected power sources in U.S. Air Force technical document AFAPL-TR-82-2057, Volume 2, High Voltage Testing: Specifications and Test Procedures.

4.2 Tests. The generator test procedure is new. This report contains the high-voltage tests and test procedures required to evaluate the generator insulation integrity. Generator coils and coil segments were tested as part of the test evaluation reported in Volume 1 of this report. These data were used to determine the tests and test parameter limits to avoid damage to the insulation system, yet give insulation integrity assurance.

4.3 Procedure. This test procedure will cover the generator armature coils in the generator assembly. The armature coils will include, but not be limited to, phase-to-phase tests and coil-to-coil tests. The generator assembly will be for either a prototype, developmental, or production generator.

5.0 REQUIREMENTS

5.1 Description. This test procedure covers the tests required for the insulation integrity of a high power, high voltage, short lifetime alternating current generator for use in or in conjuction with airborne equipment. The pertinent electrical parameters of the generator armature are:

Output Power	20.9 MW
Voltage, L-L	29.6 kV
Voltage, L-N	17.1 kV
Voltage, Coil-to-Coil	2.8 kV
Phase Current	408 amperes
Number of Phases	3
Output Frequency	200 Hz
Useful Life	100 hours
Duty Cycle	5 minutes ON
	10 minutes OFF

5.2 Tests. The following tests shall be performed using production or development generator armature coils:

Insulation resistance
Partial discharge
Dielectric withstanding voltage
Pulse

6.0 TEST PLAN

6.1 General. The generator assembly will be tested according to the acceptance test procedure outlined in document AFAPL-TR-82-2057, Volume 2, High Voltage Testing: Specifications and Test Procedures , and the manufacturer's approved test procedure for the generator.

6.2 Ambient Conditions. All tests shall be performed at 25 $\pm$5°C, atmospheric pressure of 100 $\pm$20 kilopascals, and relative humidity of 90 percent, maximum. The test articles shall be conditioned by remaining at ambient temperature, pressure, and humidity for 4 hours prior to testing.

6.3 Preparation. The test article and high voltage test equipment, high voltage terminations, connections, and exposed surfaces shall be grounded at all times except when under test. High voltage insulators shall be cleaned with alcohol or freon to remove dirt and grease which may cause surface discharges on the insulators, terminations, and interconnects. The test article shall be grounded to the same common ground as the high voltage test equipment. Ground leads shall be next to the floor and made of a braid or wire equivalent to an AWG #6 or larger.

6.4 Safety. The following safety procedures shall be in force during high voltage testing.

6.4.1 Equipment. Test equipment and the test area shall be protected with personnel exclusion barriers and warning lights and/or an interlock system to prevent unauthorized personnel from entering the test area. Warning signs shall be conspicuously posted.

6.4.2 Handling. Because of the high voltage, caution must be exercised in using the HV test equipment and in handling the interconnecting leads to the test article. When connecting or disconnecting the cables, power must be removed from the circuits. Reduce the test voltage to zero volts and turn off the test equipment.

6.4.3 Grounding. Time must be allowed for the high voltages to bleed off before attempting to ground the test equipment and test article. Fifteen (15) seconds is sufficient.

6.4.4 Caution. Before applying power to the test article, all personnel shall be at least six (6) feet away from the high voltage test article and interconnections. The grounding straps shall be removed from the test article after the test director is assured that all safety precautions are met.

7.0 TEST SEQUENCE

The following test sequence shall be followed to gain sufficient information so as to prevent damage to the test article;

A. In-process tests
B. Ancillary equipment tests
C. Generator assembly tests
D. Dynamic test

7.1 In-process Tests. In-process tests are recommended, but not mandatory, to assure insulation integrity of all armature coils prior to interconnection of the coils to form the three phases and the neutral connection. These tests are coil-to-coil and are limited to insulation resistance and dielectric withstanding voltage.

7.2 Ancillary Equipment Tests. High voltage bushings, terminations, and interconnecting cabling should be tested for dielectric withstanding voltage and insulation resistance. These tests are recommended but not mandatory tests. These components may be tested individually or interconnected.

7.3 Generator Test. The generator shall be visually inspected and subjected to the following tests in the following sequence:

A. Insulation resistance
B. Partial discharges
C. Dielectric withstanding voltage
D. Pulse
E. Partial discharges
F. Visual inspection

7.4 Dynamic Test. Six high voltage partial discharge tests are required with the generator operating at full voltage and no load; the partial discharge tests may be conducted before or after the other electrical/mechanical/environmental tests. The partial discharges per phase shall not exceed:

10 per minute over 1,000 pc

None to exceed 10,000 pc

8.0 TESTS

High voltage verification and acceptance tests shall include, but not be limited to the following: insulation resistance, dielectric withstanding voltage, pulse and partial discharges.

8.1 Insulation Resistance. When tested for insulating resistance at a potential of 500 ±50 Vdc, the minimum insulation resistance shall be greater than 1000 megohms.

8.1.1 Procedure. Insulation resistance shall be measured between the generator phases and the generator frame. The three phase leads shall be connected together. A potential of 500 ±50 Vdc shall be applied between adjacent phases and frame. The potential shall be applied for a period of one minute, minimum. However, if a stable reading is obtained in less than one minute, and the results are in excess of 1000 mehogms, the minimum allowable, the test may be terminated.

In a similar manner, a coil-to-coil insulation resistance test may be made in process with the same potential applied between adjacent coils. A reading greater than 1000 mehogms again indicates a "pass" condition.

During the energization period, the insulation resistance shall be measured with a calibrated General Radio, GR-1862C, Insulation Resistance Bridge, or equivalent. The insulation resistance shall be 1000 megohms, minimum.

8.2 Dielectric Withstanding Voltage (DWV). The test articles shall be tested for DWV. When tested to the specified test parameter listed in Table 8-1, for one minute, there shall be no evidence of breakdown, arcing, or other visible damage to the test article. The applied voltage frequency shall be 400 Hz.

8.2.1 Procedure. The three phase leads shall be connected to a high voltage electrical test circuit. The ground lead for the high voltage electrical test circuit shall be connected to the generator frame and ground. The component shall be tested in accordance with MIL-STD-202, Method 301, with the test parameters listed in Table 8-1. The duration of the test shall be one minute ±5 seconds. Leakage current shall be measured and plotted for each insulation configuration.

Table 8-1 Dielectric Withstanding Voltages

	Configuration	Rated Voltage, kV ac	DWV, kV ac
o	Coil-to-Coil (in process)	2.8	4.5 ± 0.2
o	Generator Phases-to-Frame	17.1	27 ± 1

8.2.2 Instruments. DWV measurements shall be made using certified calibrated instruments. Equipment and instruments, or equivalent, are shown in Table 8-2.

Table 8-2 DWV Instruments

	Test Equipment	Manufacturer	Model
o	AC Power Supply	TBD	TBD
o	Electrostatic Voltmeter	G.E.	TBD

8.2.3 Connections. The assembled generator shall be tested with the three phases (A, B, and C) connected together and to the high potential terminal of the high voltage source. The return line of the high voltage source shall be connected to the generator frame.

The in process coil-to-coil test shall be made by applying high voltage between adjacent coils.

8.3 Pulse Test. The test articles shall be subjected to 3 to 5 pulses separated a minimum of one minute. Testing shall be discontinued of there is evidence of breakdown, arcing, or other physical damage to the test articles.

8.3.1 Procedure. Each test article shall be connected to an electrical circuit as specified in IEEE Publication, Number 4, 1978, ANSI C-57, or ANSI C-93. The pulse voltage levels shall be as shown in Table 8-3. The pulse voltage profile shall be similar to that shown in Figure 8-1 or equivalent, using the instrumentation shown in Table 8-4.

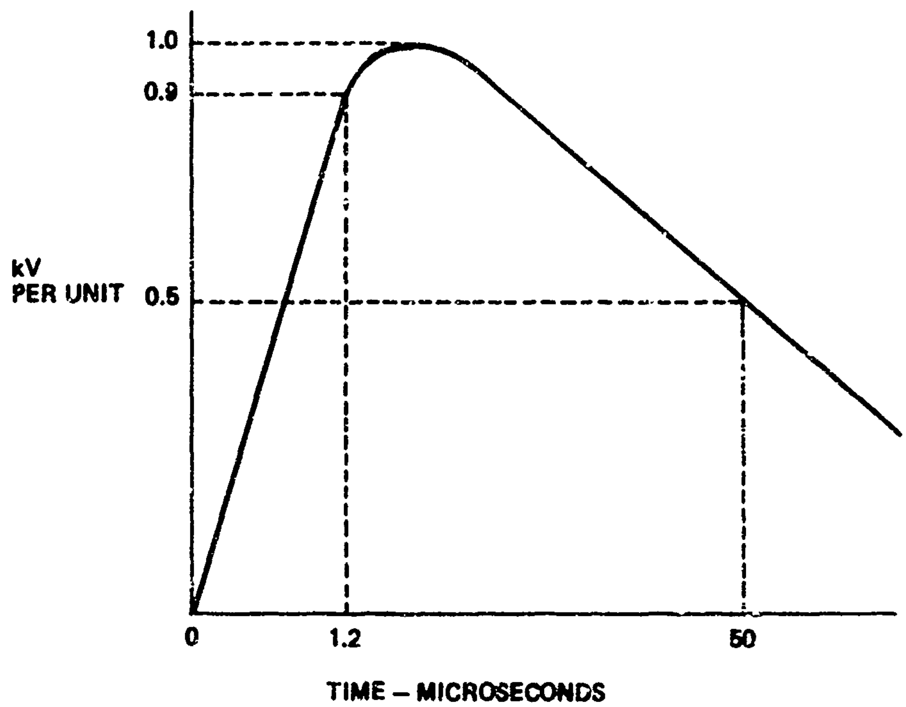

Figure 8-1: Pulse Voltage Wave Shape

Test voltage magnitudes shall be determined from the voltages calculated using the graph from Reference 1, to the values shown in Table 8-3. A calculation of the pulse test voltage is shown in the Appendix. These values were verified by evaluation testing of the generator coils.

Reference 1. R. G. Rhudy, "Impulse Voltage Strength of AC Rotation Machinery", IEEE PES Winter meeting, Atlanta, GA, February, 1981, Paper 81WM 182-5.

Table 8-3 Pulse Voltage Magnitude

Test Article	Rated Voltage, kV	Pulse Voltage (peaks), kV
o Coil-to-Coil	2.8	10
o Generator Phases-to-frame	17.1	60

Table 8-4 Pulse Test Instrumentation

Instrument	Manufacturer	Model
o 100 kV Marx Generator	TBD	TBD
o Oscilloscope	Textronix	TBD

8.3.2 Connections. The assembled generator shall be tested with the three phases (A, B, and C) connected together and to the high potential terminal of the high voltage source. The return line of the high voltage source shall be connected to the generator frame.

8.4 Partial Discharges. The test articles shall be tested for partial discharges. When tested for partial discharges to the specified test parameters, there shall be no evidence of breakdown, arcing, or other visible damage to the test article.

8.4.1 Procedure. Each test article shall be connected to the high voltage circuit of a partial discharge test facility and tested for partial discharges and/or corona. Generator coils shall be tested with ac voltages only. The following details shall apply:

(a) Magnitude of test voltage - 100% rated voltage; as specified in Table 8-5;

(b) Nature of potential - ac;

(c) Points of application of test voltage; as specified in Table 8-6;

(d) Examination after test the test article shall show no visible damage;

(e) Partial discharges shall not exceed more than 10 discharges per minute above 1,000 pc. Partial discharges greater than 10,000 pc are unacceptable;

(f) Duration of application of test voltage:

(1) Applied Voltage Test - Voltage shall be increased from 0.0 volts to operating test voltage at a rate of 500 volts per second. Partial discharges shall be measured for 3 minutes after operating voltage is obtained. Voltage shall be ramped down at the same rate as it was applied.

(2) Dynamic Test - Partial discharges shall be measured for 3 minutes after operating at full voltage for one minute.

Partial discharges within the test article shall be calculated per ASTM D1868 or ASTM D3382-75.

Table 8-5 Partial Discharge Test Voltage

	Test Article	Rated Voltage, kV ac	Test Voltage, kV ac
o	Coil-to-Coil	2.8	2.8
o	Generator		
	Phase-to-Phase	29.6	29.6
	Phase-to-frame	17.1	17.1

8.4.2 Instruments. Partial discharges shall be measured using either the corona test facility located at the U.S. Air Force Aero Propulsion Laboratory AFWAL/POOS-2, which includes a 17000-3 Partial Discharge Detector, a 150 kV (17187-2) Power Separation Filter, 400 Hz (17189-1) Power Separation Filter manufactured by J. G. Biddle Co.; an ND60

Nuclear Data, inc., Multichannel Analyzer; and a 150 kV, 400 Hz Power Supply manufactured by Hipotronics, or an equivalent test facility.

8.4.3 Connections. Test article connections shall be as shown in Table 8-6 and Figure 8-2.

Table 8-6 Partial Discharge Connections

	Test	Connection HV	Negative	Open
o	Dynamic Tests	Phase A	Phase B	Phase C, Frame
		Phase B	Phase C	Phase A, Frame
		Phase C	Phase A	Phase B, Frame
		Phase A	Frame	Phase B and C
		Phase B	Frame	Phase C and A
		Phase C	Frame	Phase A and B
o	Applied Voltage Tests	Phase A,B,C	Frame	None

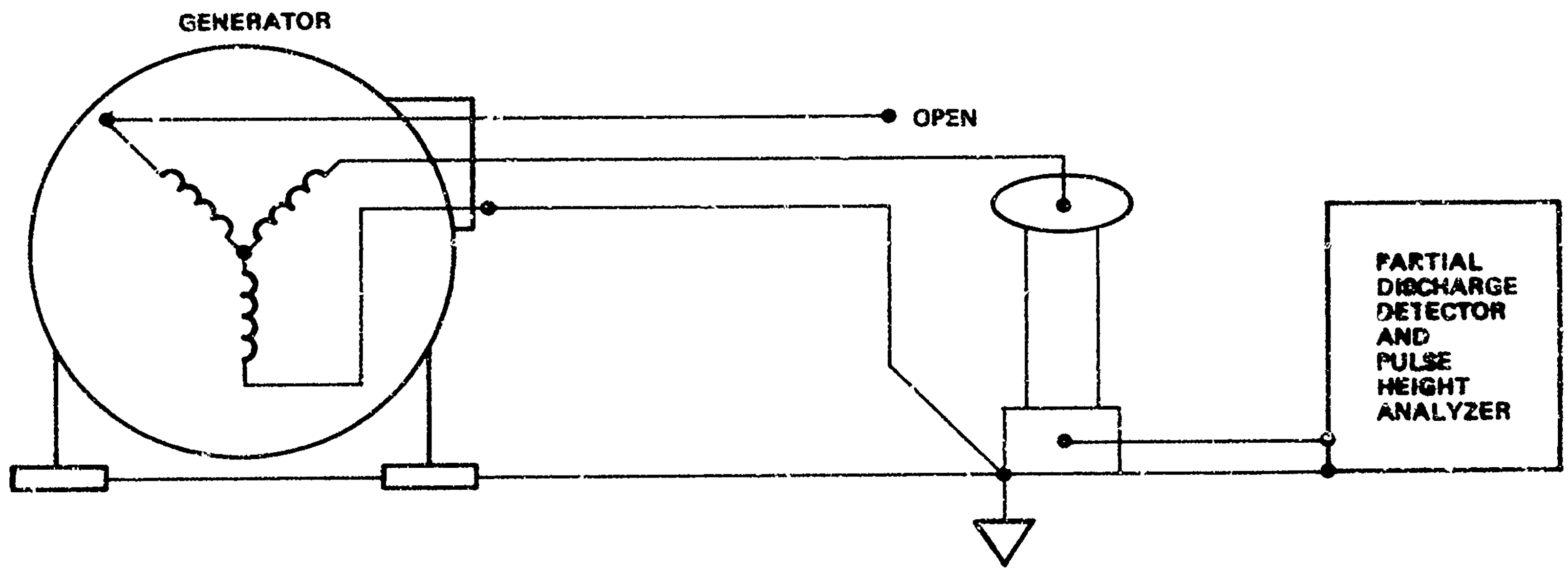

Figure 8-2: Generator — Partial Discharge Test Facility Connection — Dynamic Test

9.0 TEST RESULTS

All test data shall be recorded on Approved Engineering Test Laboratories (AETL) data sheets. Copies of the data sheets are attached. In the event of any failure or deterioration of the article, all pertinent data shall be recorded, such as time, type of failure, test parameter, and environmental conditions. Before testing resumes, engineering approval is required.

APPROVED ENGINEERING TEST LABORATORIES | Date_______________

Laboratory_______________ | Test Director_______________

Test Conductor_______________

Test Article_______________

Model Number_______________

Serial Number_______________

Certification_______________ Paragraph_______________

Test	Connection Positive	Connection Negative	Voltage Applied kVac	Leakage Current Ampere	Time Seconds	Partial Discharge PC	Pass / Fail
Insulation Resistance							
Partial Discharges							
DWV							
Partial Discharges							
Surge							
Partial Discharges							

APPENDIX A
GENERATOR TEST VOLTAGE CALCUALTION

The generator pulse voltage calculations were based upon the findings of the Rotating Machinery Committee of the IEEE Power Engineering Society (PES) presented at the IEEE PES Winter Meeting in Atlanta, Georgia, February, 1981. The findings of the committee were that the original ASA pulse voltage insulation strength for Vac rotating machinery was at least the commercial value, i.e., 1.25 times the crest of the dielectric withstanding voltage (DWV) acceptance test, regardless of pulse waveshape. The DWV of the major insulation to ground is:

$$DWV = \sqrt{2}(1 + 2\,V)\ kV$$

V = generator line-to-neutral (ground) voltage.

Then the pulse voltage is at least:

$$V\ pulse = 1.25\sqrt{2}(1 + 2V)\ kV.$$

Recent study by the working group found that the pulse voltage crest (line-to-ground) per unit voltage varies with the wave front of the applied pulse as shown in Figure A-1. Although the insulation system of some rotating machines are designed to have greater tolerance to pulse voltages than others, the data in Figure A-1 is considered representative of the pulse capability of machines developed to withstand pulse voltages. The data from Figure A-1 were used to calculate the impulse voltage used in this test procedure.

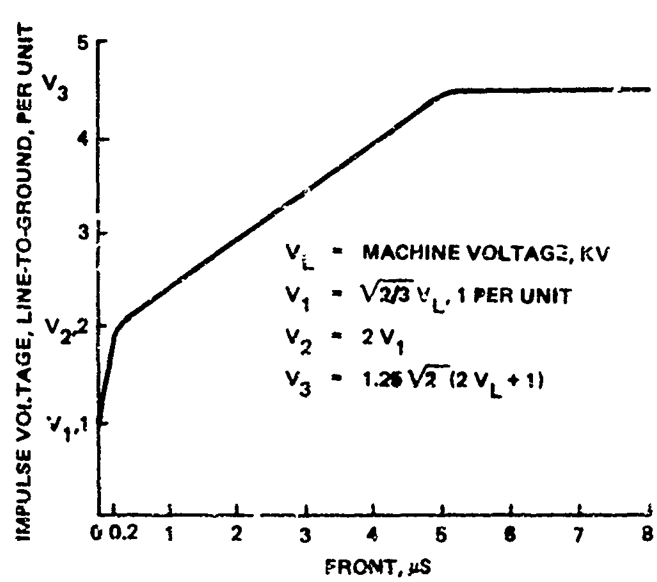

Figure A-1 Machine Pulse Voltage Withstand Voltage

The pulse voltage front has a nominal 1.2 microsecond rise to crest voltage, that is, $t = 1.2\mu s$. From Figure A-1 the slope of the curve for pulses with wave fronts less than $0.02 \mu s$ is

$V_l = 5t + 1$ per unit volts, V_l = pulse voltage line-to-ground. For wave fronts with rise time between 0.02 and $5.0 \mu s$,

$V_l = 0.5t + 1.9$ per unit volts. Using a value of $1.2 \mu s$; $V_l = 0.5(1.2)+1.9 = 2.5$ per unit volts line-to-ground.

For these tests the test voltage can be calculated to be:

$V_l = \sqrt{2}\, V\, (2.5)$

where V is the nominal rated voltage, rms.

then

$V_{l\text{-}cc} = \sqrt{2}\,(2.8 \times 2.5) = 9.92$ kV peak, coil-to-coil.

For the generator phases to frame voltage the value is:

$V_{l\text{-}pf} = \sqrt{2}\,(17.1 \times 2.5) = 60.3$ kV peak, phase-to-frame.

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