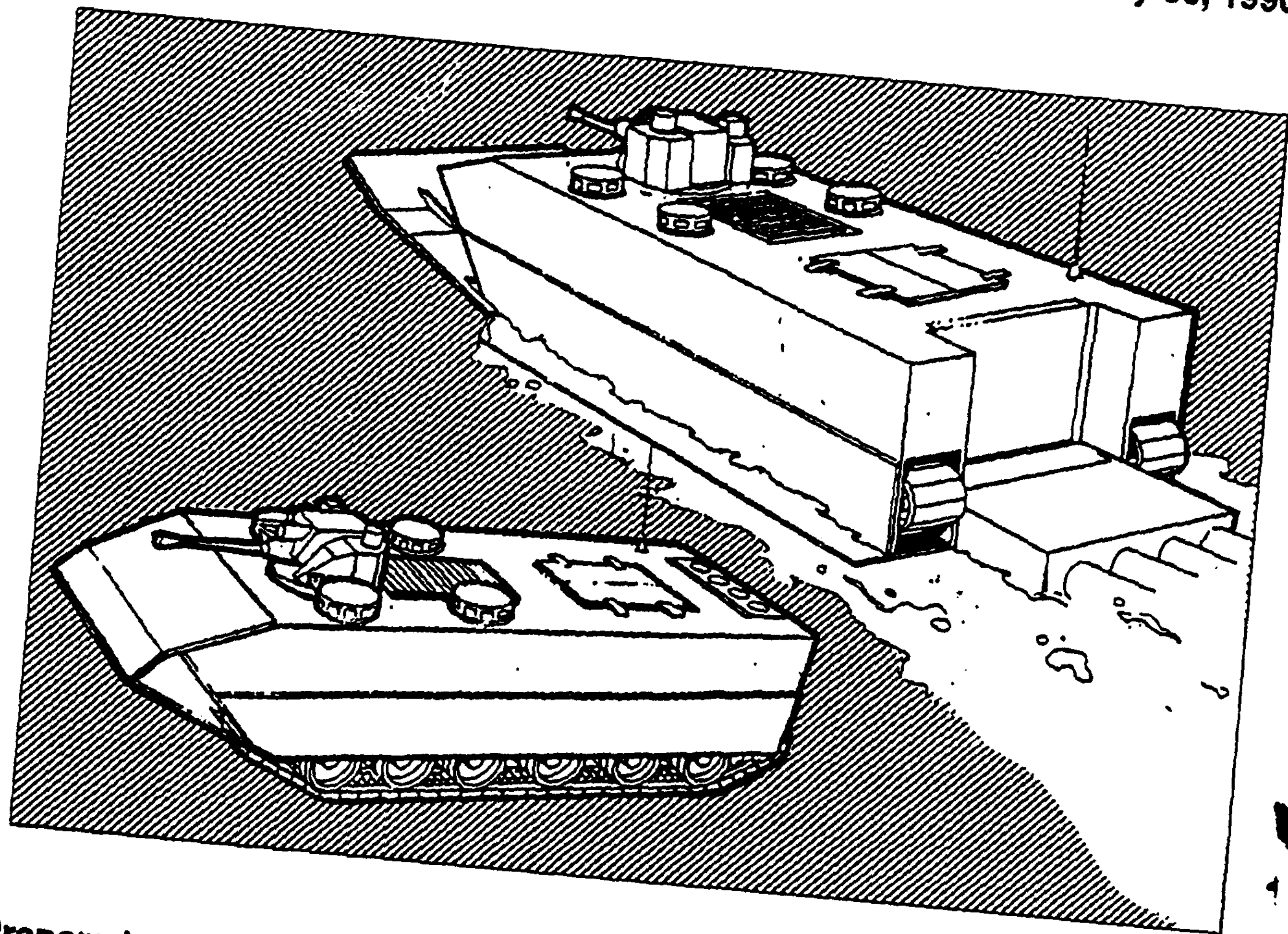
(1)

Amphibious Vehicle Propulsion System Final Report Volume II

For a Propulsion System Demonstrator (PSD) Vehicle

January 30, 1990



Prepared under
Contract No. N00167-86-C-0158
for David Taylor Research Center
Bethesda, Maryland

Westinghouse Electric Corporation
Naval Systems Division
18901 Euclid Avenue
Cleveland, Ohio 44117

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FIELD	GROUP	SUB-GROUP	ELECTRIC DRIVE MILITARY VEHICLE AMPHIBIOUS VEHICLE

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

The David Taylor Research Center has funded the development of an electric drive train for a waterjet propulsion system to demonstrate high water speed in a Marine Corps propulsion system demonstrator vehicle. In the water, this vehicle will be propelled by four waterjets, each rated at 400hp, to provide the required thrust. The task was to design and develop a system that would be compact, lightweight, efficient and available to support vehicle demonstration testing.

A system trade-off study resulted in selection of an approach which uses four identical electric water propulsion modules, consisting of: an AC alternator and alternator controller an AC induction motor with integral speed decreasing gearbox and a coupling that connects the motor/gearbox to the waterjet. This Report documents the hardware Design Effort, Fabrication and Testing completed.

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William Eastman, Technical Manager

Steven Specht, Program Manager

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Volume I and II

Volume I

Volume II

****The design report is continued from volume one.***

20L(27)-5434z

Revision: 3
Date: 1 March 1988

PRELIMINARY

INTERFACE SPECIFICATION

FOR

ELECTRIC WATER PROPULSION SYSTEM FOR

A HIGH SPEED TRACKED AMPHIBIOUS VEHICLE

BY

WESTINGHOUSE OCEANIC DIVISION-
Cleveland Operation
18901 Euclid Avenue
Cleveland, OH 44117

Prepared by: J. Witkowski 3/10/88
J. Witkowski, Technical Director — Date

Approved: J. Triner 3/16/88
J. Triner, Program Manager — Date

APPENDIX I

Interface Specification

INTERFACE SPECIFICATION
MARCH 1, 1988
(REVISION 3)

FOR
ELECTRIC WATER PROPULSION SYSTEM
FOR A HIGH SPEED TRACKED AMPHIBIOUS VEHICLE

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REVISION STATUS SHEET
FOR
INTERFACE SPECIFICATION

REVISION 1
9 MARCH 1987

SECTION	DESCRIPTION
1.1	Change - 28 Ton
2.4.3	Change - 28 Ton
	Clarify - "which includes" additional margin of 20%
2.4.3.2	Change - TBD to Section 2.4.3.3 Ref.
	Add - Coupling shear failure 2.5 times rated torque
2.4.3.3	Change - Shaft torsional shock load to "1.3" x
2.4.4	Change - Power source to 2.0 kW at 28 Volt
	Change - Gearbox to "2500" rpm
2.5	Change - "TBD" to "2.5 step-up"
2.7	Change - "420" volts to "520" volts
	Change - "140" to "-40" degrees celcius
2.7.3	Change - "motor" to "alternator"
2.7.9	Add - 130% load for 1 minute at 9000 rpm
	Change - "1.5" to "1.3" ft-lb
2.7.10	Change - "TBD" to "5000 - 7000"
2.8.1	Change - Remote location of controller
2.9	Change - "468" to "520" volts
2.94	Change - 15 to 27 degrees "F" to "C"
2.98	Clarify - Power-up regime and 100.1 volts
2.9.9	Add - "or configurable as such"
2.9.13	Add - "of seawater at 59°F"
2.9.15	Add - "or corrosion resistant stainless steel"
3.0	Add - "option"

REVISION STATUS SHEET
FOR
INTERFACE SPECIFICATION

REVISION 2
4 DECEMBER 1987

SECTION	RENUMBERED	DESCRIPTION
2.4.1.1		Clarify - Oil Lubrication Interface Details Added
2.4.2		Clarify - Envelope Added
		Delete - "19 Inch Overall Length"
2.4.2.2		Clarify - Motor Mounting Description
2.4.2.3		Delete - Shock Loads Described in Motor Section
2.4.3		Change - "1,250" to "1,274" RPM
2.4.3.3b		Change - "1,680" to "1,649" FT LB
2.4.3.3c		Change - "1,680" to "1,649" FT LB
2.4.3.3g		Change - "Figures 7, 8, 9" to "TBD"; Available Figures Do Not Adequately Describe Design Requirement
2.4.3.3k		Change - "1.0" to ".010" Inches
2.4.3.4	2.4.4	Change - "25" to "10" Feet/Second
2.4.4	2.5	Add "$\pm$4" to "28" Volts
		Change - "TBD" to "RS232 Serial Link"
		Add - Power Cable Description
2.5	2.6	Change - "1,000" to "1,100 $\pm$ 100" RPM
2.6	2.7	Add - "Maximum" Operational Speed Range, Etc.
2.7	2.8	Change - "A Brushless PMG Type" to "Equipped with a Brushless PMG"
		Change - "550" to "450" Hertz
2.7.1	2.8.1	Add - "Maximum" Operational Speed Range, Etc.
2.7.2	2.8.2	Clarify - Reworded
2.7.3	2.8.3	Change - "375" to "380"
		Add - "And the Terminal Cover/Power Sensing Box"

REVISION STATUS SHEET
FOR
INTERFACE SPECIFICATION

REVISION 2
4 DECEMBER 1987
(Continued)

SECTION	RENUMBERED	DESCRIPTION
2.7.4	2.8.4	Change - Specified Dimensions to "Outline Dimensions shall be in accordance with ICD "TBD""
2.7.5	2.8.5	Clarify - Add Reference for Cooling Air Requirements
2.7.6	2.8.6	
2.7.7	2.8.7	Add - "Measured Free Field"
2.7.8	2.8.8	Add - "The Description of this shock load is "TBD""
2.7.9	2.8.9	Change - "Shock Load of 1,680" to "Overload of 1,649"
2.7.10	2.8.10	
2.7.11	2.8.11	
2.7.12	2.8.12	
2.7.13	2.8.13	Change - "In Figure 10" to "On Westinghouse Outline Drawing No. 947F038"
2.8	2.9	
2.8.1	2.9.1	Add - Controller Volume & Outline Dimension Information
	2.9.2	Add - New Section Entitled "Weight"
2.8.2	2.9.3	
2.8.3	2.9.4	
2.8.4	2.9.5	Add - "The Description of this Shock Load is TBD
2.8.5	2.9.6	
2.8.6	2.9.7	Change - "Operate From" to "Not Exceed"
2.8.7	2.9.8	

REVISION STATUS SHEET
FOR
INTERFACE SPECIFICATION

REVISION 2
4 DECEMBER 1987
(Continued)

SECTION	RENUMBERED	DESCRIPTION
2.8.8	2.9.9	Add - "For both the Alternator and the Motor"
2.8.9		Delete
2.9	2.10	Change - "400 HP ..... 9.90PF" to "400 HP Nominal Continuous SDG Output Power Rating at 0.90PF as a Design Goal"
		Change - "8910 RPM" to "8919 RPM SDG Input Speed"
	2.10.1	Add - New Section Entitled "Shaft Speed"
	2.10.2	Add - New Section Entitled "Efficiency"
2.9.1	2.10.3	Change - "Refer to Para" to "In Accordance with ICD "TBD""
2.9.2	2.10.4	Add - "The Description of the Shock Load is "TBD""
2.9.3	2.10.5	Change - "Refer to Para" to "The Description of the Vibration Requirements is "TBD""
2.9.4	2.10.6	
2.9.5	2.10.7	Clarify - Add Seawater Flow Information
2.9.6	2.10.8	Change - "300" to "TBD"
		Add - "Calculated Weight is 329 LB"
2.9.7	2.10.9	Clarify - Specified Internal Oil & Removed References to External Hoses
2.9.8	2.10.10	Change - "3,000 RPM, 100.1 Volts L-L RMS, 150 Hz" to "2,750 ± 250 RPM"
2.9.9	2.10.11	Delete - "(Or Configurable As Such)"
2.9.10	2.10.12	Delete - "Without Any Degradation in Performance at Maximum Speed"

REVISION STATUS SHEET
FOR
INTERFACE SPECIFICATION

REVISION 2
4 DECEMBER 1987
(Continued)

SECTION	RENUMBERED	DESCRIPTION
2.9.11	2.10.13	Change - "a." to "Class H or Better"
		Add - "c." and "d".
2.9.12	2.10.14	Clarify - Delete and Rewrite per Updated Information
2.9.13	2.10.15	
2.9.14	1.10.16	Change - "Which could be Continuous or Intermittent During" to "Distributed Randomly Over"
2.9.15	2.10.17	Add - "External and" Internal Etc.
2.10	2.11	
3.0		Delete - Not Applicable to Interface Document

REVISION STATUS SHEET
FOR
INTERFACE SPECIFICATION

REVISION 3
1 MARCH 1988

SECT?	DESCRIPTION
2.?	Change - "Diesel" to "Either a turbine or rotary"
2.3	Change - "TBD" to "Contractually Prescribed"
2.4.1	Change - "Westinghouse" reference to "Gould Interface Control Drawing (ICD), Drawing No. E77497"
	Change - "Diesel engine is" to "Prime movers are"
2.4.2.1	Add - "Or Composite Structure"
2.4.2.2	Change - "TBD" to "Drawing No. J77496"
2.4.3.3.g.	Change - "DTNSRDC" to "DTRC"
2.4.3.3.i.	Change - "25" to "2"
2.4.3.3.j.	Add - "Motor/SDG including"
	Change - "25" to "1"
2.5	Clarify - Reworded
	Change - "25 feet ± 6 inches" to "Approximately 25 feet"
2.6	Change - "Diesel" to "Rotary and Turbine" and reword accordingly
	Change - "When the engine is at 1,100 ± 100 RPM" to "At 4,300 ± 100 RPM"
2.7	Change - "Diesel" to "Rotary"
	Add - "The turbine shall operate over a 2.09:1 speed range"
	Change - "2,500" and "125" to "4,300" and "215"
2.8.1	Change - "2,500" to "4,300"
	Reword for multiple prime movers
2.8.4	Change - "TBD" to "Drawing No. E77497"
2.8.5	Change ' "Westinghouse" reference to "Drawing No. E77497"
2.8.9	Change - "A Diesel" to "Either a rotary or a turbine"

REVISION STATUS SHEET
FOR
INTERFACE SPECIFICATION

REVISION 3
1 MARCH 1988
(continued)

SECTION	DESCRIPTION
2.8.13	Change - "Westinghouse" ref to "Drawing No. E77497"
2.9.8	Clarify - Reworded to describe signals
2.10.3	Change - "TBD" to "Drawing No. J77496"
2.10.9	Change - "7078" to "7808"
2.10.10	Change - "2,750 ± 250" to "4,300 ± 100"

FIGURE	DESCRIPTION
1	Changed Diesel/Gearbox to reflect Rotary/Turbine/Gearboxes

REV

1.0 SCOPE

1.1 Definition

1. This interface document establishes the requirements for the design, documentation, and fabrication of an electric water propulsion system for use in a 28 ton, high water speed, tracked amphibious vehicle.

2.0 REQUIREMENTS

2.1 Electric Water Propulsion Module (EWPM)

An electric water propulsion module includes a modified Westinghouse alternator, an alternator controller, power cabling, a propulsion drive unit (ac motor and speed decreasing gear), and a shaft coupling.

2.2 General Description

3. Four EWPMs are required to meet the water propulsion needs of the aforementioned Marine Corps amphibious vehicle. The alternator of the module will be directly coupled to a high speed splitter gearbox driven by either a turbine or rotary prime mover as shown in Figure 1. The mechanical power will be converted to electrical power by the three phase brushless alternator. This power will be supplied to the propulsion module where it will be converted to low speed mechanical power to direct drive a waterjet. The electrical system for the EWPM is shown in Figure 2. The alternator controller performs the control and protection function within the EWPM.

2.3 Electrical Power System Installation

3. The actual installation of the electric drive system components into the vehicle will be the responsibility of the vehicle integrator. The vendor shall provide the integrator with the assistance and support in the form of documentation of the hardware and a contractually prescribed amount of technical support at the vehicle integrator's facility.

2.4 Interface Requirements

2.4.1 Splitter Gearbox

3. Each alternator shall be mounted to a splitter gear box per drawing TBD and shall have the spline and bolt circle details as shown on Gould Interface Control Drawing (ICD), Drawing No. E77497. The splitter gear box ratio shall be such to provide 9000 rpm at its output shaft (to each alternator) when the prime movers are at maximum operational speed.

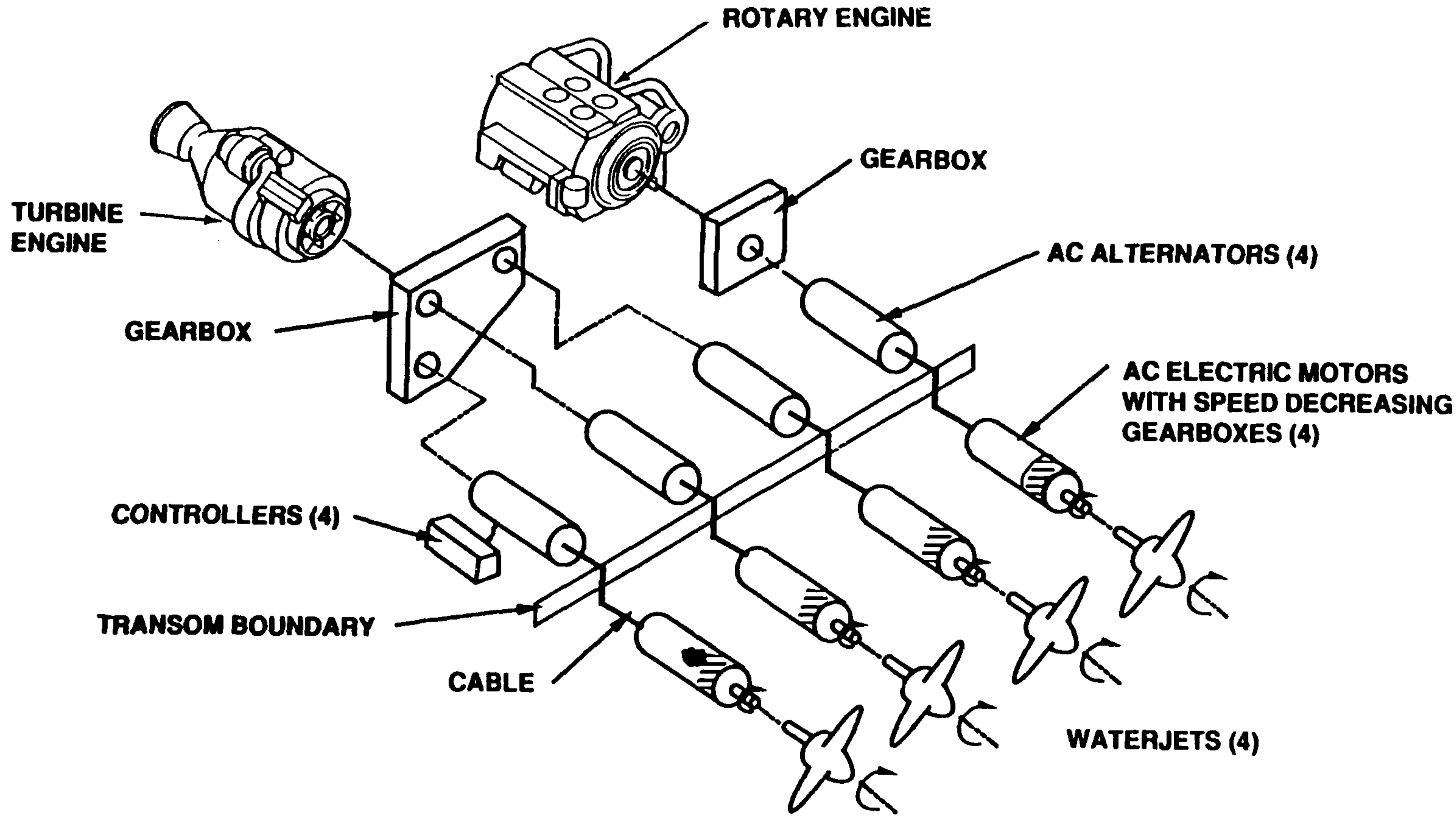

Figure 1. Propulsion System

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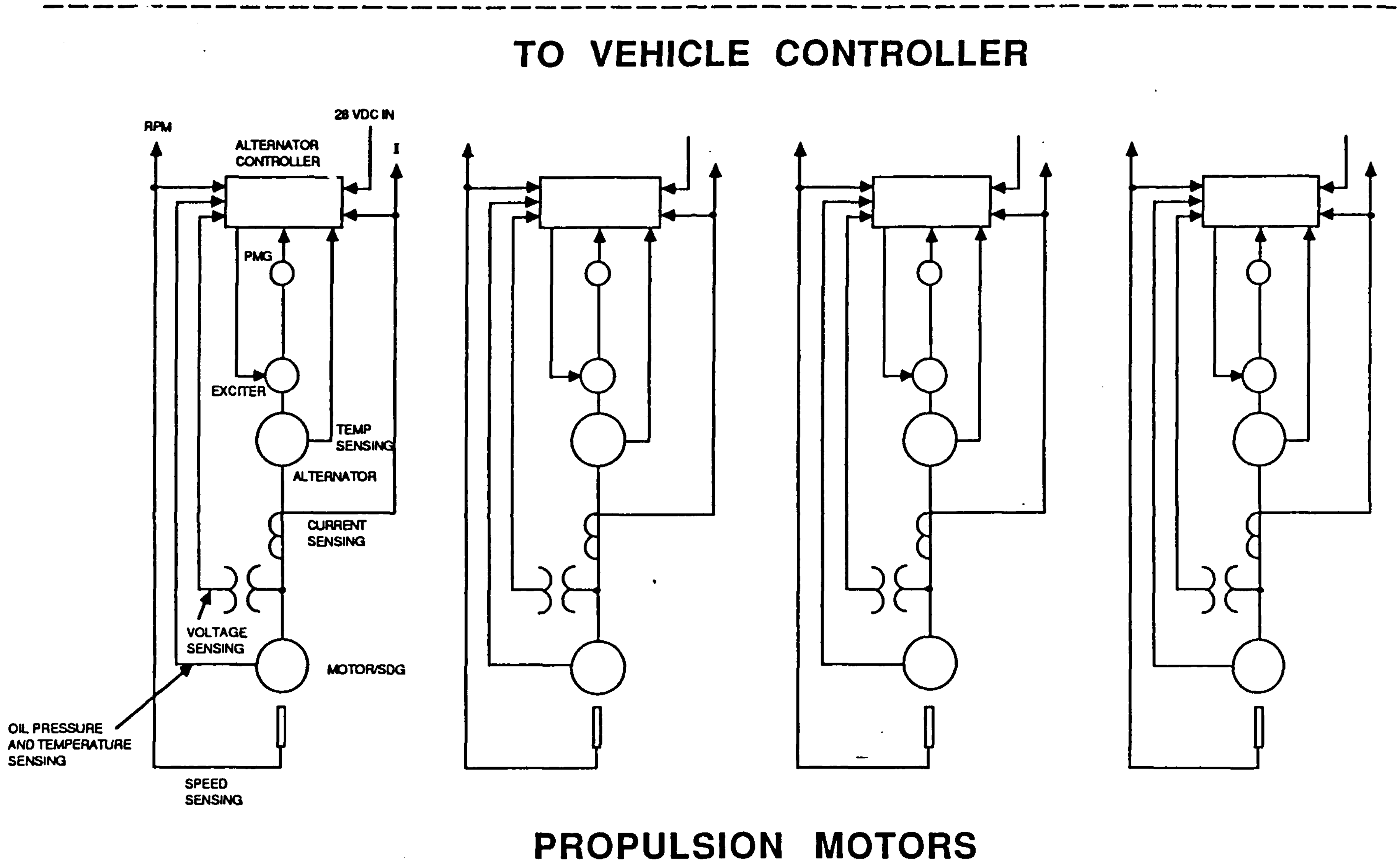

Figure 2. EWPM Electrical System

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REV

2.4.1.1 Alternator Bearing Lubrication Oil

2. Figure 3 shows a portion of the alternator with an exhaust shroud and gearbox mounting added for reference.

In most applications, the engine, gearbox, and alternator share a common oil supply. A number of variations can be made to the oil system, however, without adversely affecting the alternator operation or requiring changes to the alternator design.

Oil to the alternator must be supplied at a pressure of 1 $\pm$ .5 psig (measured at reference ports "A" and "B" in Figure 3). Approximately 115 cc/minute is required for each bearing. Oil is typically supplied from a higher pressure line and regulated down to the 1 $\pm$ .5 psig pressure. The oil supply line for the drive-end bearing must be separate from the line for the fan-end bearing. If the two lines are common one bearing can be starved. The oil exits at the bottom of the alternator (reference ports "F" and "G").

The bearing cavities are enclosed by close-clearance seals. To prevent leakage the bearing cavity pressure must be lower than the surrounding ambient pressure. On the fan end, the pressure head developed by the fan is sufficient and this cavity may be gravity drained back to the supply reservoir or gearbox provided they are vented to atmospheric pressure.

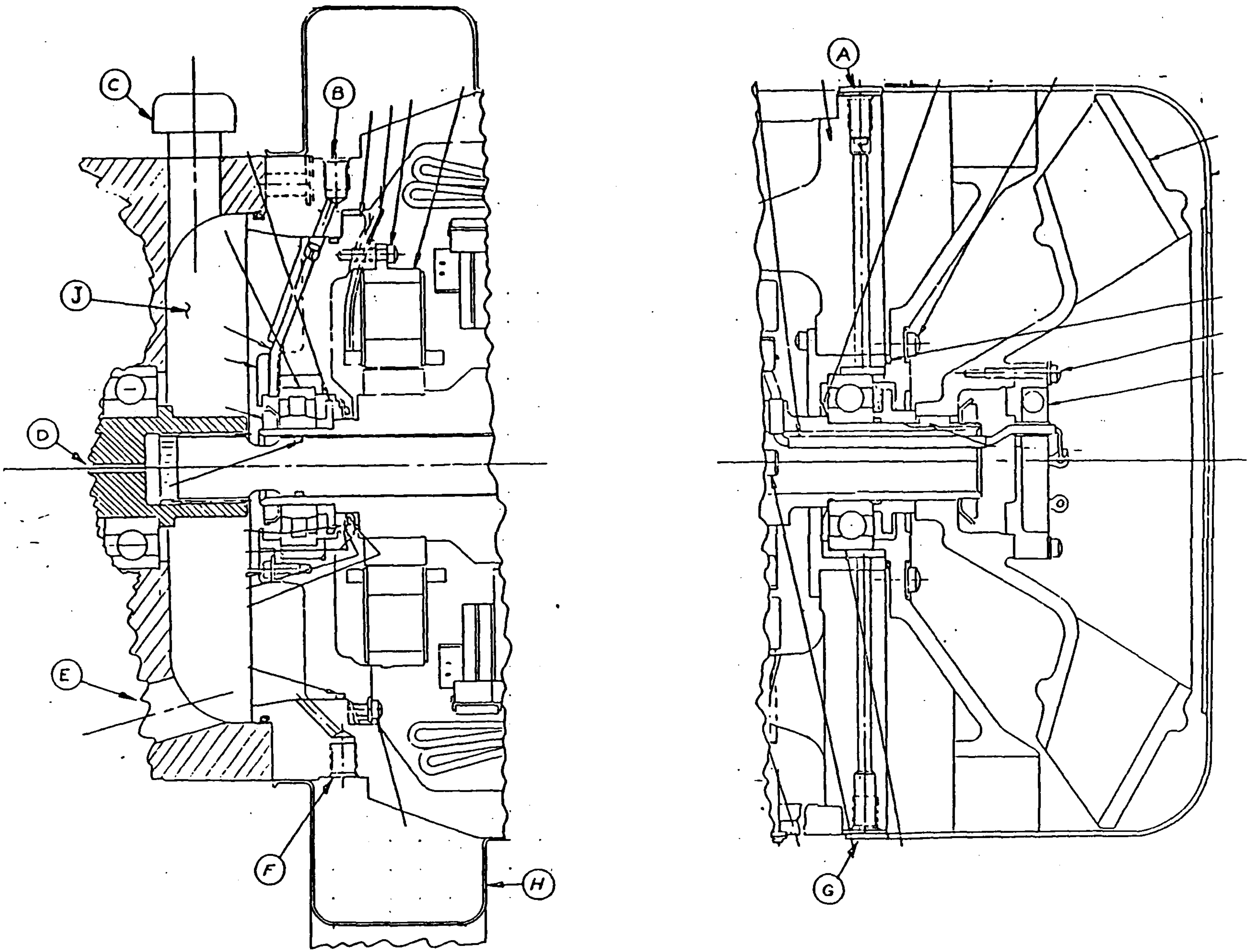
The drive-end bearing lubricating oil flows into the cavity between the alternator and gearbox (reference location "J"). An exhaust shroud (reference "H") is required to provide a back pressure of approximately 3 inches of water. If the cavity between the gearbox and alternator is sealed, the oil must be evacuated thru port "F". The recommended sump line pressure is 1.0 $\pm$ .5 psig vacuum measured at port "F".

An alternate method is to provide a drain directly back into the gearbox through port "E" in conjunction with a gearbox pad vent "C". The exhaust shroud is still required but the drive-end bearing drain port "F" can be plugged.

Spline lubricant is typically provided from the gearbox through a hold "D" in the drive shaft.

2.4.2 Transom

2. The motor/speed decreaser and coupling envelope shall not be greater than 16.0" in diameter and be within the envelope as shown in Figure 4. The coupling can be in the transition area. The motor/speed decreaser shall be on the same center line as the waterjet drive shaft.



12/212/87J – 002

FIGURE 3. ALTERNATOR / GEARBOX / TYPICAL INSTALLATION

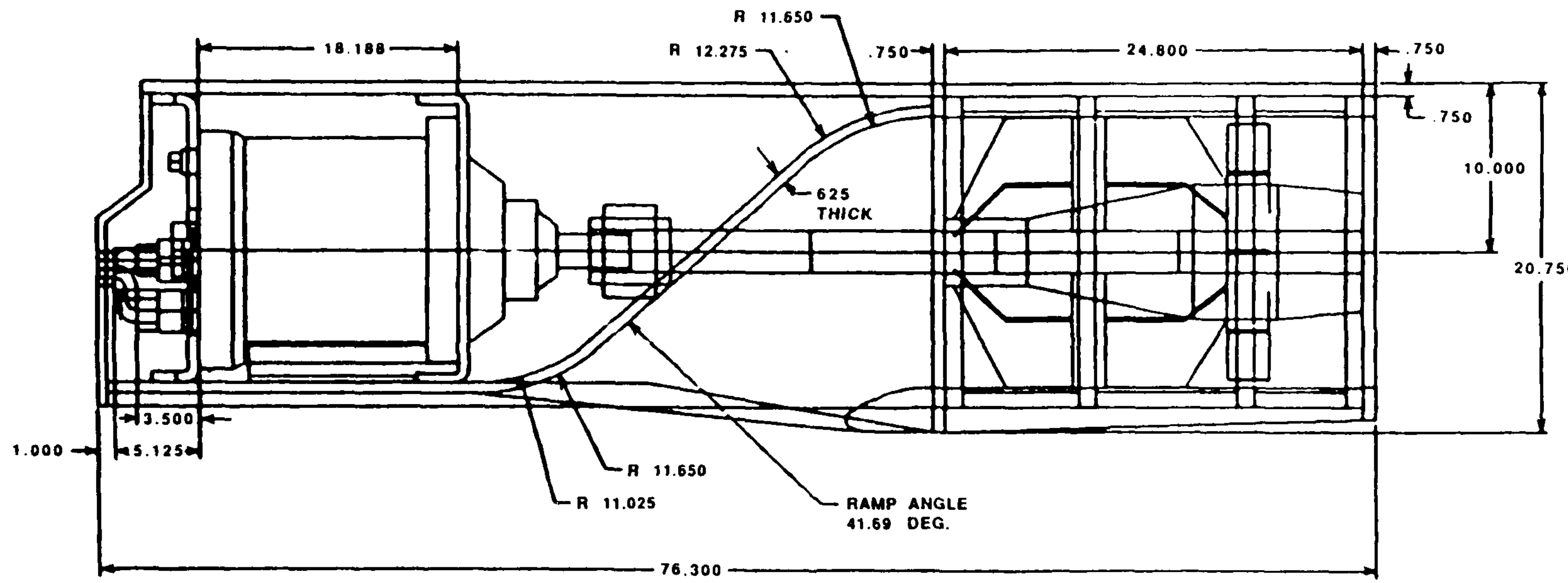


FIGURE 4. TRANSOM / MOTOR / SDG / COUPLING
INTERFACE ENVELOPE

12/212/87J - 003

REV

2.4.2.1 Transom Construction

3. The transom will be a welded truss or composite structure design for the sides and lateral bulkhead. The top, back, and bottom panels will be bolted to allow access to the motors. The bulkhead location is flexible.

2.4.2.2 Motor/SDG Installation

2., 3. The Motor/SDG shall be mounted rigidly within the transom as shown in Figure 4. The Motor/SDG shall be fastened to two brackets by a total of eight bolts, four each bracket. The Motor/SDG mounting features shall be in accordance with Gould ICD, Drawing No. J77496.

2.4.3 Waterjet

1., 2. Each waterjet for the 28 ton vehicle must produce 3900 pounds of thrust at nominally 1,274 rpm, producing a nominal 400 shp load on the motor. The waterjet will be rigidly mounted to the transom flap.

2.4.3.1 Waterjet Thrust

The thrust of the waterjet will be absorbed aft of the motor coupling in accordance with the vehicle integrator requirements.

2.4.3.2 Waterjet/SDG Coupling

1. The vendor shall provide a coupling between the motor/SDG and the waterjet. The coupling shall take up axial and radial misalignment as specified in Section 2.4.3.3. There shall be no thrust transmitted from the waterjet through the coupling. The coupling shall have a shear failure mode at 2.5 times rated torque.

2.4.3.3 Power Delivery to Waterjets

1.,2.,3.
a. Nominal Power delivered to the waterjet: 400 hp
b. Maximum shaft steady-state torsional load: 1649 ft-lbs.
c. Maximum shaft torsional overload: 1.3 x 1649 ft-lbs.
d. Repetition frequency of torsional overload: 100 events/hour
f. Flooded waterjet rotational inertia: 21 lb-ft^2
g. Speed-Torque characteristics: DTRC Figures "TBD"
h. Waterjet breakaway torque: 7-14 lb-ft.
i Breakaway torque of system thrust bearing: 2 lb-ft. max.
j. Breakaway torque of motor/SDG including shaft seals: 1 lb-ft. max.
k. Maximum shaft off-set misalignment: .010 inches
l. Maximum shaft angular misalignment: 0.2 degrees

REV

2.4.4 Thermal Management

2. The seawater flowrate past the motor housing shall be directly proportional to vehicle speed. At full vehicle speed the flow rate shall be 10 feet/second minimum. The temperature of the seawater shall be 80 °F maximum.

2.5 Electrical

1., 2.,3. A separate on-board power source shall provide 28 ± 4 volts dc to each alternator regulator; a total of 2.0 KW of power shall be available. From each alternator/motor module, data will be transmitted to the vehicle controller via RS232 serial link.

Each alternator shall be hard wired to each motor with flexible cable and be rated for the proper voltages and currents. The cables, three per motor, shall be sealed and capable of withstanding long term exposure to seawater and limited exposure to hydraulic oil and battery acid. The motor cables shall be of the construction shown in Figure 5, and shall be approximately 25 feet long. The cables shall exit the motor axially from the forward end and shall be capable of a one foot bend radius. The installation and termination of the cables shall be the responsibility of the vehicle integrator.

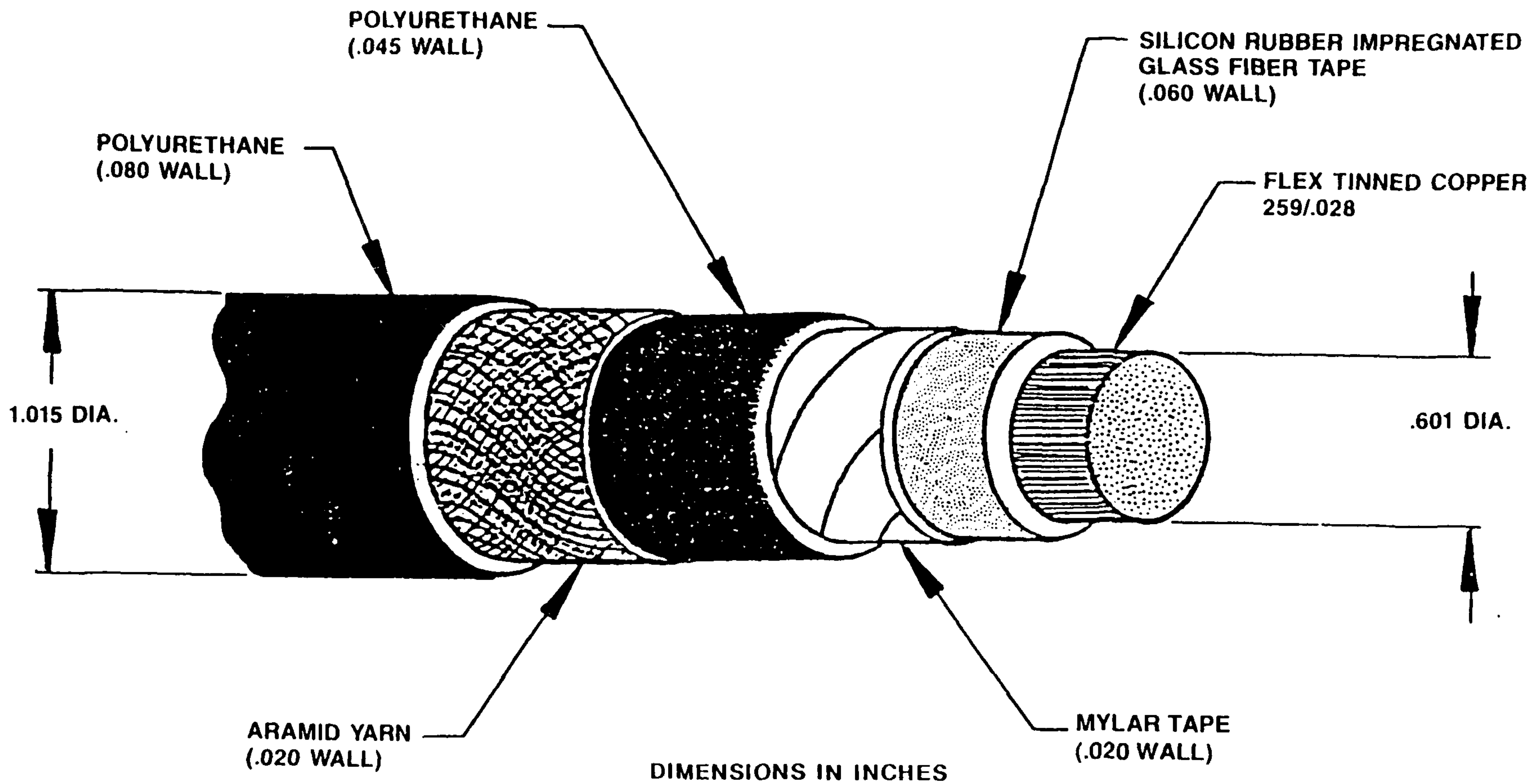
2.6 Power-Up Regime

1., 2.,3. The rotary and turbine engines shall be coupled to splitter gearboxes that provide 9,000 RPM input to the alternators at full engine power. Both engine transient speed regulations shall be ± 2% at full speed.

Each alternator/motor module shall be started sequentially, one at a time. Each alternator will be brought on line at 4,300 ± 100 RPM.

2.7 Operating Regime

2.,3. The rotary engine shall operate over a 3.6:1 speed range. The turbine shall operate over a 2.09:1 speed range. The alternator shall have a maximum operational speed range of 4,300 - 9000 rpm (215 - 450 hertz).



CABLE SIZE: 4/0 AWG
BEND RADIUS: 6 INCHES MIN.
NOMINAL WEIGHT: .944 POUNDS PER LINEAR FOOT

FIGURE 5. MOTOR / ALTERNATOR CABLE

12/212/87J - 004

REV

2.8 Alternator

1., 2. The vendor shall design, fabricate, and acceptance test alternators that meet the specifications listed below. The alternator shall be equipped with a brushless PMG and provide the following output characteristics at nominal conditions:

322 kW Nominal Continuous Power Rating at 0.85 PF
520 Volts L-L RMS, 3 Phase
450 Hertz

The alternator shall have an overload capability of at least 1.3 times 322 kW for a period of one minute at the maximum speed and an ambient air temperature of 38 degrees Celsius. The storage and transportation temperature will be -40 to 125 degrees Fahrenheit (-40 to 51.5 degrees celsius).

2.8.1 Shaft Speed

2., 3 The maximum speed of the alternator shall be 9000 rpm. The maximum operational speed range shall be 4300 - 9000 rpm. The splitter gearboxes between the alternators (four) and the engines shall be properly sized and geared to provide 9000 rpm input to the alternators at full engine speed.

2.8.2 Efficiency

2. The efficiency of the alternator shall be at least 88 percent at 322 kW, 9000 RPM (100% electrical power). This value shall be computed from the ratio of alternator output power divided by shaft input power. The efficiency calculation shall include the excitation power required for the rotating exciter.

2.8.3 Weight

1., 2. Each alternator shall weigh less than 380 pounds. This weight shall include all oil normally contained within the alternator and the terminal cover/power sensing box.

2.8.4 Dimensional Constraints

2., 3. The alternator shall be designed for minimum volume without compromising the other specified design criteria. Greater emphasis shall be placed on reducing length versus diameter. The alternator/power sensing box outline dimensions shall be in accordance with Gould ICD, Drawing No. E77497.

REV

2.8.5 Cooling

2., 3. The alternator shall be air cooled. The maximum ambient temperature will be 100 degrees fahrenheit (38 degrees celsius). Required air flow for each alternator shall not exceed 1,100 CFM. Reference Section 2.4.1.1 and Gould ICD, Drawing No. E77497, for cooling air requirements.

2.8.6 Excitation Characteristics

2. The excitation of the alternator shall be provided by an integral brushless rotating exciter. The operating characteristics of the vehicle will provide the constraints on the exciter design.

2.8.7 Noise Characteristics

2. It is desired to have the noise level produced by the alternator, measured free field at a point three feet from the housing, be no greater than 93 dBA. This will be treated as a design goal.

2.8.8 Shock Loads

2. The design of bearings and mounts shall use the criteria of 10.0 G in any direction with the alternator running at any speed (including stopped) within its operating range. These loads shall also be planned for in the transport and shipping of the alternators. The alternators will be cantilever mounted from the splitter gearbox. The description of this shock load (G Force vs. Time) is "TBD".

2.8.9 Service Factor

1., 2., 3. The alternators shall be driven by either a rotary or a turbine engine. In the operating mode, each alternator will be loaded by a 400 HP ac induction Motor/SDG. For the 28 ton test vehicle, four (4) alternators and motors will be used. The alternator shall provide a 130% load for one minute at 9000 rpm, 520 volts L-L rms.

The possibility of waterjets ingesting air or foreign matter could result in momentary loading or unloading of the motors, but not in excess of the maximum permissible torsional overload of 1649 X 1.3 ft-lb.

2.8.10 Service Life Cycle

1., 2. The alternator shall be designed to operate at its full power for 1500 hours. This shall be assumed to be evenly distributed over the vehicle's 10 year life. Estimated number of alternator starts (0 to 9000 RPM) during the life of the vehicle is 5000 - 7000.

REV

2.8.11 Drive Shaft Bearing

2. The alternators shall be a two-bearing design and shall not depend on a driving gear for support of its drive shaft. Bearings shall be sized to support the specified shock loads as well as the specified torsional loads.

2.8.12 Insulation

2. Insulation of the alternator windings shall be selected to meet the following criteria:

a. The design limits and over temperature limits resulting from the offeror's cooling calculations.

b. Storage of the vehicle in damp salt air environments for extended periods of time.

c. An alternator shelf life of 10 years with intermittent use (to 1500 hours) spaced randomly through the 10 year period.

2.8.13 Alternator Mounting

2., 3. Each alternator shall be directly bolted to the speed increasing gearbox. The bolt hole pattern for the alternator mounting flange is shown on Gould ICD, Drawing No. E77497.

2.9 Alternator Controller

2. The alternator controller will provide protection and control capability for the electric water propulsion system. A bus compatible interface will be supplied for transfer of data to and from the propulsion system. The alternator controller will allow transparent control of the propulsion system over the entire operating range of the propulsion system. The controller will be designed to the operational requirements outlined below.

2.9.1 Dimensional Constraints

1., 2. The Contractor shall strive to minimize the size of the controller. The Contractor shall locate the controller remote to the alternator. The controller shall be less than one cubic foot volume. Controller outline dimensions shall be in accordance with ICD "TBD".

2.9.2 Weight

2. The controller, less cables, shall weigh less than 20 pounds.

REV

2.9.3 Cooling

2. The controller shall be cooled by natural convection. No source of forced air cooling shall be required.

2.9.4 Auxiliary Power

2. An auxiliary power source of 28 Vdc is available onboard the vehicle. A total of 2 kW is available for all vehicle controllers.

2.9.5 Shock Loads

2. The controller shall be designed to withstand 10G shock loads in all axes. The description of this shock load (G Force vs. Time) is "TBD".

2.9.6 Temperature

2. The compartment temperature limits for the alternator controller shall be between 0°C (32°F) and 50°C (122°F).

2.9.7 Data Bus Compatibility

2. All digital signals will be compatible with TTL logic, analog signals will not exceed -10V to +10V.

2.9.8 Data Required

2., 3 A single, V/Hz speed control signal will be supplied to the alternator controller by the alternator PMG. An output signal, proportional to motor speed, will be supplied by the alternator controller.

2.9.9 Protection

2. Electrical overload protection will be provided by the alternator controller for both the alternator and the motor.

2.10 Motor/SDG

2. The vendor shall design, fabricate, and acceptance test motors that meet the specifications listed below. The motor shall be a liquid cooled, 6 pole ac induction motor with a cage rotor construction and have the following output characteristics:

1. 400 HP Nominal Continuous SDG Output Power Rating at 0.90 PF as a design goal
520 Volts L-L RMS, 3-phase
8919 RPM SDG Input Speed (450 Hz)

REV

The motor must have a single output shaft that is to be mated with an integrally mounted speed decreasing gear (SDG). The Motor/SDG shall be capable of being mounted to the transom forward and aft bulkhead. Refer to Section 2.4.2.2, Motor/SDG Installation.

2.10.1 Shaft Speed

2. Synchronous motor speed at nominal conditions is 9000 rpm (450 Hz). The induction motor rotor slip under these conditions is calculated to be 0.9% which results in an SDG input shaft speed of 8919 rpm. The SDG speed reduction ratio is 7:1 which produces an output speed of 1274 rpm and a delivered torque of 1649 lb-ft.

2.10.2 Efficiency

2. The Motor/SDG shall have a minimum combined efficiency of 92% at nominal conditions (400 hp SDG output power, 520 volts L-L RMS, 1274 RPM SDG output speed, 450 Hz). The calculated efficiency of the motor alone is 96.2% at nominal conditions. The calculated SDG minimum efficiency is 96.0%.

2.10.3 Size

2., 3. The Motor/SDG outline dimensions shall be in accordance with Gould ICD, Drawing No. J77496.

2.10.4 Environmental

2. The motor/SDG, in any operational position shall sustain a shock load of 7.0 G in all axes at full power without any adverse impact. The motor/SDG shall operate in salt water without any degradation of structural members, seals, terminations, insulation system or motor performance. The description of the shock load (G Force vs. Time) is "TBD".

2.10.5 Transportation Vibration

2. The description of the vibration requirements is "TBD".

2.10.6 Operating Temperature

1., 2. The operating temperatures are as follows: Water temperature of 59 to 80 degrees F (15 to 27 degrees C). Transportation temperature of -40 to 125 degrees F (-40 to 51.5 degrees C).

2.10.7 Flooded Motor Area

2. The motor/SDG shall operate with the transom motor compartment flooded with seawater at a maximum temperature of 80 degrees fahrenheit. The water inlet size is 18 square inches/motor. Seawater shall flow axially past all external surfaces of the motor housing at the rate of 10 feet per second minimum at full vehicle speed. The seawater flow rate is proportional to the vehicle speed.

REV

2.10.8 Weight

2. The entire drive unit, motor, SDG, and coupling, shall not exceed "TBD" pounds. The calculated weight of the motor, SDG and coupling is 329 pounds.

2.10.9 Cooling/Lubrication

2., 3 The motor/SDG shall be self cooled using an integral heat exchanger with a maximum seawater temperature of 80 degrees fahrenheit. The same fluid, MIL-L-7808 turbine oil, shall be used for both cooling and lubrication in the gearbox and the motor. The oil circulation pump inlet and discharge ports shall remain constant with bi-directional drive. Oil passages from the gearbox to the motor shall be internal (no external hoses).

2.10.10 Power-Up Regime

1. The motor will be brought on line when the alternator is at 4,300 ±
2.,3. 100 RPM.

2.10.11 Operating Regime/Motor Reversing

1.,2. Refer to paragraph 2.7, Operating Regime. The requirement for the motors to be operated in reverse rotation after initial installation is not necessary. The possibility for half of the motors to operate clockwise and half to operate counterclockwise exists, so the oil circulation pump shall be bi-directional.

2.10.12 Overload Torque

2. The motor/SDG shall be capable of developing an overload torque of 130% of full load torque for one minute.

2.10.13 Motor Insulation

2. The insulation of the motor windings shall be selected to meet the following criteria:

a. Materials selected will be temperature class H (180°C) or better and consistent with the required Motor/SDG life requirements.

b. Storage of the vehicle in damp salt air environments for extended periods of time.

c. 500 hour operating life distributed randomly over a 10 year period.

d. Compatible with MIL-L-7808 internal cooling oil.

REV

2.10.14 Drive Unit Sensors

2. The motor shall have the following devices to provide data about its operating condition:

1) A magnetic-type speed sensor which has an output voltage rating of 28 V peak-to-peak minimum @ 1000 IPS with a 20 DP gear and a .005" air gap into 100,000 ohms. The coil resistance of the sensor is 850 ohms maximum. The full scale frequency is 1050 Hz.

2) An oil pressure transducer which has a .1 millivolt/psi outlet at 5 VDC excitation and has a bridge resistance of 350 Ω. The full scale range is 25 psi.

3) An oil temperature transducer; which is a platinum RTD with a resistance of 100 Ω at 0°C and a nominal temperature coefficient of resistance of .385 Ω/°C. The transducer is rated at 200°C maximum.

4) 6 Stator winding temperature transducers, each being a platinum RTD with a resistance of 100 Ω at 0°C and a nominal temperature coefficient of resistance of .385 Ω/°C. The transducer is rated at 200°C maximum.

* The selection of these components is by Gould. The instrumentation should be durable and put as far forward as possible if there is a need to access them. Routing of sensor leads and wiring will be the responsibility of the vehicle integrator.

2.10.15 Hydrostatic Head

1., 2. The motor shall withstand a hydrostatic head of 20 feet of seawater at 59°F.

2.10.16 Service Lifecycle

2. The motor shall have a service life of 500 hours distributed randomly over a period of 10 years.

2.10.17 Corrosion Protection

1., 2. The motor shall be completely sealed and the external and internal components protected from corrosive environments encountered during both operation and storage. All exposed fasteners shall be plated or corrosion resistant stainless steel.

REV

2.11 Vehicle Pitch Angle Data

2. From the enclosed pitch numbers, the absolute pitch angle that the motors could see is the sum of the vehicle pitch angle (worst case for either calm water or sea state 2) and the relative flap angle.

Speed	Vehicle Pitch Angle		Flap	Total
MPH	Calm Water	Sea State 2	Angle	Flap Angle
8	5.1	~ 10	0.5-2.5	5.6-12.5
10	7.0	10.4	.6-3.4	7.6-13.8
12 *	11.1	10.2	.8-4.4	11.0-15.5
14	8.9	10.2	1.0-5.4	9.9-15.6
16	8.5	10.3	1.3-6.5	9.8-16.8
18	8.9	10.5	1.5-8.0	10.4-18.5
20	9.1	10.3	1.7-7.7	10.8-18.0
22	8.8	9.1	2.2-7.3	11.0-16.4
24	7.8	8.2	2.5-7.0	10.3-15.2
26	6.9	7.4	3.2-6.8	10.1-14.2
28	~ 7	~ 7		

* This is Model Data Scaled up to full size and ~12 mph was where hump was reached on the model. This condition is only momentary.

APPENDIX II

Alternator Vendor Survey

APPENDIX II

Alternator Vendor Survey

Prior to selecting the Westinghouse Electric Corporation (Lima Facility) as the supplier of the alternator, an alternator vendor survey was conducted and is summarized in Figure II.1. The preliminary technical data was based upon the dedicated alternator/motor configuration. Requests were sent to six vendors of which three responded with proposals.

The Westinghouse alternator came closest to meeting the performance and weight requirements for the electric propulsion system. It has been in service for over ten years and is in current production. The alternator was originally designed for the U.S. Navy's Pegasus Program.

The Niehoff alternator would have required a new electromagnetic and cooling system design to meet the electrical system requirements. Approximately 200 pounds of auxiliary hardware would be required to support 24 GPM of cooling oil for each alternator. This would have added 800 pounds to the electric propulsion system with its attendant penality on vehicle performance.

The alternator proposed by Garrett would have required a major development effort on their part since they did not have anything in their current product inventory to meet the electric system requirements. Their alternator was significantly heavier and would not have met the program delivery schedule.

Vendor	Dimensions	Wt	Volts	Freq	Speed	Eff	Advantages	Disadvantages
Westinghouse	25.9"x 13.4"	373#	520	500	10KRPM	90.1	a. Air Cooled b. Existing design c. Extensive design experience	36 lbs. heavier than spec
Niehoff	22"x17"	374#	500	800	12KRPM	88.8		a. 37 lbs heavier than spec b. 300# of hardware to support 24 GPM/ Alt for ea. alt. c. New design effort d. Eff less than 90%
Garrett	21.5"x20"	1200#	800	250	15KRPM	92	a. Eff > 90%	a. Wt. 860 lb. heavier b. New product - major development effort required
Bendix	No Bid							
Lear Siegler	No Bid							
Sundstrand	No Bid							

Figure II-1. Alternator Vendor Summary

05/204/88/024-C

The remaining vendors, who build military alternators, declined to bid based primarily because of the 322 kW power requirements. Their alternator power ratings were in the range of 70 - 100 kW.

APPENDIX III

Alternator Description

APPENDIX III

322 kW Brushless Alternator

The power source for each induction motor is a commercially available air-cooled 322 kW brushless alternator. The alternator is being purchased from the Westinghouse Electric Company, Lima Facility, part number 977J031-6. The alternator was originally designed for the U.S. Navy for use in the Pegasus program in 1972 and as such is a proven design.

The internal features of the alternator are shown in Figure III.1. The alternator is made up of three major elements as follows:

a. Permanent Magnet Generator (PMG)

b. Exciter with rotating rectifier bridge

c. Main alternator

The PMG provides voltage information for the system controller. The PMG is located at the drive end of the alternator. The permanent magnet rotor is assembled on a common shaft with the main field assembly. The single phase stator winding assembly is attached to the alternator housing.

The rotating exciter armature and rectifier bridge provide excitation to the main field windings. The exciter field winding is attached to the anti-drive end bearing housing. The exciter field winding which provides excitation for the exciter armature gets its power from the PMG. This transfer of power is accomplished without the use of brushes or slip rings. The output of the rectifiers are hard wired to the main field winding which is assembled on a common shaft. The field coil end turns are supported and banded to withstand the centrifugal forces encountered during operation. The alternator three phase output is brought out just inboard of the anti-drive end bearing support to an external terminal board.

The alternator is air cooled requiring 1100 cfm of air. Air is brought into the machine at the anti-drive end and is exhausted at the drive end. A separate oil source is required for bearing lubrication.

The propulsion alternator technical specifications are summarized in Table III.1.

Table III.1 - Propulsion Alternator Technical Specifications

Nominal Power Rating (Continuous)	332 + 3% - 0%
KW	
Power Factor	.85
Overload Capability - 1 Minute Duration, 9000 RPM	419 kW
Minimum Starting Current @ 215.3 Hz	900 Amps for 3 Sec
Nominal Voltage L-L VRMS @ 450 Hz	520 ± 5%
Nominal Frequency Hz	450 Hz
Nominal Shaft Speed	9000 RPM
Number of Phases	3
Efficiency at Nominal Rating	88% Minimum
Operating Speed Range (Max./Min.)	4300 - 9000 RPM
Weight Limit (Lbs.)	>337*
Voltage Control Method	Constant Volt/Hz over speed range
Volts/Hz (Ratio) Regulation	1% for a 0-100% Current Load
Excitation Type	Brushless PMG
Shock & Vibration	10 g - all axes
Mounting Envelope	15" dia. x 17" long
Service Life	1500 hrs. dist. evenly over 10 years
Noise Level	93 DBA at 3 ft.
Method of Cooling	Air Cooled, 1100 CFM @ 9000 RPM
Lubrication - Each Bearing	MIL-L-7808 Oil, 115 cc/min @ .5-1.5 psi
Electrical Load Type	Induction Motor
Prime Mover Power	Diesel Engine Via Gear Box

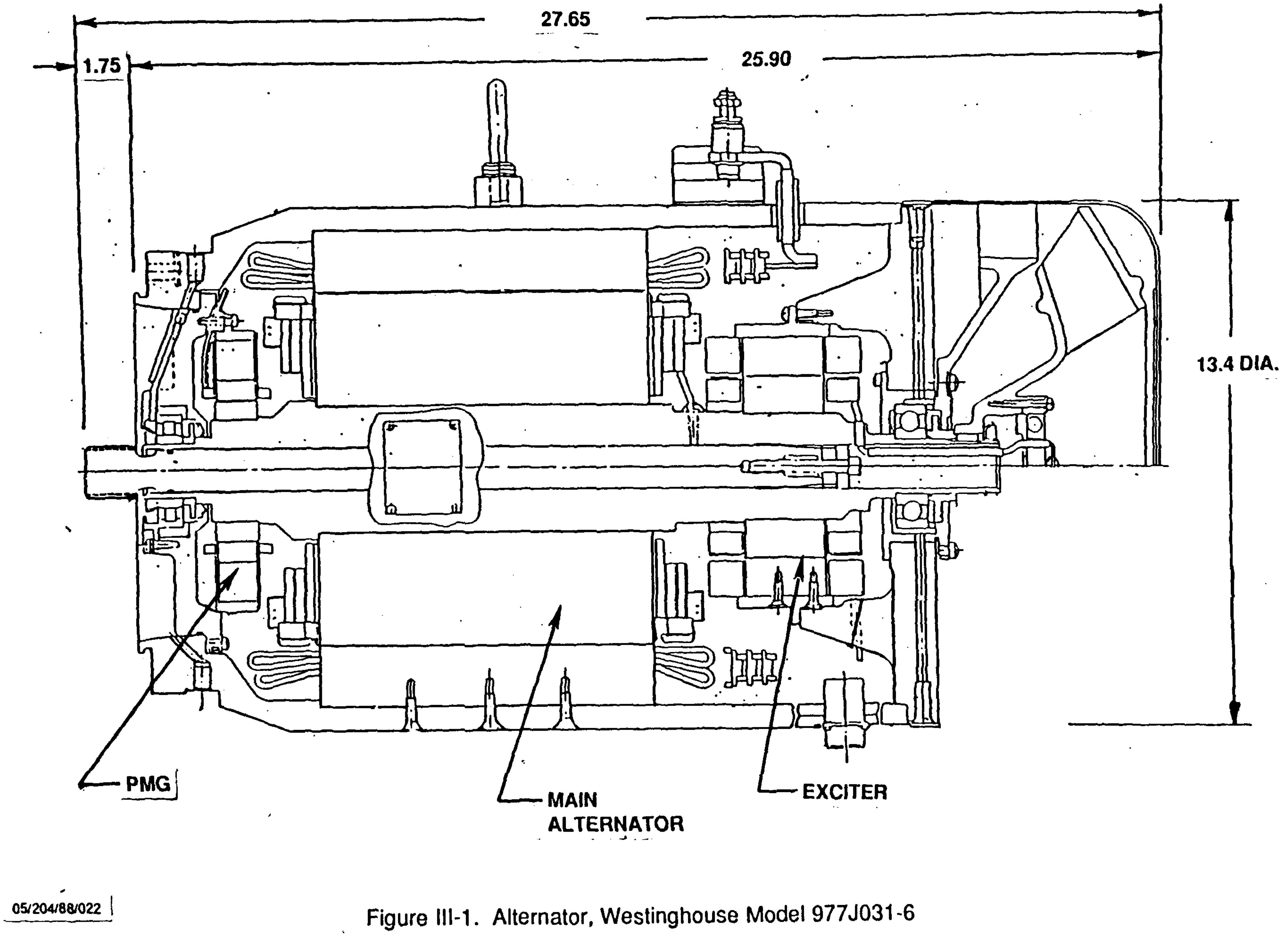
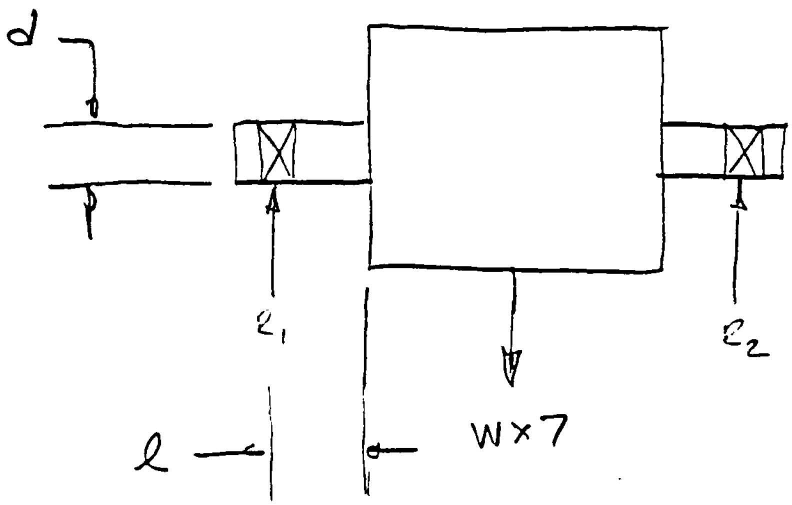


Figure III-1. Alternator, Westinghouse Model 977J031-6

APPENDIX IV

Stress Calculations

SHAFT BENDING STRESS - 7g SHOCK LOAD



DUE TO SYMETRY $R_1 = R_2 = \frac{W \times 7}{2}$ lb

$W = 76$ lb. WEIGHT

$R_1 = 266$ Lb. REACTION FORCE

BENDING MOMENT $M = R_1 \ell$ in. Lb

$\ell = .875$ in. LENGTH

$M = 232$ in Lb. MOMENT

$S_b = \frac{M}{Z}$ PSI BENDING STRESS

$Z = \frac{\pi d^3}{32}$ in^3 SECTION MODULUS

$d = 1.25$ DIAMETER

$Z = .1917 \ in^3$

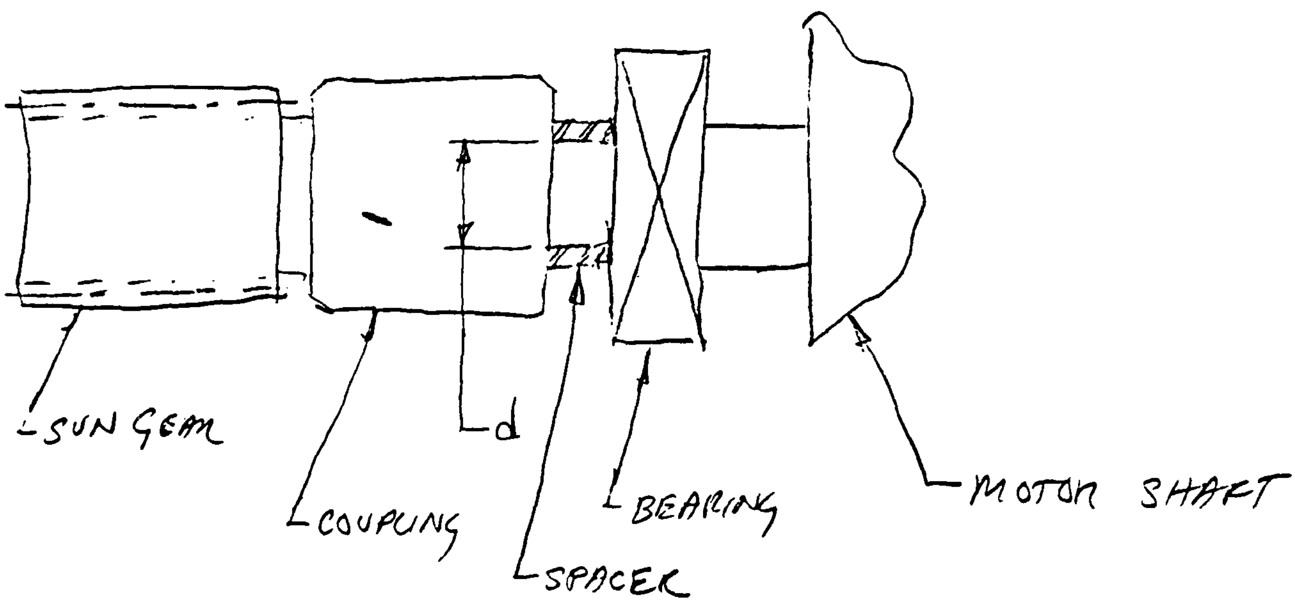
$S_b = 1214$ PSI

MATERIAL; PH13-8 MO

SAFE WORKING STRESS: 190,500 PSI BENDING

FACTOR OF SAFETY = 157

SHAFT TORSIONAL SHEAR STRESS - 1.3 OVERLOAD



$S_s = \frac{Tr}{J}$ PSI — SHEAR STRESS

$J = \frac{\pi d^4}{32}$ $IN.^4$ — POLAR MOMENT OF INERTIA

$d = .95$ IN — DIAMETER

$r = d/2$ — RADIUS

$T = 1.3 \times 2919 = 3795$ IN-LB TORQUE

$J = .0799$

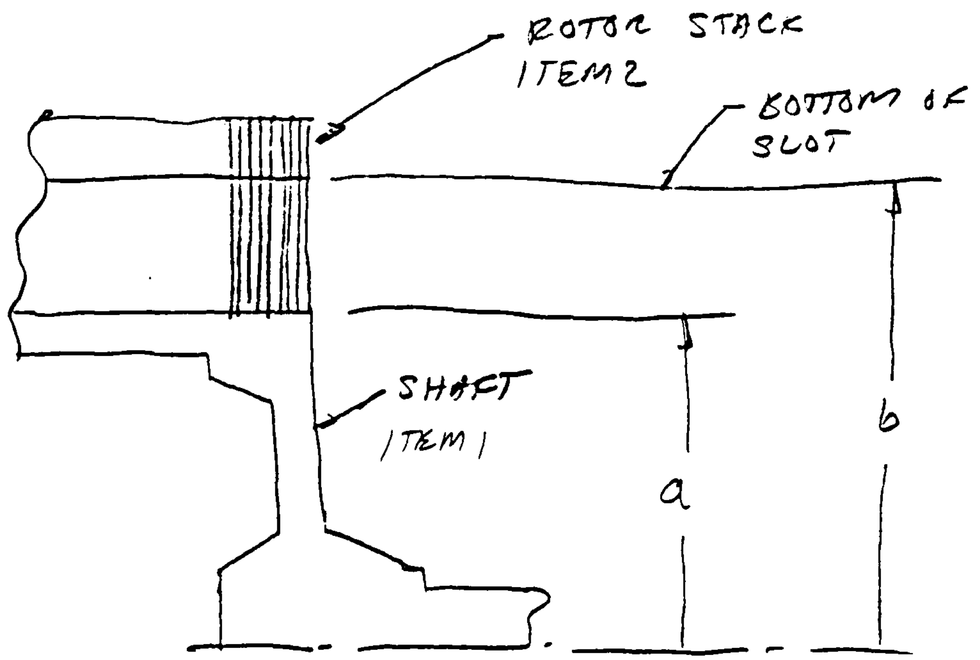
$S_s = 22{,}600$ PSI

MATERIAL: PH13-8 MO

SAFE WORKING STRESS: 75000 PSI SHEAR

FACTOR OF SAFETY = 3.32

ASSEMBLY STRESS OF ROTOR LAMINATION ON SHAFT



$$\Delta_1 = P_1 \frac{a}{E_1}(1-\nu_1)$$ ROARK, FORMULAS FOR STRESS AND STRAIN 4RTH EDITION P308, CASE 34

$$\Delta_2 = P_2 \frac{a}{E_2}\left(\frac{b^2+a^2}{b^2-a^2}+\nu_2\right)$$ ROARK P308, CASE 33

$P_1 = P_2 = P$ = PRESSURE AT INTERFACE

$\Delta = \Delta_1 + \Delta_2$ = TOTAL INTERFERENCE BETWEEN PARTS

REARRANGING:

$$\frac{1}{P} = \frac{1}{\Delta}\left[\frac{a}{E_1}(1-\nu_1) + \frac{a}{E_2}\left(\frac{b^2+a^2}{b^2-a^2}+\nu_2\right)\right]$$

Δ = .0015 IN MAX RADIAL INT.

$E_1 = E_2 = 30 \times 10^6$ PSI ELASTIC MODULUS

$\nu_1 = \nu_2 = .3$ POISSON'S RATIO

$a = 2.875$ IN. $b = 3.887$ IN.

$P = 3550$ PSI

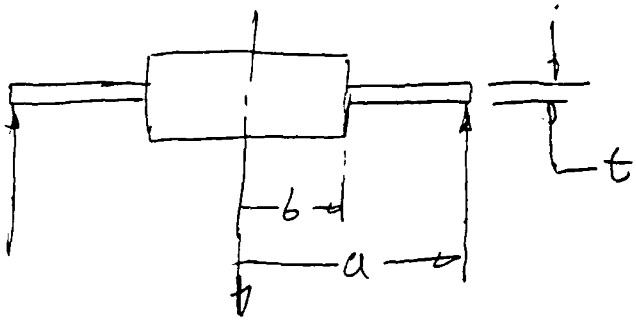
$$S_t = P\frac{b^2+a^2}{b^2-a^2}$$ ROARK P308, CASE 33

$S_t = 12000.$ PSI TANGENTIAL STRESS

MATERIAL PERMENDUR V SPECIFIED MIN. Y.P = 30,000 PSI

FACTOR OF SAFETY = 2.5.

FORWARD BULKHEAD - TO SHOCK



$F = 7W$

INNER EDGE FIXED, OUTER EDGE SIMPLY SUPPORTED

ROARK P. 222 CASE 22

$$S_{MAX} = \frac{\beta F}{t^2} \qquad y_{max} = \frac{\alpha F a^2}{E t^3}$$ ROARK P242

$a = 6.5$ in INSIDE RADIUS

$b = 1.625$ in OUTSIDE RADIUS

$E = 10 \times 10^6$ PSI ELASTIC MODULUS

$t = .688$ in THICKNESS

$\alpha = .293 \qquad \beta = 1.514$ ROARK P. 241

$W = 76$ lb ROTOR WEIGHT

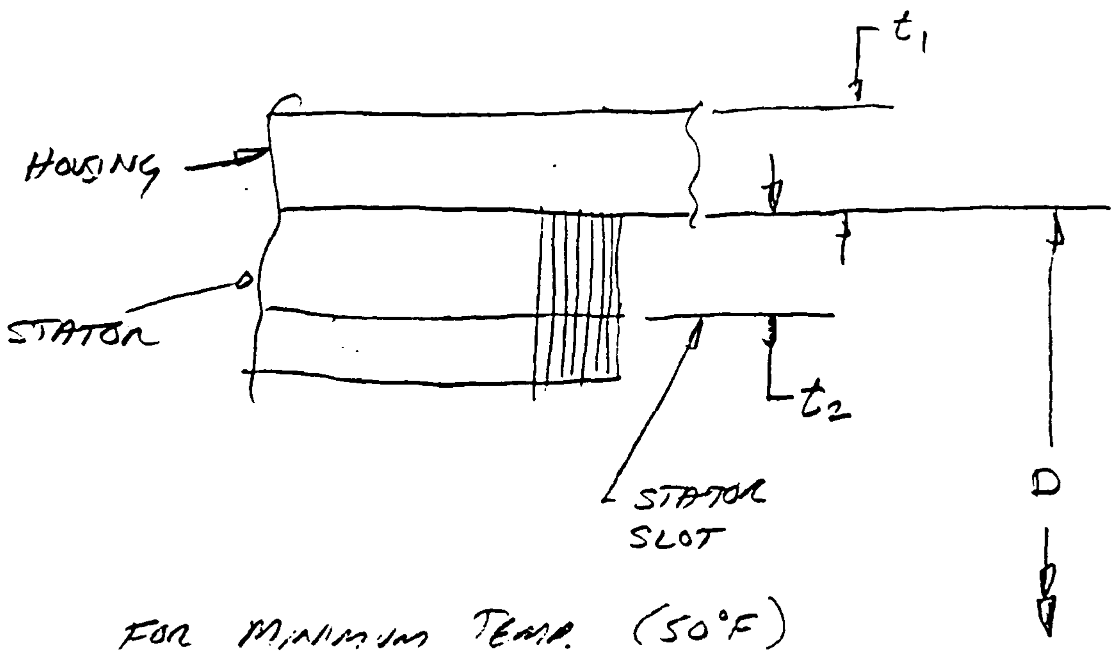
$F = 532$ lb FORCE DUE TO SHOCK LOAD

$S_{MAX} = 1700$ PSI BENDING STRESS

$y_{max} = .0020$ IN. DEFLECTION

MAT'L 6061-T6 ALUMINUM - SAFE BENDING STRESS: 40,000 PSI
S.F. = 23.5

HOUSING AND STATOR INT. FIT



FOR MINIMUM TEMP. (50°F)

$\Delta_{T_1} = K_1 D(T_1 - T_{RT})$ = THERMAL GROWTH OF HOUSING

$\Delta_{T2} = K_2 D(T_2 - T_{RT})$ = THERMAL GROWTH OF STATOR

$\Delta m = .014$ IN. MECHANICAL INTERFERENCE AT ROOM TEMP ($T_{RT} = 72°F$)

$T_1 = T_2 = 50°F$

$\Delta = \Delta_m + \Delta_{T2} - \Delta_{T1}$ NET INTERFERENCE

$K_1 = 13.6 \times 10^{-6}$ /°F

$K_2 = 5.44 \times 10^{-6}$/°F

$D = 11.625$

$\Delta = .0161$ in.

ASSEMBLY PRESSURE

$$\Delta_1 = \frac{P_1}{E_1}\frac{D^2}{2t_1} \qquad \delta_2 = \frac{P_2}{E_2}\frac{D^2}{2t_2}$$

THIN WALL PIPE

$$\Delta = \Delta_1 + \Delta_2 \qquad P = P_1 = P_2$$

COMBINING ABOVE EQUATIONS

$$\frac{1}{P} = \frac{D^2}{2\Delta}\left(\frac{1}{E_1 t_1} + \frac{1}{E_2 t_2}\right)$$

$E_1 = 10 \times 10^6$ PSI ELASTIC MODULUS

$E_2 = 30 \times 10^6$ PSI " "

$t_1 = .625$ in. WALL THICKNESS

$t_2 = .625$ in. " "

$D = 11.625$ in. DIAMETER

$P = 1120$ PSI ASSEMBLY PRESSURE

$$S_1 = \frac{PD}{2t_1} = 10{,}400 \text{ PSI}$$

$$S_2 = \frac{PD}{2t_2} = 10{,}400 \text{ PSI}$$

MATERIAL :

ITEM 1 6061-T6 SAFE STRESS 40,000 PSI

FACTOR OF SAFETY 3.84

ITEM 2 PERMENDUR V SPECIFIED MINIMUM Y.P = 30,000 PSI

FACTOR OF SAFETY 2.88

MINIMUM INTERFERENCE AT OPERATING TEMPERATURE

$$\Delta = \Delta_M + \Delta_{T2} - \Delta_{T3}$$

$T_1 = 136\ °F$ AVG HOUSING TEMPERATURE

$T_2 = 170°F$ AVG STATOR TEMPERATURE

$\Delta_M = .008$ IN. MINIMUM MECHANICAL INTERFERENCE

$\Delta = .0041$ IN. ∴ INTERFERENCE MAINTAINED.

BEARING LIFE

$T = 39$ LB THRUST LOAD

$nd^2 = .8789$ BEARING CONSTANT BARDEN CAT P. 98

$T/nd^2 = 44.4$

$\phi = 9.6°$ CONTACT ANGLE BARDEN CAT. P. 98

$P = XR + YT$, BARDEN CAT. P. 88

$R = 37.5$ LB = RADIAL LOAD

$X = f(\phi, T/nd^2) = .46$ BARDEN CAT. P. 89

$Y = f(\phi) = 1.70 = 1.70$ " " P. 89

$P = 23.55$

$L_{10} = \left(\frac{C}{P}\right)^3 \times 10^6$ BARDEN CAT. P. 88

$C = 2380$ LB DYNAMIC CAPACITY " " P. 98

$L_{10} = 2.311 \times 10^{10}$ REVOLUTIONS (MINIMUM LIFE OF 90% OF BEARINGS)

@ 9000 RPM

LIFE = 42810 HRS

REQUIRED LIFE 500 HRS

FACTOR OF SAFETY 85.6

SHOCK LOADS

$C_0 = 1{,}136$ lb STATIC RADIAL CAPACITY BARDEN P. 98

$R = 7 \times 37.5 = 262.5$ RADIAL LOAD WITH SHOCK

FACTOR OF SAFETY : 4.33

$T_0 = 1{,}772$ lb STATIC THRUST CAPACITY BARDEN P. 98

$T = 7 \times 75 = 525$ LB THRUST LOAD WITH SHOCK

FACTOR OF SAFETY : 3.375

Engineering

Bearing Performance

Bearing Life

The useful life of a ball bearing has historically been considered to be limited by the onset of fatigue or spalling of the raceways and balls, assuming that the bearing was properly selected and mounted, effectively lubricated and protected against contaminants.

This basic concept is still valid, but refinements have been introduced as a result of intensive study of bearing failure modes. Useful bearing life may be limited by reasons other than the onset of fatigue.

Service life

When a bearing no longer fulfills minimum performance requirements in such categories as restraining torque, vibration or elastic yield, its service life may be effectively ended.

If the bearing remains in operation, its performance is likely to decline for some time before fatigue spalling takes place. In such circumstances, bearing performance is properly used as the governing factor in determining bearing life.

Lubrication can be an important factor influencing service life. Many bearings are prelubricated by the bearing manufacturer with an appropriate quantity of lubricant. They will reach the end of their useful life when the lubricant either migrates away from the bearing parts, oxidizes or suffers some other degradation. At that point, the lubricant is no longer effective and surface distress of the operating surfaces, rather than fatigue, is the cause of failure. Bearing life is thus very dependent upon characteristics of specific lubricants, operating temperature and atmospheric environment.

Specific determination of bearing life under unfavorable conditions can be difficult, but experience offers the following guidelines to achieve better life.

1. Reduce load—particularly minimize applied axial preload.
2. Decrease speed to reduce the duty upon the lubricant and reduce churning.
3. Lower the temperature. This is important if lubricants are adversely affected by oxidation, which is accelerated at high temperatures.
4. Increase lubricant supply by improving reservoir provisions.
5. Increase viscosity of the lubricant, but not to the point where the bearing torque is adversely affected.
6. To reduce introduction of contaminants, substitute sealed or shielded bearings for open bearings and use extra care in installation.
7. Improve alignment and fitting practice, both of which will reduce duty on the lubricant and tend to minimize wear of bearing cages.

The most reliable bearing service life predictions are those based on field experience under comparable operating and environmental conditions.

Fatigue life

The concept that bearing life is limited by the onset of fatigue is generally accurate for bearings operating at normal speeds in general machinery applications. The basic relationship between bearing capacity, imposed loading and expected fatigue life is:

$$L_{10} = \left(\frac{C}{P}\right)^3 \times 10^6 \text{ revolutions.*} \qquad \text{(Formula 1)}$$

In the above expression:

L_{10} = Minimum life in revolutions for 90% of a typical group of apparently identical bearings.

C = Basic Load Rating.

P = Equivalent Radial Load, computed as follows:

$$P = XR + YT \qquad \text{(Formula 2)}$$

or

$$P = R \qquad \text{(Formula 2)}$$

whichever is greater.

In the preceding equation:

R = Radial load.

T = Thrust load.

X = Radial load factor relating to contact angle.

Y = Axial load factor depending upon contact angle, T and ball complement.

For Basic Load Ratings, see Data Reference Tables starting on page 95. For X and Y factors, see Tables 19 and 20.

*See AFBMA Standard 9 for more complete discussion of bearing life in terms of usual industry concepts.

Engineering

Bearing Performance

Tabular engineering data listed for miniature and instrument bearings are for bearings with rings and balls of AISI 440C stainless steel. Data for spindle and turbine bearings are for bearings of SAE 52100. See page 67 for definitions of static and dynamic load ratings. Static capacities for deep groove bearings are based on Code 5 radial play.

Data Reference Numbers — 200 cont. and 300

Data Reference Number	Load Factor Table	Initial Contact Angle, degrees: Radial Play Range Code 3	Code 5	Code 6	Std.	Ball Complement: Number n	Diameter d	Value nd²	Static Capacity: Radial C_o (lbs.)	Thrust T_o (lbs.)	Basic Dynamic Load Rating C (lbs.)
201HJB	20		12.8	16.4	15.3	10	15/64"	.5493	661	876	1,432
202	20	10.7	15.2	19.5		7	1/4"	.4375	510	701	1,306
202H	20		12.4	15.9	14.8	10	1/4"	.6250	769	1,093	1,622
203	20	10.4	14.8	18.9		8	17/64"	.5645	692	1,094	1,614
203H	20		12.0	15.4	14.4	10	17/64"	.7056	894	1,885	1,825
203HJB	20		12.0	15.4	14.4	11	17/64"	.7761	983	1,626	1,945
203HX37	20		12.0	15.4	12.9	10	17/64"	.7056	903	1.503	1,839
204	20	9.6	13.6	17.5		8	5/16"	.7813	969	1,537	2.173
204H	20		11.1	14.2	15.1	10	5/16"	.9766	1,241	2,034	2,440
204HJB	20		11.1	14.2	15.1	11	5/16"	1.074	1,370	2,237	2.601
205	20	9.6	13.6	17.5		9	5/16"	.8789	1,136	1,772	2.380
205H	20		11.1	14.2	15.1	11	5/16"	1.074	1,440	2,295	2,607
205HJB	20		11.1	14.2	15.1	13	5/16"	1.270	1,698	2,712	2.914
206	20	8.8	14.5	17.9		9	3/8"	1.270	1,627	2,525	3,295
206H	20				15.1	11	13/32"	1.820	2,364	5.295	4,248
2C7	20	8.1	13.4	16.6		9	7/16"	1 723	2,228	4,056	4,363
207H	20		12.0		14.8	12	7/16"	2.297	3,079	5,554	5,165
208	20	7.8	12.9	16.0		9	15/32"	1.978	2,600	6,182	4,954
208H	20				15.0	12	15/32"	2.637	3,580	8,076	5,843
209	20	7.8	12.9	16.0		10	15/32"	2.197	3,071	5,327	5,318
209H	20				15.0	13	15/32"	2 856	3.973	7,071	6,145
210H	20				15.0	14	1/2"	3.500	4,879	8.713	7,250
211H	20				14.9	14	9/16"	4 430	6,140	13,923	8.973
212H	20				14 9	14	5/8"	5.469	7,569	13,579	10,870
213H	20				15.2	14	11/16"	6.617	9.104	20.706	12,880
214H	20				15.2	15	11/16"	7 090	9.921	22.613	13.447
215H	20				15.2	17	11/16"	8.035	11,396	26.070	14,558
216H	20				15.1	15	3/4"	8.440	11,920	27.195	15,691
218H	20				15.3	15	7/8"	11.48	16,098	36,781	20,739
220H	20				15.2	15	1"	15.00	20,909	47,637	26,417
304H	20				15.1	9	13/32"	1.485	1,720	3,786	3,567
305H	20				15 0	10	15/32"	2.197	2,606	5,747	5.007
306H	20				15.0	10	17/32"	2 822	3,412	7,544	6,326
307H	20				15 0	11	9/16"	3.480	4,339	9.607	7,549
308H	20				14.9	11	5/8"	4 297	5,427	12,040	9,164
309H	20				15.2	11	11/16"	5.199	6,561	14,679	10,864
310H	20				15.1	11	3/4"	6.188	7,850	17,510	12,732

Table 19. Load Factors for Miniature and Instrument Bearings

T/nd^2	Contact Angle, degrees			
	5	10	15	20
	Values of Axial Load Factor Y			
25	3.23	2.23	1.60	1.18
50	2.77	2.09	1.56	1.18
100	2.41	1.93	1.51	1.18
150	2.22	1.83	1.46	1.18
200	2.10	1.76	1.43	1.18
300	1.92	1.66	1.38	1.18
500	1.71	1.53	1.31	1.18
750	1.55	1.43	1.25	1.18
1000	1.43	1.35	1.21	1.18
	Values of Radial Load Factor X			
	0.56	0.46	0.44	0.43

Table 20. Load Factors for Spindle and Turbine Bearings

T/nd^2	Contact Angle, degrees								
	5	6	7	8	9	10	15	20	25
	Values of Axial Load Factor Y								
10	—	—	—	2.38	2.27	2.13	1.57	1.00	0.87
20	2.40	2.32	2.23	2.14	2.10	1.94	1.50	1.00	0.87
30	2.22	2.15	2.08	2.00	1.92	1.83	1.46	1.00	0.87
40	2.09	2.03	1.97	1.91	1.84	1.76	1.42	1.00	0.87
50	1.99	1.94	1.89	1.83	1.77	1.70	1.40	1.00	0.87
60	1.91	1.87	1.82	1.77	1.71	1.65	1.37	1.00	0.87
70	1.85	1.81	1.76	1.72	1.67	1.61	1.35	1.00	0.87
80	1.79	1.76	1.72	1.68	1.63	1.58	1.33	1.00	0.87
90	1.75	1.71	1.68	1.64	1.59	1.55	1.31	1.00	0.87
100	1.71	1.57	1.64	1.60	1.56	1.52	1.30	1.00	0.87
150	1.55	1.53	1.50	1.47	1.45	1.41	1.23	1.00	0.87
200	1.45	1.43	1.41	1.38	1.36	1.34	1.19	1.00	0.87
300	1.31	1.30	1.28	1.26	1.25	1.23	1.12	1.00	0.87
400	1.22	1.21	1.20	1.18	1.17	1.16	1.07	1.00	0.87
500	1.15	1.14	1.13	1.12	1.11	1.10	1.02	1.00	0.87
600	1.10	1.09	1.08	1.07	1.05	1.05	1.00	1.00	0.87
700	1.06	1.05	1.04	1.03	1.02	1.01	1.00	1.00	0.87
800	1.03	1.02	1.01	1.00	1.00	1.00	1.00	1.00	0.87
900	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.87
1000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.87
	Values of Radial Load Factor X								
	0.56	0.51	0.49	0.48	0.47	0.46	0.44	0.43	0.41

Note: Values of nd^2 are given in Data Reference Tables starting on page 95.

SDG STRESS CALCULATIONS

INPUT SHAFT KEY STRESS

TORQUE = 1.3 x 2943 IN. -LB.

SHAFT DIA = .984

KEY 1/4 x 1/4 x 1 1/4 LG

SHEAR AREA = .312 in^2

SHEAR FORCE = 1.3 x 2943 ÷ .492 = 7775 lb.

S_S = 7775 ÷ .312 = 24920 PSI

ALLOWABLE SHEAR = 132000 ÷ 2 = 66,000 PSI
(BETHLEHEM STEEL : 4140 STL @ 311 BHN)

F.S. = 2.65

COMPRESSIVE STRESS

AREA = .156 in^2

S = 7775 ÷ .156 = 49,000 PSI

ALLOWABLE STRESS = 132000 PSI (4140 AS ABOVE)

F.S. = 2.69

COUPLING STRESSES

NECK

$d_o = 2.00$ in.

$di = 1.625$ in.

$R = \frac{di}{do} = .8125$

$d =$ EQUIV. SOLID SHAFT $= d_o \sqrt[3]{1 - R^4}$

$d = 1.652$

$S_s = \frac{5.093\,T}{d^3} = \frac{5.093 \times 2942 \times 1.3}{1.652^3} = 4321$ PSI

ACCOWABLE SHEAR STRESS = $145000 \div 2 = 72000$ PSI
(J&L STEEL : 4150 STEEL @ 350 BHN)

S.F. = 16.7

SPLINE

$S_S = 1.2732 \frac{T}{LD^2}$

L = SPLINE LENGTH = .312 in.

D = PITCH DIAMETER = 1.392 in.

T = TORQUE = 2942×1.3 in. LB.

$S_s = 8020$ PSI

S.F. = 8.98

COMPRESSIVE STRESS ON TEETH/

A = .125 in. ACTIVE PROFILE x .312 FACE WIDTH
x 12 TEETH = .468 $in.^2$

F = 2942 x 1.3 ÷ .781 = 4900 LBS

S = 4900 ÷ .468 = 10,100 PSI

ALLOWABLE STRESS = 145000 PSI

S.F. = 14.4

RING GEAR TANG

TOTAL LOAD ON RING GEAR TANG = 4217 x 1.3 LB

BENDING STRESS = $\frac{WL}{Z}$

L = .2 in.

$Z = \frac{bd^2}{12}$

b = .375 in.

d = .750 in

Z = .0176

S = 62,400 PSI

SAFE BENDING STRESS = 145,000 PSI (4150 STL AS ABOVE)

S.F. = 2.32

COMPRESSIVE STRESS OF DOWEL ON ALUMINUM BULKHEAD

AREA = .62 x .8 = .5 in^2

$$S = \frac{4217 \times 1.3}{.5} = 11{,}000 \text{ PSI}$$

SAFE COMPRESSIVE STRESS = 22,000 PSI
(A356 CAST ALUMINUM)

S.F. = 2.00

APPENDIX V

Thermal Calculations

REQUIRED OIL FLOW RATE

$$\dot{m} = \frac{q}{\Delta T C_p 3600}$$

$q = 50400$ Btu/HR TOTAL HEAT FLOW INTO OIL

$T_H = 215°F$ HOT OIL TEMP

$T_C = 155°F$ COLD OIL TEMP

$\Delta T = 60°F$

$C_p = .514$ Btu/lbm °F

$\dot{m} = .4543$ lbm/sec FLOW RATE

$$Q = \frac{1728 \times 60}{231} \frac{\dot{m}}{\rho}$$

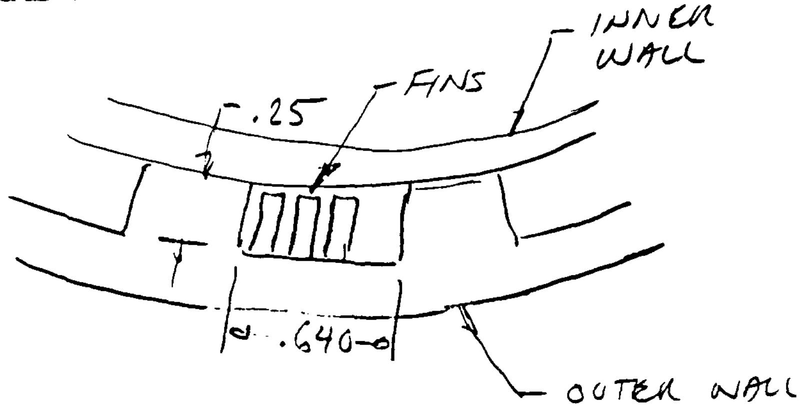
$\rho = 58.28$ lbm/ft^3 DENSITY OF OIL

$Q = 3.5$ GPM FLOW RATE

HEAT EXCHANGER RESISTANCES

NOTE: HEAT EXCHANGER TREATED AS TWO SEPARATE UNITS - UNIT 1 OVER STATOR CARRIES HEAT FROM THE STATOR AS WELL AS THE OIL AND UNIT 2 ADJACENT TO THE STATOR CARRIES HEAT FROM THE OIL ONLY

CONVECTION TO OUTER WALL



FINS:

28 FINS/IN.
.240 IN. HIGH
.005 THICK
3003 ALUMINUM

$P = .5414$ IN.	PERIMETER
$A_p = .007368\ IN^2$	AREA OF ONE PASSAGE
$4r_h = .0544$ in	HYDRAULIC DIAMETER
$A/V = 715\ ft^2/ft^3$	HEAT TRANSFER AREA PER UNIT OF FIN VOLUME
$A_f/A = .9399$	FIN AREA PER UNIT OF HEAT TRANSFER AREA

$$R_E = \frac{12}{g_c} \frac{\dot{m} D}{A \mu}$$

$\dot{m} = .223$ lbm/sec (FLOW SPLIT INTO 2 PARALLEL PATHS)

$D = 4r_h = .0544$ in.

$A = .1289\ in^2$ AREA OF TOTAL PASSAGE

$\mu = 7.032 \times 10^{-5}$ lbf-sec/ft^2 VISCOSITY OF OIL

$R_e = 499.1$

$$P_r = 3600 \times 32.2 \times \frac{c_p \mu}{K}$$

$c_p = .514$ Btu/lbm °F SPECIFIC HEAT OF OIL

$K = .07$ Btu/hr · ft · °F THERMAL CONDUCTIVITY OF OIL

$P_r = 59.86$

$$N_u = f\left(\frac{R_e P_r D}{L}\right)$$ KREITH, PRINCIPLES OF HEAT TRANSFER, 2ND ED. P. 590

$D = 4 r_h = .0544$ in. HYDRAULIC DIAMETER

$L = 159.9$ in. TOTAL LENGTH OF OIL CHANNEL OF HEAT EXCHANGER

$$\frac{R_e P_r D}{L} = 11.63$$

$N_u = 4.2$ KREITH P. 590

$$h_c = \frac{12\, N_u k}{D} = 64.8 \text{ Btu/hr} \cdot \text{ft}^2 \cdot {}^\circ\text{F}$$ HEAT TRANSFER COEFFICIENT

FIN EFFICIENCY

$$m = \sqrt{\frac{2 h_c}{K \delta}}$$ KAYS & LONDON, COMPACT HEAT EXCHANGERS 2ND ED., P. 14

$K = 100$ Btu/hr · ft · °F THERMAL CONDUCTIVITY OF FIN

$\delta = .005$ IN FIN THICKNESS

$m = 55.77\ ft^{-1}$

$\eta_f = f(ml)$ KAYS & LONDON P50

$l = .240$ IN. LENGTH OF FIN

$ml = 1.116$

used directly in the log-mean-rate equations for heat exchangers presented in Chapter 11.

The mean Nusselt numbers for laminar flow in tubes at a uniform wall temperature have been calculated analytically by various investigators. Their results are shown in Fig. 8-12 for several velocity distributions. All of these solutions are based on the idealizations of a constant tube-wall temperature and a uniform temperature distribution at the tube inlet and apply strictly only when the physical properties are independent of temperature. The abscissa is the dimensionless quantity $Re_D Pr D/L$, usually

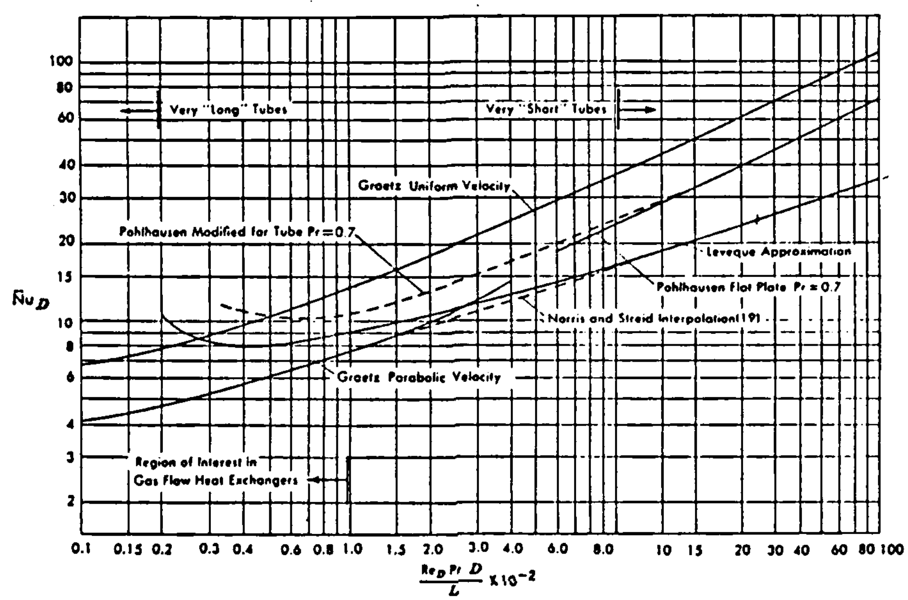
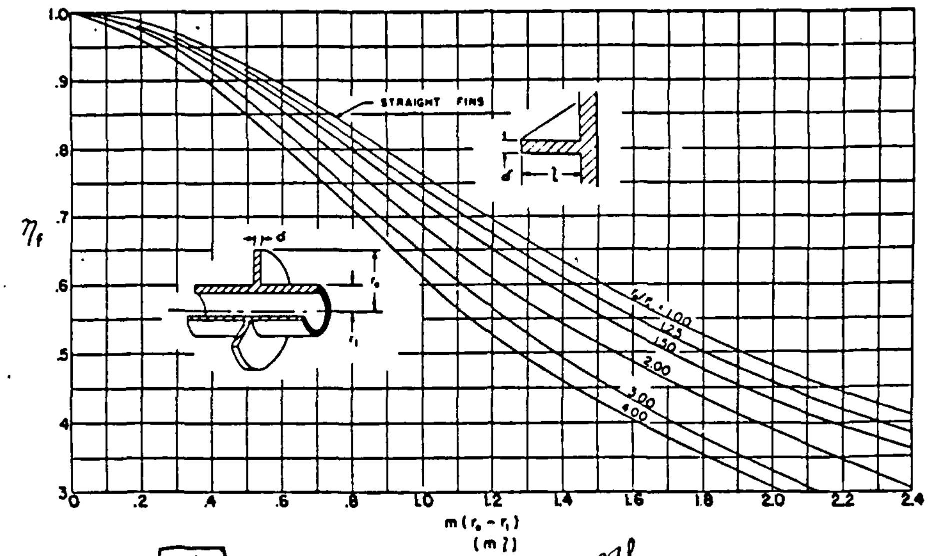


FIG. 8-12. Curves illustrating solutions for laminar-flow heat transfer at constant wall temperature. (Extracted from "Numerical Solutions for Laminar Flow Heat Transfer in Circular Tubes," by W. M. Kays, published in *Trans. ASME*, Vol. 77, 1955, with permission of the publishers, The American Society of Mechanical Engineers)

called the Graetz number Gz. To determine the mean value of the Nusselt number for a given tube of length L and diameter D, one evaluates the Reynolds number Re_D, the Prandtl number Pr, forms the dimensionless parameter $Re_D\, Pr D/L$, and enters the curve of Fig. 8-12. The selection of the curve representing the conditions which most nearly correspond to the physical conditions depends on the nature of the fluid and the geometry of the system. For high-Prandtl-number fluids, such as oils, the velocity profile is established much more rapidly than the temperature profile. Consequently the application of the curve labeled "parabolic velocity" does not lead to a serious error in long tubes when $Re_D Pr D/L$ is less than 100.

Fig. 2-11. Heat transfer effectiveness of straight and circular fins.



$m = \sqrt{\frac{2h}{k\delta}}$ circ. fins

$= \sqrt{\frac{4h}{kd}}$ rods

Fig. 2-12. Heat transfer effectiveness as a function of number of transfer units and capacity rate ratio; counterflow exchanger.

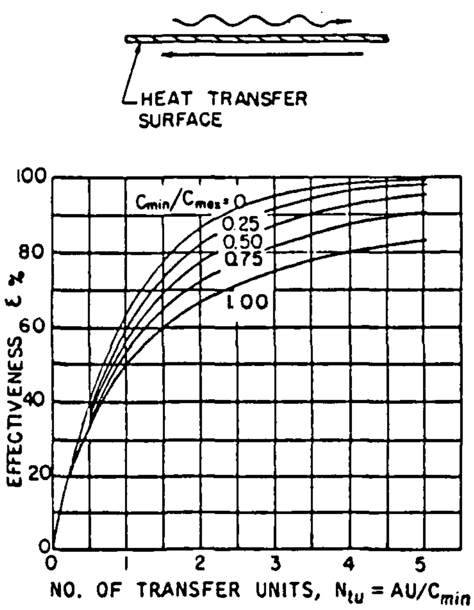
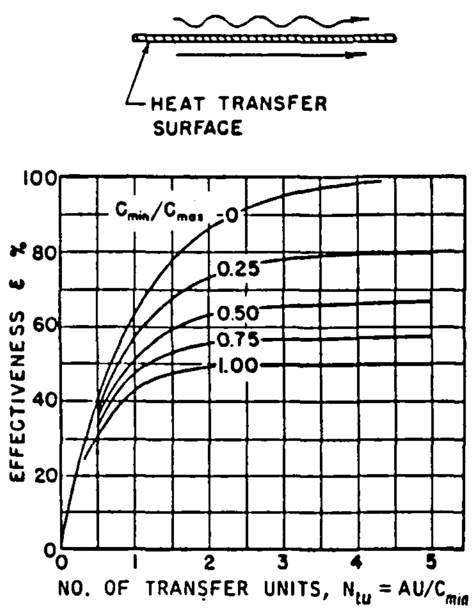


Fig. 2-13. Heat transfer effectiveness as a function of number of transfer units and capacity rate ratio; parallel-flow exchanger.



$\eta_f = .73$ FIN EFFICIENCY

$\eta_o = 1 - A_f/A\,(1-\eta_f)$ KAYS & LONDON P 14

$\eta_o = .7462$ OVERALL EFFICIENCY

$R = \dfrac{1}{\eta_o h_c (A/V) V}$ RESISTANCE

$V_1 = .01789 \ ft^3$ VOLUME OF HEAT EXCHANGER OVER STATOR

$V_2 = .006388 \ ft^3$ VOLUME OF HEAT EXCHANGER ADJACENT TO STATOR

$R_1 = .001617 \ HR \cdot {}^\circ F/BTU$

$R_2 = .004526 \ HR \cdot {}^\circ F/BTU$

CONVECTION TO INNER SHELL

$R = \dfrac{1}{h_c A}$ RESISTANCE

$A_1 = .7670 \ ft^2$ AREA OF INNER SHELL OVER STATOR

$A_2 = .4474 \ ft^2$ AREA OF INNER SHELL ADJACENT TO STATOR

$h_c = 64.8 \ Btu/HR \cdot Ft^2 \cdot {}^\circ F$

$R_1 = .02011 \ HR \cdot {}^\circ F/Btu$

$R_2 = .03448 \ HR \ {}^\circ F/Btu$

INNER SHELL TO OUTER SHELL

$R = \dfrac{1}{h_c A}$ RESISTANCE

$A_1 = .4602\ ft^2$ AREA OF INNER SHELL & OUTER SHELL CONTACT ZONE OVER STATOR

$A_2 = .2684\ ft^2$ AREA ADJACENT TO STATOR

$1/h_c = .0002\ \dfrac{Hr \cdot Ft^2 \cdot °F}{Btu}$ GENERAL ELECTRIC, HEAT TRANSFER DATA BOOK, SECT 502.5 P 13

$R_1 = .0004346\ Hr \cdot °F/Btu$

$R_2 = .0007452\ Hr \cdot °F/Btu$

OUTER WALL

$R = \dfrac{t}{KA}$ RESISTANCE

$t = .375\ in.$ WALL THICKNESS

$K = 119\ Btu/Hr \cdot Ft \cdot °F$ THERMAL CONDUCTIVITY OF ALUMINUM

$A_1 = 1.432\ ft^2$ AREA OVER STATOR

$A_2 = .8183\ ft^2$ AREA ADJACENT TO STATOR

$R_1 = .0001834\ Hr \cdot °F/Btu$

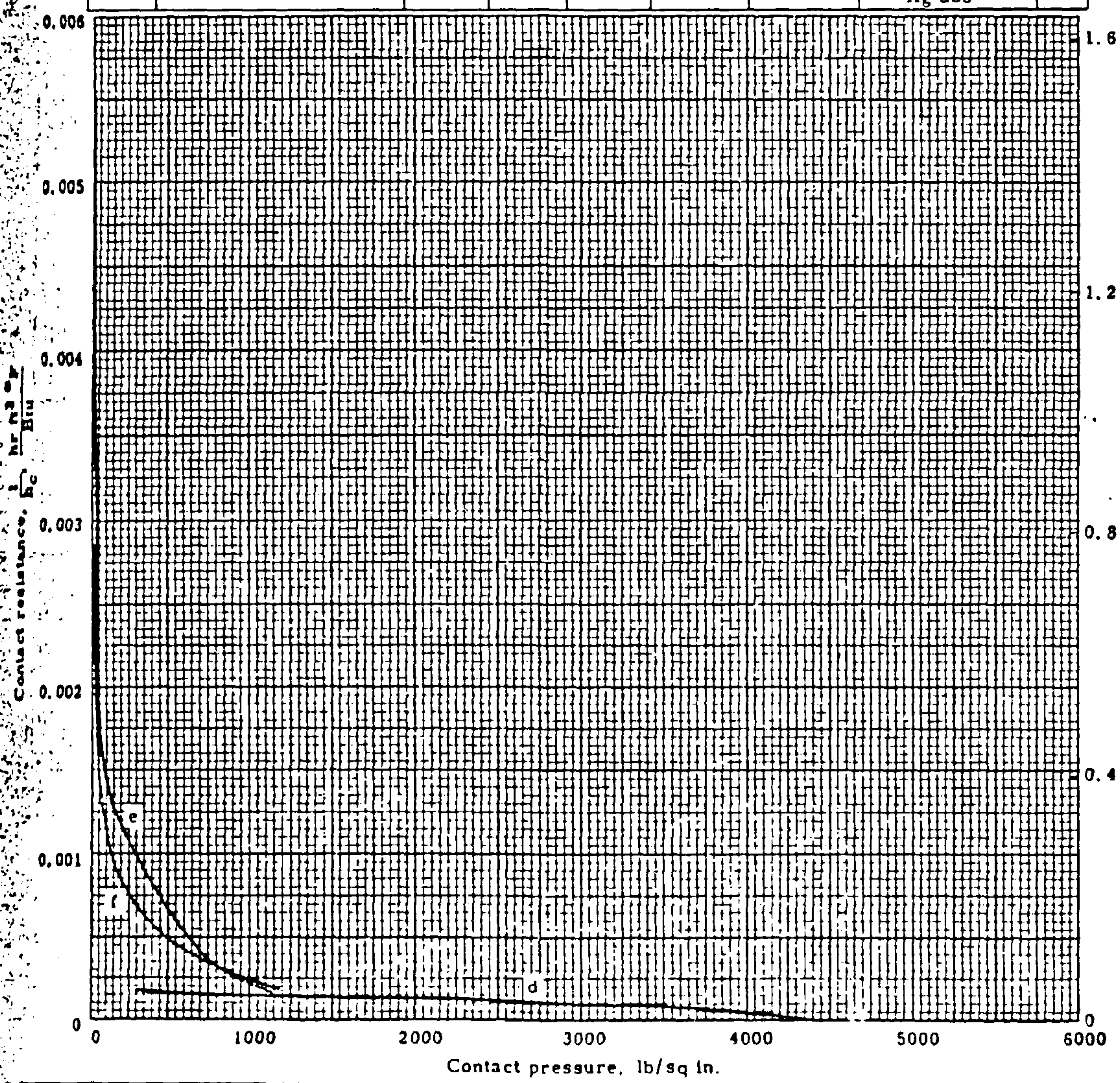
$R_2 = .0003209\ Hr \cdot °F/Btu$

8.

ALUMINUM, BARE SURFACES (200 to 6000 psi) - Solid blocks in air at reduced pressure ($p < 0.1$ atm)

For aluminum in air at 1 atm absolute pressure, see pages 10-11.
For aluminum at lower contact pressures and at reduced air pressure ($p < 0.1$ atm), see page 12.
For aluminum in other gases, see page 14.
For aluminum with sandwich material in air, see page 15; at reduced pressure ($p < 0.1$ atm), see page 16.
For aluminum with dissimilar metal in air, see page 20; at reduced pressure ($p < 0.1$ atm), see page 21.
For other metals in air, see pages 5-6, 17; at reduced pressure ($p < 0.1$ atm), see pages 18-19.
For aluminum with riveted joints in air, see page 22.

Curve	Material[4]	Finish	Roughness Rms (μ in.) Block 1	Roughness Rms (μ in.) Block 2	Fluid in Gap	Temp ($^{\circ}$F)	Condition	Ref. No.[5]
d	Aluminum[9]	Ground	53-53		Air	R. T.	Clean, 4.5 mm Hg abs	10
e	Aluminum 6061-T6	Milled	8-16	8-16	Air	83	Clean, 10^{-4} mm Hg abs	45
f	Aluminum 6061-T6	Milled	50-60	50-60	Air	112	Clean, 10^{-4} mm Hg abs	45



4,5,9 See page 24

FOULING FACTOR

$$R = \frac{1}{h_c A}$$

$h_c = 2000$ KREITH P505

$A_1 = 1.432 ft^2$ AREA OVER STATOR

$A_2 = .8183 ft^2$ AREA ADJACENT TO STATOR

$R_1 = .0003492$ HR·°F/BTU

$R_2 = .0006110$ HR·°F/BTU

CONVECTION TO WATER

$$Re = \frac{1}{12 g_c} \frac{\rho V \ell}{\mu}$$

$\rho = 62.4$ lbm/ft³ DENSITY OF WATER

$V = 10$ ft/sec. WATER VELOCITY

$\ell = 11$ in. LENGTH OF SHELL

$\mu = 1.5 \times 10^{-5}$ lbf-sec/ft² VISCOSITY OF WATER

$Re = 1.184 \times 10^6$

$h_c = .036 \frac{k}{\ell} Pr^{\frac{1}{3}} Re^{.8}$ KREITH P 314

$P_r = 5.07$ PRANDTL NO OF WATER

$K = .353$ Btu/Hr-Ft-°F THERMAL CONDUCTIVITY OF WATER

$h_c = 1856$ Btu/Hr-ft²·°F

$R = \frac{1}{h_c A}$ RESISTANCE

$A_1 = 1.432\ ft^2$ AREA OVER STATOR

$A_2 = .8183\ ft^2$ AREA ADJACENT TO STATOR

$R_1 = .0003763\ HR\text{-}°F/BTU$

$R_2 = .0006584\ HR\text{-}°F/BTU$

PRESSURE DROP THROUGH HEAT EXCHANGER

$f = 64/R_e$

$R_e = 499.1$ REYNOLDS NUMBER OF OIL

$f = .1282$ FRICTION FACTOR

$$\Delta P = \frac{144}{2g_c} f \left(\frac{l}{D}\right) \frac{1}{\rho} \left(\frac{\dot{m}}{A}\right)^2$$

$l = 139.9$ in. LENGTH OF PASSAGE

$D = 4r_h = .0544$ in. HYDRAULIC DIAMETER OF PASSAGE

$\rho = 58.28\ lbm/ft^3$ DENSITY OF OIL

$\dot{m} = .223\ lbm/sec$ FLOW RATE OF OIL

$A = .1289\ in^2$ AREA OF TOTAL PASSAGE

$\Delta P = 37.8$ PSI

THERMAL ANALYSIS OF HEATSINK ASSEMBLY (ALTERNATOR VOLTAGE CONTROLLER)

THE HEATSINK ASSEMBLY CONTAINS THE POWER SEMICONDUCTORS FOR BOTH THE BOOST CONVERTER AND THE FIELD REGULATOR, WHICH IT POWERS. THESE COMPONENTS ALL CONDUCT HEAT TO A COMMON EXTRUDED HEATSINK. THE INTENT OF THIS ANALYSIS IS TO DETERMINE THE JUNCTION TEMPERATURES OF BOOST CONVERTER POWER CUBES (2) AND THE FIELD REGULATOR POWER MOSFETS (2) AND BACK DIODES (2) AT MAXIMUM AMBIENT OF 50 DEGREES C.

SINCE THE FIELD REGULATOR GETS ITS POWER FROM THE BOOST CONVERTER, THE OPERATING POINTS OF THE TWO ARE RELATED. SYSTEMS MODELING SHOWS A STEADY STATE FIELD CURRENT NEAR 2.5 AMPS AND STARTING CURRENT OF 9 AMPS (CURRET LIMIT) FOR 3 SECONDS MAXIMUM. THE STEADY STATE THERMAL ANALYSIS USED 3 AMPS FIELD CURRENT. THE BOOST CONVERTER SUPPLIES 150V AT ABOUT 0.6 AMPS AT THIS OPERATING POINT.

AFTER DETERMINING THE STEADY STATE TEMPERATURES OF THE JUNCTIONS AND THE HEATSINK, A RE-START IS ASSUMED TO OCCUR. THE START TAKES A MAXIMUM OF 3 SECONDS WITH FIELD CURRNT OF 9 AMPS AND BOOST CONVERTER CURRENT OF 5.5 AMPS. SINCE THE HEATSINK HAS A THERMAL TIME CONSTANT OF ABOUT 20 MINUTES, IT WILL NOT CHANGE TEMPERATURE SIGNIFICANTLY DURING THE 3 SECOND START. THE JUNCTION TEMPERATURE IS TAKEN AS THE STEADY STATE HEATSINK TEMPERATURE PLUS THE DELTA T FROM JUNCTION TO SINK CALCULATED DURING START.

THREE BASIC PROGRAMS AND ONE SPICE PROGRAM ARE USED TO DO THE THERMAL ANALYSIS. THE FIRST ONE CALCULATES THE DUTY CYCLE OF THE BOOST CONVERTER FOR A GIVEN OUTPUT CURRENT. THIS IS NEEDED BY THE SECOND PROGRAM TO CALCULATE LOSSES. THE LISTINGS OF THESE TWO BOOST CONVERTER PROGRAMS FOLLOWS:

PROGRAM #1

```
5 REM PGM TO CALCULATE DUTY CYCLE AS FN OF VBUS,TR,VIN,IPEAK
6 REM NAME OF PGM IS DTBOOSTDC.BAS
10 INPUT 'VBUS(OUTPUT),VSOURCE(IN),ISEC=';VB,VS,ISEC
15 INPUT 'VDIODE,RDS(AT 150C),RSOURCE,RPRIM,RSEC=';VD,RDS,RIN,RTF,RSEC
20 INPUT 'TURNS RATIO=';TR
25 OPEN "DC.DAT" FOR OUTPUT AS FILE #2%, ACCESS WRITE, &
   SEQUENTIAL VARIABLE
30 VPRIM= (VS-2*RDS*IP-RIN*IP*DC-RTF*IP)
35 DC=(VB + 2*VD + ISEC*RSEC)/(TR*VPRIM)
26 IP= ISEC*TR
36 PRINT #2%,'INPUTS'
37 PRINT #2%
40 PRINT 'VBUS,VSOURCE,IPEAK,ISEC=';VB,VS,IP,ISEC
45 PRINT #2%,'VBUS,VSOURCE,IPEAK,ISEC=';VB,VS,IP,ISEC
50 PRINT 'VDIODE,RDS,RSOURCE,RPRIM,RSEC=';VD,RDS,RIN,RTF,RSEC
55 PRINT #2%,'VDIODE,RDS,RSOURCE,RPRIM,RSEC=';VD,RDS,RIN,RTF,RSEC
66 PRINT #2%
67 PRINT #2%
68 PRINT #2%,'OUTPUTS'
69 PRINT #2%
80 PRINT 'DUTY CYCLE=';DC
85 PRINT #2%,'DUTY CYCLE=';DC
70 PRINT 'VPRIMARY=';VPRIM
75 PRINT #2%,'VPRIMARY=';VPRIM
60 PRINT 'TURNS RATIO(STEP-UP)=';TR
65 PRINT #2%,'TURNS RATIO(STEP-UP)=';TR
90 CLOSE #2%
100 END
```

PROGRAM #2

```
10 REM THIS PGM CALCULATES LOSSES IN DT BOOST CONVERTER
12 REM AND CALULATES TRANSIENT DELTA T FROM CASE TO JUNCTION
13 REM THIS PGM CALLED DTBOOSTDIS.BAS
15 OPEN "DIS.DAT" FOR OUTPUT AS FILE #2%, ACCESS WRITE, &
   SEQUENTIAL VARIABLE
20 INPUT 'VBUS,VS,DUTY,TR=';VB,VS,DC,TR
30 INPUT 'FREQ,LFILT,IPEAKPRIM=';FREQ,LFILT,IP
40 INPUT 'RDS(FET),VDIODE=';RDS,VD
50 INPUT 'QGATE,IQGATE=';QG,IQG
60 INPUT 'QMILLER,VQMILLER=';QM,VQM
70 INPUT 'VGATE TO SWITCH ID=';VID
80 INPUT 'VGATE PS,RGATE=';VG,RG
85 INPUT 'TRANSIENT THERM Z FOR FET MODULE=';ZTMOD
86 INPUT 'TCASE OR TSINK BEFORE TRANSIENT=';TCASE
90 VL=(VB/DC)-VB
100 DT=DC/(2*FREQ)
110 DISEC=(VL*DT)/LFILT
120 DIPRIM=DISEC*TR
130 IA=IP-(DIPRIM/2)
140 IB=IP+(DIPRIM/2)
150 DCFET=DC/2
160 IRMSSQ=DCFET*(IA*IA + IA*(IB-IA) + ((IB-IA)*(IB-IA))/3)
170 PCOND=IRMSSQ*RDS
180 DCDIODE=(1-DC)/2
190 PDIODE=VD*DCDIODE*((IA+IB)/2)
200 TIR= (QG*(IP/IQG))/(.75*(VG/RG))
210 TVF= (QM*(VS/VQM))/((VG-VID)/RG)
220 PSWON= .5*VS*IA*FREQ*(TIR+TVF)
230 PSWOFF= .5*VS*IB*FREQ*(TIR+TVF)
240 PSW= PSWON+PSWOFF
250 PTOT=PSW + PCOND + PDIODE
251 PMOD= PTOT*2
252 PBOOST=2*PMOD
270 DELT_T= PMOD*ZTMOD
280 TJ= TCASE+DELT_T
281 PIN=VS*IP*DC
282 POUT=VB*IP/TR
283 EFF1=POUT/PIN
284 EFF2=POUT/(POUT+PBOOST)
300 PRINT 'INPUTS'
310 PRINT #2%,'INPUTS'
320 PRINT
321 PRINT #2%
330 PRINT 'VBUS,VS,DUTY,TR=';VB,VS,DC,TR
331 PRINT 'FREQ,LFILT,IPEAKPRIM=';FREQ,LFILT,IP
332 PRINT 'RDS(FET),VDIODE=';RDS,VD
333 PRINT 'QGATE,IQGATE=';QG,IQG
334 PRINT 'QMILLER,VQMILLER=';QM,VQM
335 PRINT 'VGATE TO SWITCH ID=';VID
336 PRINT 'VGATE PS,RGATE=';VG,RG
337 PRINT 'TRANSIENT THERM Z FOR FET MODULE=';ZTMOD
338 PRINT 'TCASE OR TSINK BEFORE TRANSIENT=';TCASE
430 PRINT #2%,'VBUS,VS,DUTY,TR=';VB,VS,DC,TR
431 PRINT #2%,'FREQ,LFILT,IPEAKPRIM=';FREQ,LFILT,IP
432 PRINT #2%,'RDS(FET),VDIODE=';RDS,VD
433 PRINT #2%,'QGATE,IQGATE=';QG,IQG
434 PRINT #2%,'QMILLER,VQMILLER=';QM,VQM
435 PRINT #2%,'VGATE TO SWITCH ID=';VID
```

```
436 PRINT #2%,'VGATE PS,RGATE=';VG,RG
437 PRINT #2%,'TRANSIENT THERM Z FOR FET MODULE=';ZTMOD
438 PRINT #2%,'TCASE OR TSINK BEFORE TRANSIENT=';TCASE
450 PRINT
451 PRINT
452 PRINT #2%
453 PRINT #2%
454 PRINT 'OUTPUTS'
455 PRINT #2%,'OUTPUTS'
456 PRINT
457 PRINT #2%
500 PRINT 'SEC RIPPLE IP-P,PRIM RIPPLE IP-P=';DISEC,DIPRIM
501 PRINT 'I TURN ON TIME,I TURN OFF TIME=';TIR,TVF
502 PRINT 'PCOND,PSW,PDIODE=';PCOND,PSW,PDIODE
503 PRINT 'POWER MODULE,POWER BOOST=';PMOD,PBOOST
504 PRINT 'DELT_T,JUNCTION T=';DELT_T,TJ
505 PRINT 'EFF1,EFF2=';EFF1,EFF2
600 PRINT #2%,'SEC RIPPLE IP-P,PRIM RIPPLE IP-P=';DISEC,DIPRIM
601 PRINT #2%,'I TURN ON TIME,I TURN OFF TIME=';TIR,TVF
602 PRINT #2%,'PCOND,PSW,PDIODE=';PCOND,PSW,PDIODE
603 PRINT #2%,'POWER MODULE,POWER BOOST=';PMOD,PBOOST
604 PRINT #2%,'DELT_T,JUNCTION T=';DELT_T,TJ
605 PRINT #2%,'EFF1,EFF2=';EFF1,EFF2
620 CLOSE #2%
630 END
```

THE THIRD BASIC PROGRAM CALCULTES POWER LOSSES IN THE FIELD REGULATOR FOR A GIVEN FIELD CURRENT.THE LISTING IS GIVEN BELOW:

PROGRAM #3

```
10 REM PGM IS CALLED DTFREG.BAS
20 REM IT CALCULATES DUTY CYCLE,POWERS,SW TIMES,CAP I,BOOST I
30 REM INPUTS ARE FLD I,BUS V,FREQ,RFLD,RDS,VGATE,RGATE &
35 REM QGATE,QMIL,IQ,VQ,VID,VD
40 INPUT 'FIELD I, BUS V=';IFD,VB
50 INPUT 'FLD REG FREQ=';FREQ
60 INPUT 'EXC RESISTANCE=';RFLD
70 INPUT 'BACK DIODE V=';VD
80 RDS=.72
85 VG=15
90 RG=100
95 QG=17E-9
100 IQ=13
105 QMILL=64E-9
110 VQ=360
115 VID=5
120 OPEN "FREG.DAT" FOR OUTPUT AS FILE #2%, ACCESS WRITE, &
    SEQUENTIAL VARIABLE
130 DC=(IFD*RFLD + VB - 2*VD)/(2*VB -2*IFD*RDS - 2*VD)
140 ISEC=(2*DC - 1)*IFD
150 REM BELOW CALCULATES POWER
155 REM ********************************************
160 IRMSSQ=IFD*IFD*DC
161 PCON=IRMSSQ*RDS
170 TIR=(QG*(IFD/IQ))/(.75*VG/RG)
180 TVF=(QMILL*(VB/VQ))/((VG-VID)/RG)
190 PSW = VB*IFD*FREQ*(TIR+TVF)
200 PDIODE=VD*IFD*(1-DC)
210 PTOT=(PCON + PSW + PDIODE)*2
220 PFLD=IFD*IFD*RFLD
225 REM OUTPUT
230 REM ****************************************
240 PRINT 'IFLD,VBUS,FREQ=';IFD,VB,FREQ
245 PRINT #2%,'IFLD,VBUS,FREQ=';IFD,VB,FREQ
250 PRINT 'FIELD RES, VDIODE=';RFLD,VD
255 PRINT #2%,'FIELD RES, VDIODE=';RFLD,VD
260 PRINT
265 PRINT #2%
270 PRINT 'OUTPUTS'
275 PRINT #2%,'OUTPUTS'
280 PRINT 'BOOST OUTPUT I=';ISEC
285 PRINT #2%,'BOOST OUTPUT I=';ISEC
290 PRINT 'FLD REG DUTY CYCLE=';DC
295 PRINT #2%,'FLD REG DUTY CYCLE=';DC
300 PRINT 'PCON,PDIODE=';PCON,PDIODE
305 PRINT #2%,'PCON,PDIODE=';PCON,PDIODE
310 PRINT 'TIR,TVF,PSW=';TIR,TVF,PSW
315 PRINT #2%,'TIR,TVF,PSW=';TIR,TVF,PSW
320 PRINT 'PTOTAL FLD REG=';PTOT
325 PRINT #2%,'PTOTAL FLD REG=';PTOT
326 PRINT 'POWER IN FLD=';PFLD
327 PRINT #2%,'POWER IN FLD=';PFLD
330 CLOSE #2%
340 END
```

AFTER ALL OF THE POWER LOSSES WERE CALCULATED USING THE ABOVE THREE PROGRAMS, A SPICE NETWORK MODEL WAS USED TO DETERMINE THE JUNCTION TEMPERATURES OF THE SEMICONDUCTORS. THE THERMAL RESISTANCES WERE OBTAINED FROM DATA SHEETS OF THE DEVICES. THE SPICE LISTING IS GIVEN BELOW:

SPICE MODEL

```
DAVID TAYLOR SS THERMAL MODEL,BOOST AND FIELD REG
***NAME OF PGM IS DTTEMP.IGS
********* ENTER TOTAL POWER LOSS FIELD REG DIODES
IPD2 0 1 2.2
********************************
******** ENTER 1/2 ZJC AND ZCS,FIELD REG DIDOE
RJCD2 1 4 .4
RCSD2 4 7 .2
********************************
********** ENTER TOTAL POWER LOSS FIELD REG FETS
IPFET2 0 2 13.14
****************************
********** ENTER 1/2 ZJC AND ZCS FOR FIELD REG FETS
RJCFET2 2 5 .4
RCSFET2 5 7 .2
**********************************
************ ENTER TOTAL BOOST CONVERTER LOSS
IPBOOST 0 3 18.4
******************************
*********** ENTER 1/2 ZJC AND ZCS FOR BOOST MODULES
RJCMOD2 3 6 .125
RCSMOD2 6 7 .05
*********************************
*********** ENTER HEAT SINK ZSA
RSA 7 0 .3
.END
```

FIGURES A5-1 AND A5-2 SUMMARIZE THE STEADY STATE ANALYSIS AND TRANSIENT (STARTING) ANALYSIS, RESPECTIVELY. IN ALL CASES, THE JUNCTION TEMPERATURES ARE BELOW 150 DEGREE C, THE MAXIMUM ALLOWED JUNCTION TEMPERATURE. UNDER STEADY STATE CONDITIONS, THE JUNCTIONS ARE ONLY BETWEEN 60 AND 70 DEGREES C, RESULTING IN HIGH RELIABILITY.

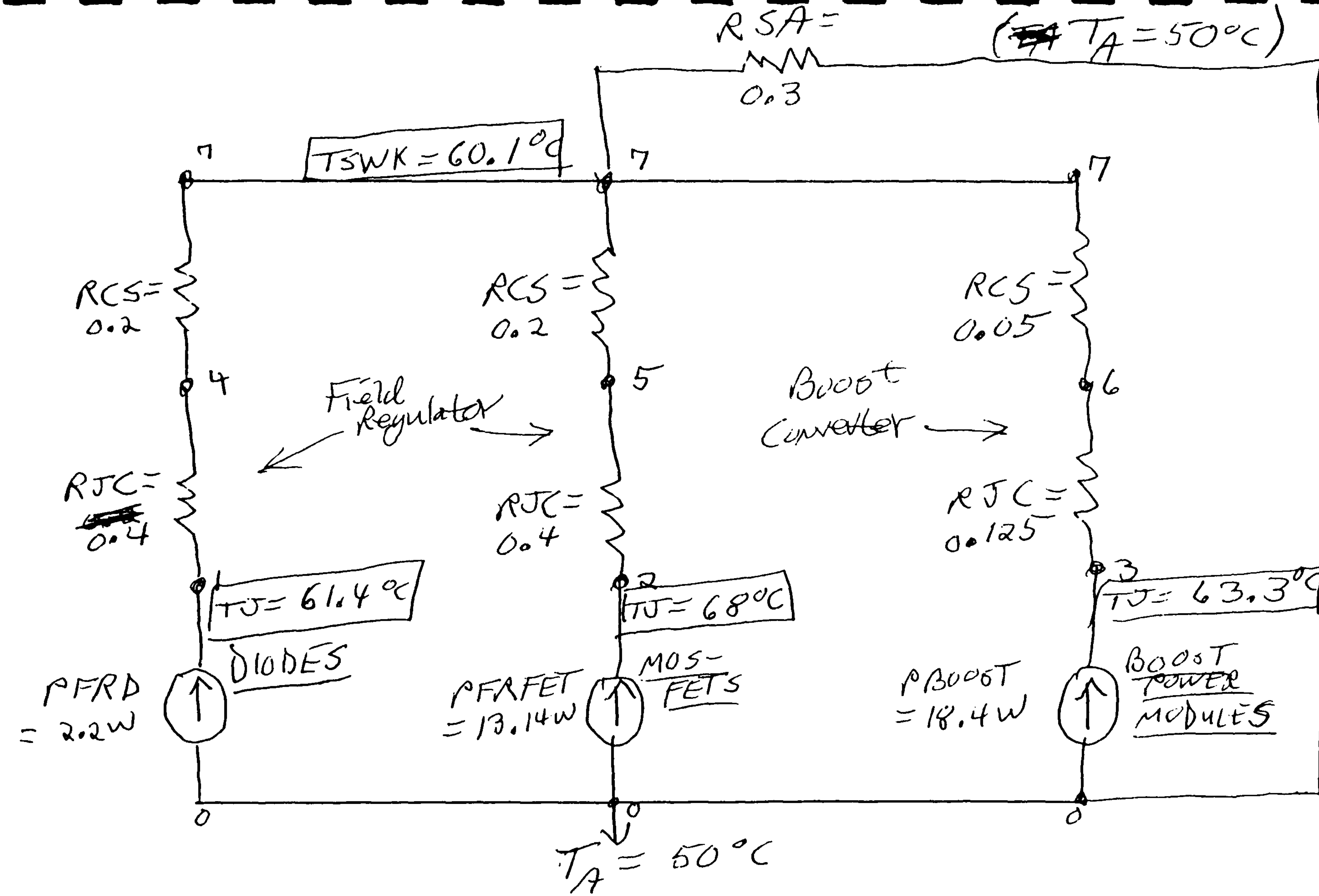


Figure A5-1, Steady State Thermal Profile

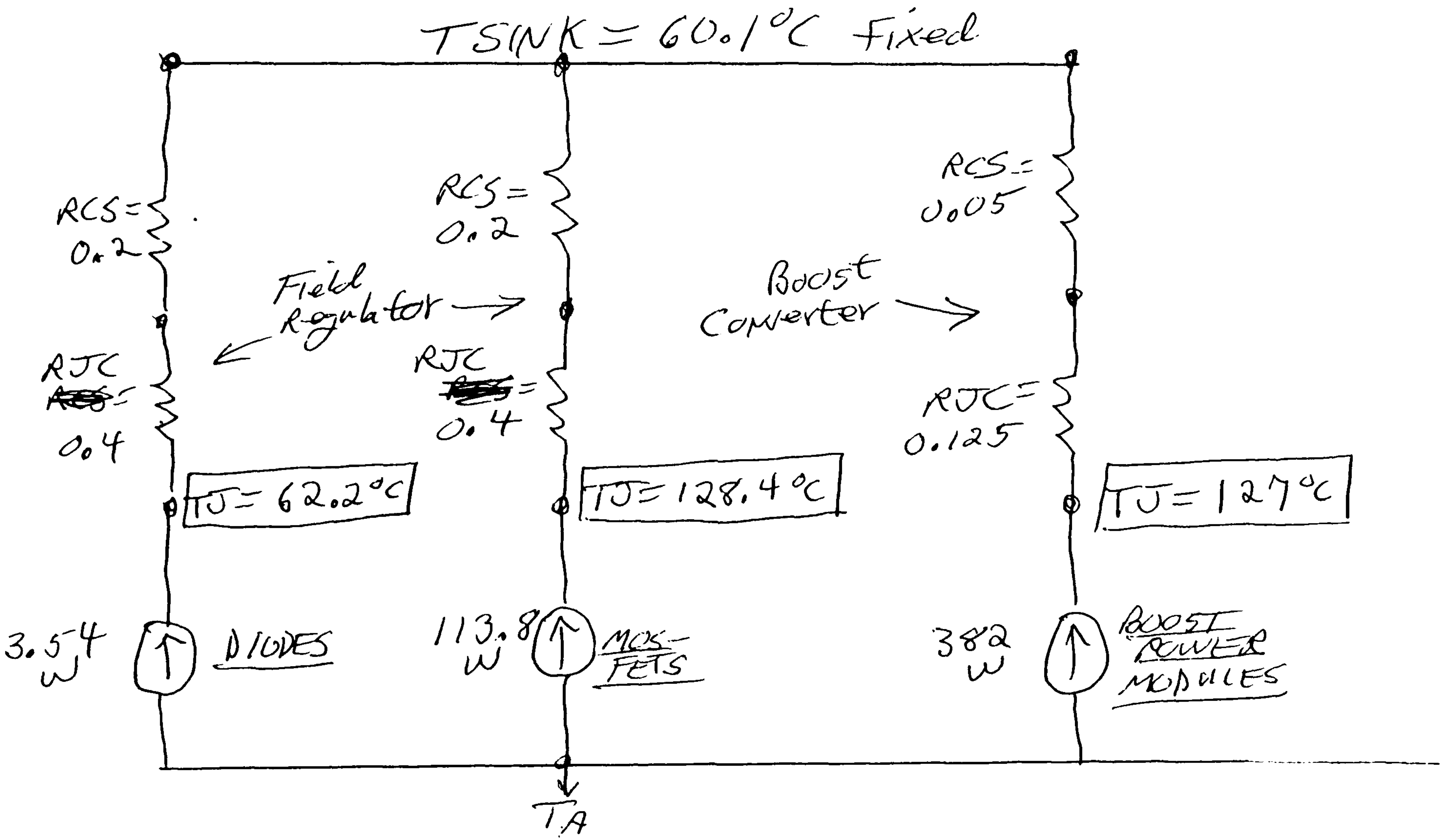


Figure A5-2. Re-Start Thermal Profile.

APPENDIX VI

Sensitivity Analysis

APPENDIX VI SENSITIVITY ANALYSIS

A digital computer model was used to investigate the sensitivity of dynamic performance to variations of the parameters of the David Taylor amphibious vehicle electric propulsion system.

The model is described in Appendix VI-A. The results of the simulation runs using the model are shown in 56 computer plots that are included in a separate Appendix VI-B available on request.

The effects of varying the parameters were found to be small or negligible for all but one type of case.

The only significant sensitivity to variation of the system parameters was found for the case of starting the motor with an increased value of the resistance of the field winding of the main alternator. The results for these cases raise the concern that a small difference between the predicted value and the actual resistance of the alternator field winding could cause motor starting times to be too long so that thermal limits are exceeded. A summary of these results is shown in Tables VI-I and VI-II

Table VI-I

COLD START TIME VERSUS ALTERNATOR FIELD WINDING RESISTANCE

Field winding resistance (at base temperature of 25 deg C)	Time to start
Nominal R_FIELD_ALT = .455 ohm	2.2 seconds
R_FIELD_ALT x 1.2 = .546 ohm	2.9 seconds
R_FIELD_ALT x 1.3 = .5915 ohm	3.45 seconds
R_FIELD_ALT x 1.5 = .6825 ohm (Slip = 39 % at 3.8 seconds)	more than 3.8 seconds 6 seconds estimated
R_FIELD_ALT x 0.5 = .2275 ohm	1.5 seconds

Table VI-II

HOT START TIME VERSUS ALTERNATOR FIELD WINDING RESISTANCE

Field winding resistance (at base temperature of 25 deg C)	Time to start
Nominal R_FIELD_ALT = .455 ohm	2.4 seconds
R_FIELD_ALT x 1.1 = .5005 ohm	3.05 seconds
R_FIELD_ALT x 1.2 = .546 ohm (Slip = 19 % at 3.8 seconds)	more than 3.8 seconds 4 seconds estimated
R_FIELD_ALT x 1.5 = .6825 ohm (Slip = 56 % at 3.8 seconds)	more than 3.8 seconds 8 seconds estimated
R_FIELD_ALT x 0.5 = .2275 ohm	1.1 seconds

Sensitivity to parameter variation was studied for three cases of dynamic performance :

1. Load variation at 9000 rpm nominal speed with system hot.
2. Motor start at 4306 rpm alternator speed with system cold.
3. Motor start at 4306 rpm alternator speed with system hot.

Case 1

With the system operating in a steady-state condition at a main alternator speed of 9000 rpm with a motor output power of 310 kilowatts (416 horsepower), the load was reduced to zero and then returned to normal value to simulate the case where the propellor might be out of the water momentarily. It is believed that the load variation for an actual case that might occur would probably have a pattern that would be somewhat similar to a parabola. A ramp variation of the load was selected as an easily implemented approximation since the actual curve is not known.

The load torque was instantly reduced to zero and remained at zero for 150 milliseconds which is a sufficient time for the system to reach a steady-state no load condition. The load torque was then increased from zero to the normal value along a linear ramp over a time period of 100 milliseconds.

One simulation was run for this case with the nominal values for all parameters except that the propellor torque was increased by a factor of 1.3, i.e. the same nominal speed, but a motor output power of 400 kilowatts (535 horsepower).

Table VI-III shows a summary of the parameter variations that were simulated for case 1.

The first column in each of the tables shows the identification number for each simulation run.

Case 2

Starting of the motor from zero speed was simulated for the condition of a main alternator speed of 4306 rpm with all parts of the system cold at a temperature of 20 degrees Celsius. The simulated time duration was chosen to be 3.8 seconds for convenience; the nominal time to start is 2.2 seconds when cold and 2.4 seconds when hot.

Table VI-IV shows a summary of the parameter variations that were simulated for case 2.

Case 3

Starting of the motor from zero speed was simulated for the condition of a main alternator speed of 4306 rpm with all parts of the system at temperatures the same as for the case of nominal 9000 rpm steady-state operation. (Temperatures the same as for case 1 above.)

Table VI-V shows a summary of the parameter variations that were simulated for case 3.

For those simulation runs that have a condition of EXC_SAT_CURVE x 0.90, (run numbers 5_24_88_2, 5_24_88_3, 5_24_88_4) the magnetic saturation curves of the exciter were modified as shown in Figures VI-1, VI-2, and VI-3. The magnetic saturation effect in the exciter was made more severe by making a ten percent reduction of the exciter output voltage to be applied to the input to the field of the main alternator for values of the exciter field current that are in the saturation region. This was not a very significant change in the simulated system because the exciter field current was limited to a maximum value of 9 amperes which is not very far into saturation (Figures VI-1, VI-2, and VI-3). In the steady-state operating condition at 9000 rpm, the exciter field current is about 2.5 amperes; the exciter field current is at or near the limit only during transient conditions of starting or dynamic load variations.

Table VI-III

LOAD VARIATION AT NOMINAL 9000 RPM HOT WITH 100 MILLISECOND LOAD RAMP

RUN NUMBER	CONDITIONS	
5_6_88_0	Nominal	
5_6_88_1	L_FIELD_ALT x 1.5	
5_6_88_2	L_FIELD_ALT x 0.5	
5_6_88_3	R_FIELD_ALT x 0.5	
5_6_88_4	R_FIELD_ALT x 1.5	
5_6_88_5	L_FIELD_ALT x 1.5	R_FIELD_ALT x 1.5
5_6_88_6	L_FIELD_ALT x 1.5	R_FIELD_ALT / 1.5
5_6_88_7	L_FIELD_EXC x 1.5	
5_6_88_8	L_FIELD_EXC x 0.5	
5_6_88_9	R_FIELD_EXC x 1.5	
5_6_88_10	L_FIELD_EXC x 1.5	R_FIELD_EXC / 1.5
5_6_88_11	T_COULOMB_MOTOR x 2	
5_6_88_12	R_2_MOTOR x 1.5	
5_24_88_2	EXC_SAT_CURVE x 0.90	
5_26_88_3	I_FIELD_EXC_LIMIT = 7 A	
5_26_88_4	I_FIELD_EXC_LIMIT = 7 A	V_FIELD_EXC_BUSS = 100 V
5_26_88_5	I_FIELD_EXC_LIMIT = 5 A	V_FIELD_EXC_BUSS = 100 V
5_24_88_1	K_LOAD_PROP_MOTOR x 1.3	

Table VI-IV

COLD START AT NOMINAL 4306 RPM

RUN NUMBER	CONDITIONS	
5_10_88_0	Nominal	
5_10_88_1	L_FIELD_ALT x 1.5	
5_10_88_2	L_FIELD_ALT x 0.5	
5_10_88_3	R_FIELD_ALT x 0.5	
5_10_88_4	R_FIELD_ALT x 1.5	
5_10_88_5	L_FIELD_ALT x 1.5	R_FIELD_ALT x 1.5
5_10_88_6	L_FIELD_ALT x 1.5	R_FIELD_ALT / 1.5
5_10_88_7	L_FIELD_EXC x 1.5	
5_10_88_8	L_FIELD_EXC x 0.5	
5_10_88_9	R_FIELD_EXC x 1.5	
5_10_88_10	L_FIELD_EXC x 1.5	R_FIELD_EXC / 1.5
5_10_88_11	T_COULOMB_MOTOR x 2	
5_10_88_12	R_2_MOTOR x 1.5	
5_10_88_13	R_FIELD_ALT x 1.2	
5_10_88_14	R_FIELD_ALT x 1.3	
5_24_88_3	EXC_SAT_CURVE x 0.90	
5_26_88_2	I_FIELD_EXC_LIMIT = 7 A	
5_26_88_8	I_FIELD_EXC_LIMIT = 7 A	V_FIELD_EXC_BUSS = 100 V
5_26_88_9	I_FIELD_EXC_LIMIT = 5 A	V_FIELD_EXC_BUSS = 100 V

Table VI-V

HOT START AT NOMINAL 4306 RPM

RUN NUMBER	CONDITIONS	
5_9_88_0	Nominal	
5_9_88_1	L_FIELD_ALT x 1.5	
5_9_88_2	L_FIELD_ALT x 0.5	
5_9_88_3	R_FIELD_ALT x 0.5	
5_9_88_4	R_FIELD_ALT x 1.5	
5_9_88_5	L_FIELD_ALT x 1.5	R_FIELD_ALT x 1.5
5_9_88_6	L_FIELD_ALT x 1.5	R_FIELD_ALT / 1.5
5_9_88_7	L_FIELD_EXC x 1.5	
5_9_88_8	L_FIELD_EXC x 0.5	
5_9_88_9	R_FIELD_EXC x 1.5	
5_9_88_10	L_FIELD_EXC x 1.5	R_FIELD_EXC / 1.5
5_9_88_11	T_COULOMB_MOTOR x 2	
5_9_88_12	R_2_MOTOR x 1.5	
5_9_88_13	R_FIELD_ALT x 1.2	
5_9_88_14	R_FIELD_ALT x 1.1	
5_24_88_4	EXC_SAT_CURVE x 0.90	
5_26_88_1	I_FIELD_EXC_LIMIT = 7 A	
5_26_88_6	I_FIELD_EXC_LIMIT = 7 A	V_FIELD_EXC_BUSS = 100 V
5_26_88_7	I_FIELD_EXC_LIMIT = 5 A	V_FIELD_EXC_BUSS = 100 V

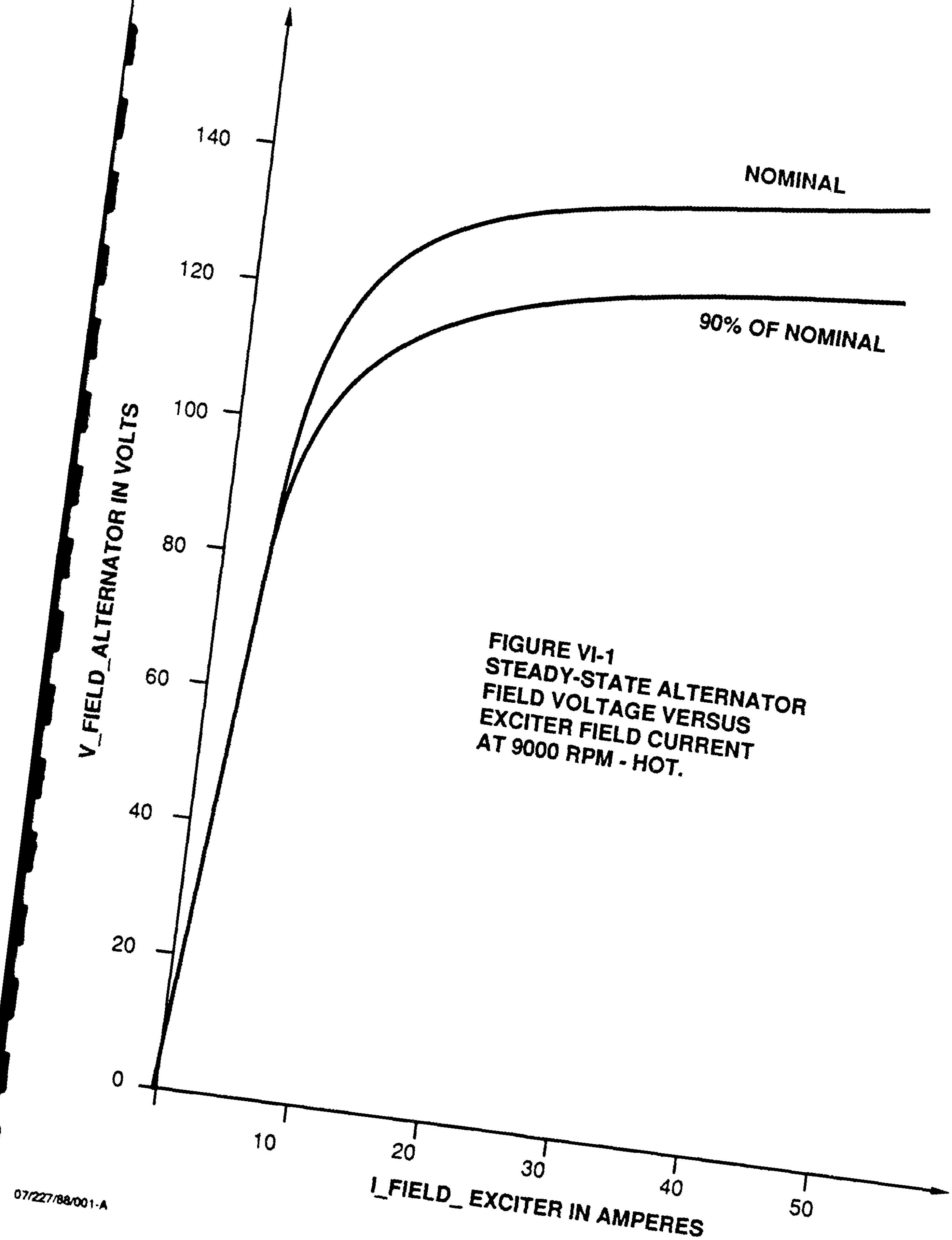


FIGURE VI-1
STEADY-STATE ALTERNATOR
FIELD VOLTAGE VERSUS
EXCITER FIELD CURRENT
AT 9000 RPM - HOT.

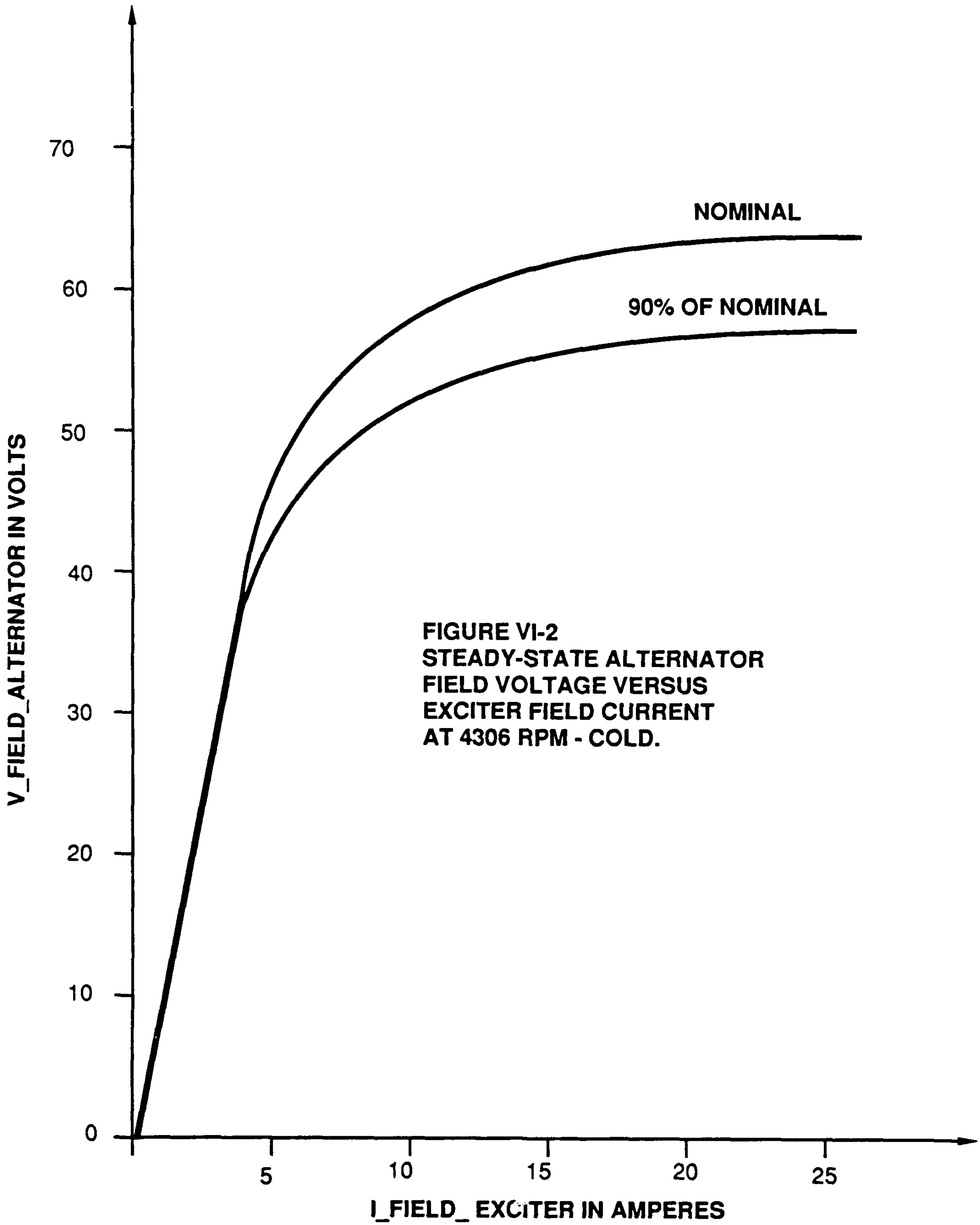


FIGURE VI-2
STEADY-STATE ALTERNATOR
FIELD VOLTAGE VERSUS
EXCITER FIELD CURRENT
AT 4306 RPM - COLD.

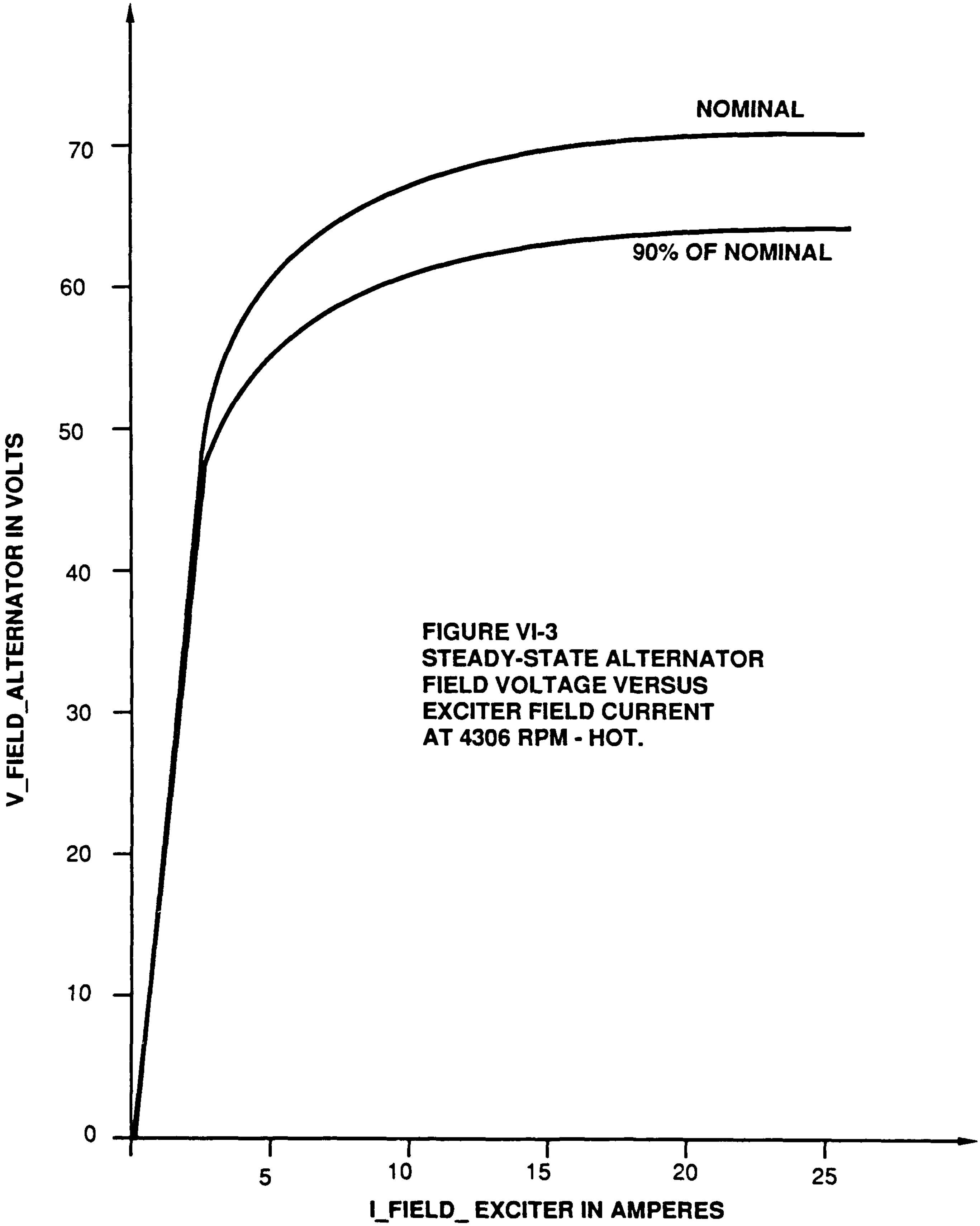


FIGURE VI-3
STEADY-STATE ALTERNATOR
FIELD VOLTAGE VERSUS
EXCITER FIELD CURRENT
AT 4306 RPM - HOT.

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APPENDIX VI-A

Appendix VI-A contains a description of the digital computer model that has been used to simulate the dynamic performance of the electric propulsion system of the David Taylor amphibious vehicle.

SYSTEM MODEL

The system provides a speed at the load that is directly proportional to the speed of the prime mover for steady-state conditions. The speed of the load is always impelled toward a value that is directly proportional to the speed of the prime mover under dynamic conditions.

Figure VI-A-1 shows a general block diagram of the model of the system.

The model represents the characteristics of the actual system hardware with sufficient detail to provide simulation results that accurately predict the steady-state and dynamic behavior of the system.

Each portion or block of the model will be discussed separately in the following, starting from the prime mover and moving through the model to the load.

Prime Mover

The prime mover is taken to be an ideal mechanical power source. In the model, the prime mover can deliver any needed amount of power at any speed and the speed is not affected by the mechanical load.

Permanent Magnet Generator

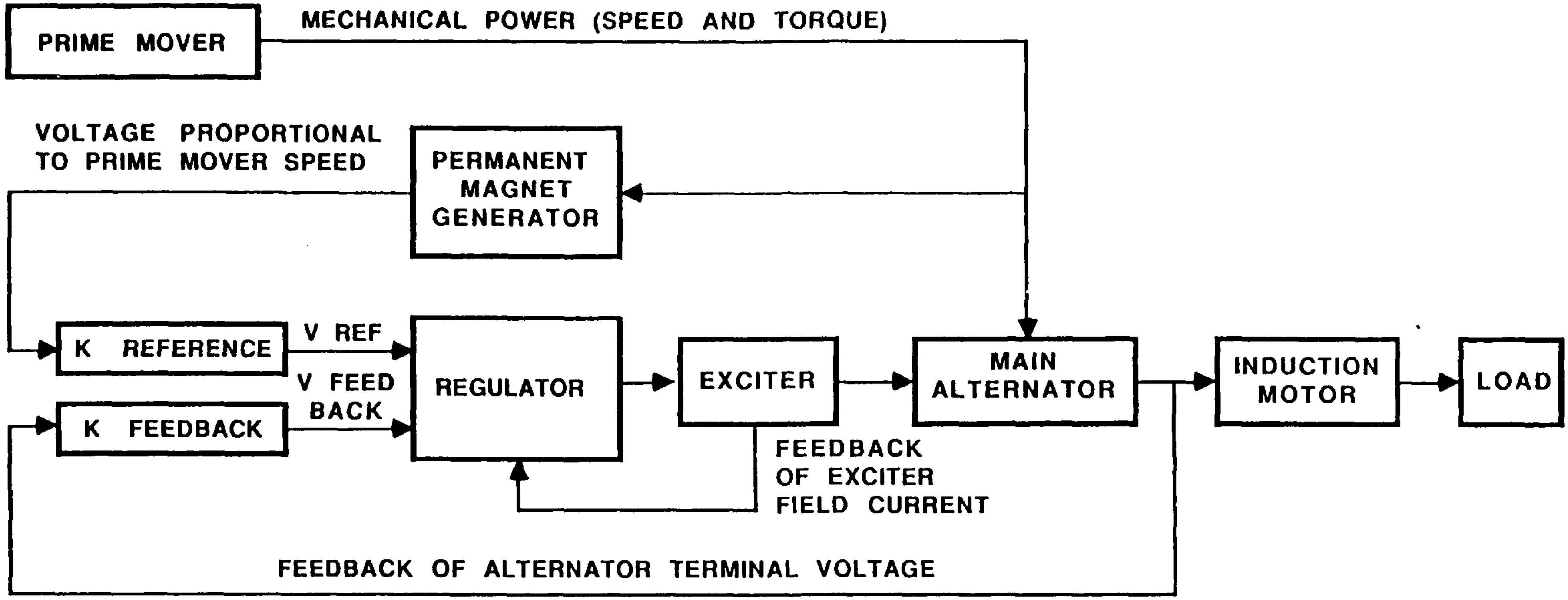
The permanent magnet generator is in effect a tachometer that produces an output voltage that is directly proportional to the speed of the prime mover. The output voltage of the permanent magnet generator is the input to the dynamic control system. The terminal voltage of the main alternator is controlled to be directly proportional to the output voltage of the permanent magnet generator.

Regulator

Figure VI-A-2 shows a simplified block diagram of the regulator.

In the model, the reference voltage input to the regulator is calculated as a simple constant times the speed of the prime mover. The feedback of the alternator terminal voltage is also calculated by means of a simple constant that takes into account the three phase rectification and attenuation of the system hardware.

The model represents the proportional-integral feedback control method of the regulator, the pulse width modulation drive of the exciter field current, and the inner loop of feedback of the exciter field current that is used to limit the current to the 9 ampere thermal capability of the hardware.



7/227/88/4

Figure VI-A-1. Block Diagram System Model

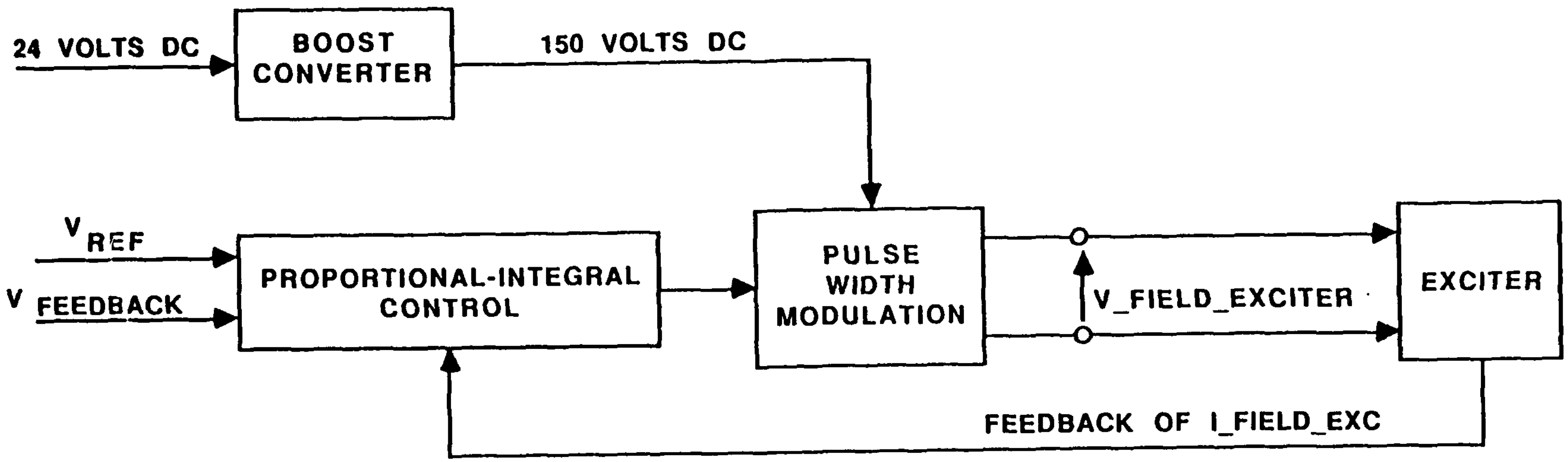


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Figure VI-A-2. Regulator Model

A boost converter is used to obtain 150 volts DC from a 24 volt DC source. The 150 volts is needed to provide sufficient drive with the pulse width modulation to change the exciter field current fast enough to maintain stability during dynamic system variations due to changes of prime mover speed, changes of system load, or combinations of speed and load change.

Exciter

Figure VI-A-3 shows a schematic representation of the exciter model.

The output of the regulator is represented in the model as a voltage input to the terminals of the exciter field winding. This voltage may be - DC buss voltage (- 150 volts) or any value within the range of 0 to + DC buss voltage (0 volts to + 150 volts). At each time step of the model execution, the differential equation of the exciter field circuit with this input voltage is solved by a fourth order Runge-Kutta numerical procedure to obtain a value for the exciter field current.

The exciter field current is limited to a maximum positive value of 9 amperes. The input voltage to the exciter field is allowed to be equal to negative buss voltage to force the current toward zero, but the field current is not allowed to go negative.

The exciter field current is used as the input to a lookup table that is interpolated to obtain a value for the input voltage to the field of the main alternator. Since the exciter field current is allowed to have only positive values, the input voltage to the field of the main alternator can only have positive values. This simulates the operation of the rectifiers between the exciter output and the main alternator field winding of the actual hardware.

The lookup table has different sets of values for different system operating conditions. A different lookup table is used for each of three equivalent speeds of the prime mover and for the system cold or hot.

The lookup table values have been derived from the transfer curves shown in Figures VI-A-4, and VI-A-5. The curves show the steady-state relation between the current in the exciter field and the current in the main alternator field with magnetic saturation and machine temperatures taken into account. This information has been translated into curves of DC voltage input to the main alternator field winding versus exciter field current.

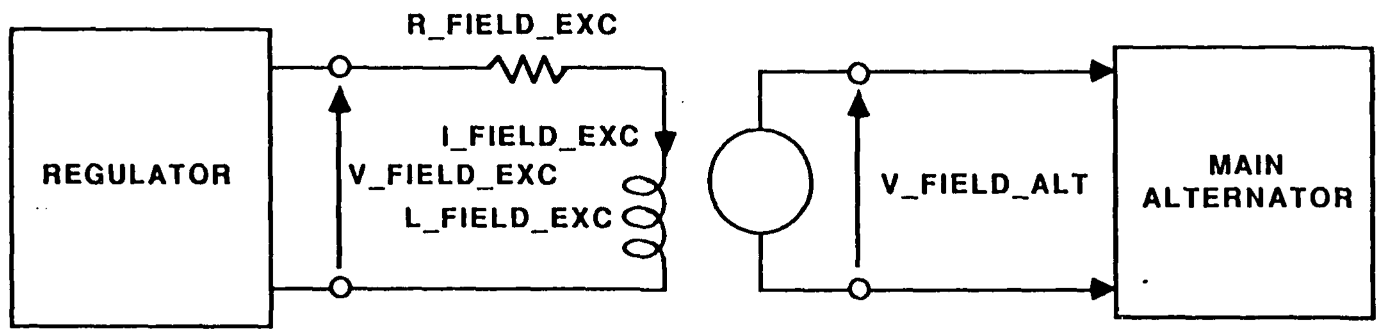

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Figure VI-A-3. Exciter Model

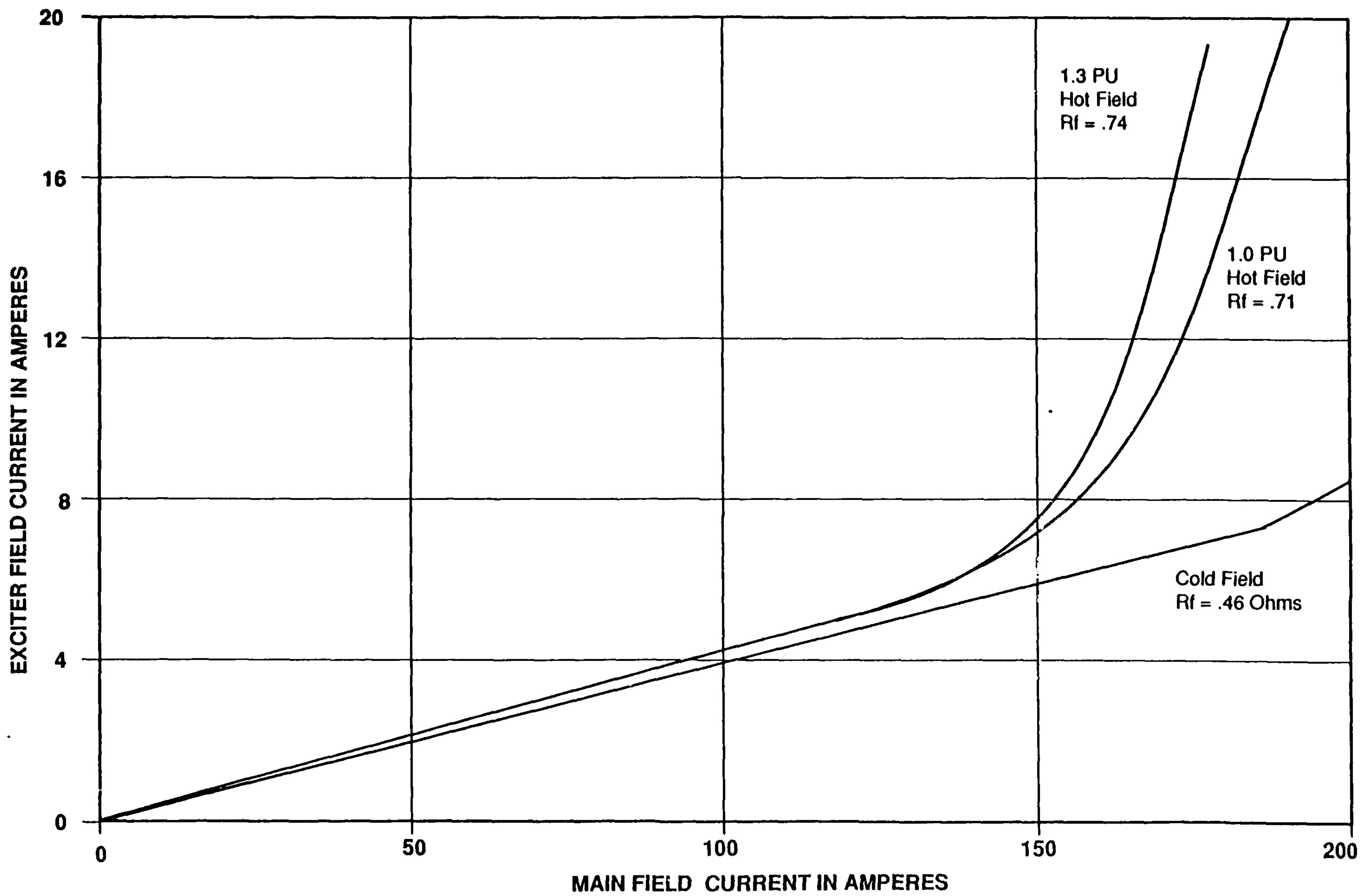

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Figure VI-A-4. Exciter Field Current vs. Main Field Current (9000 RPM - Hipersco 50)

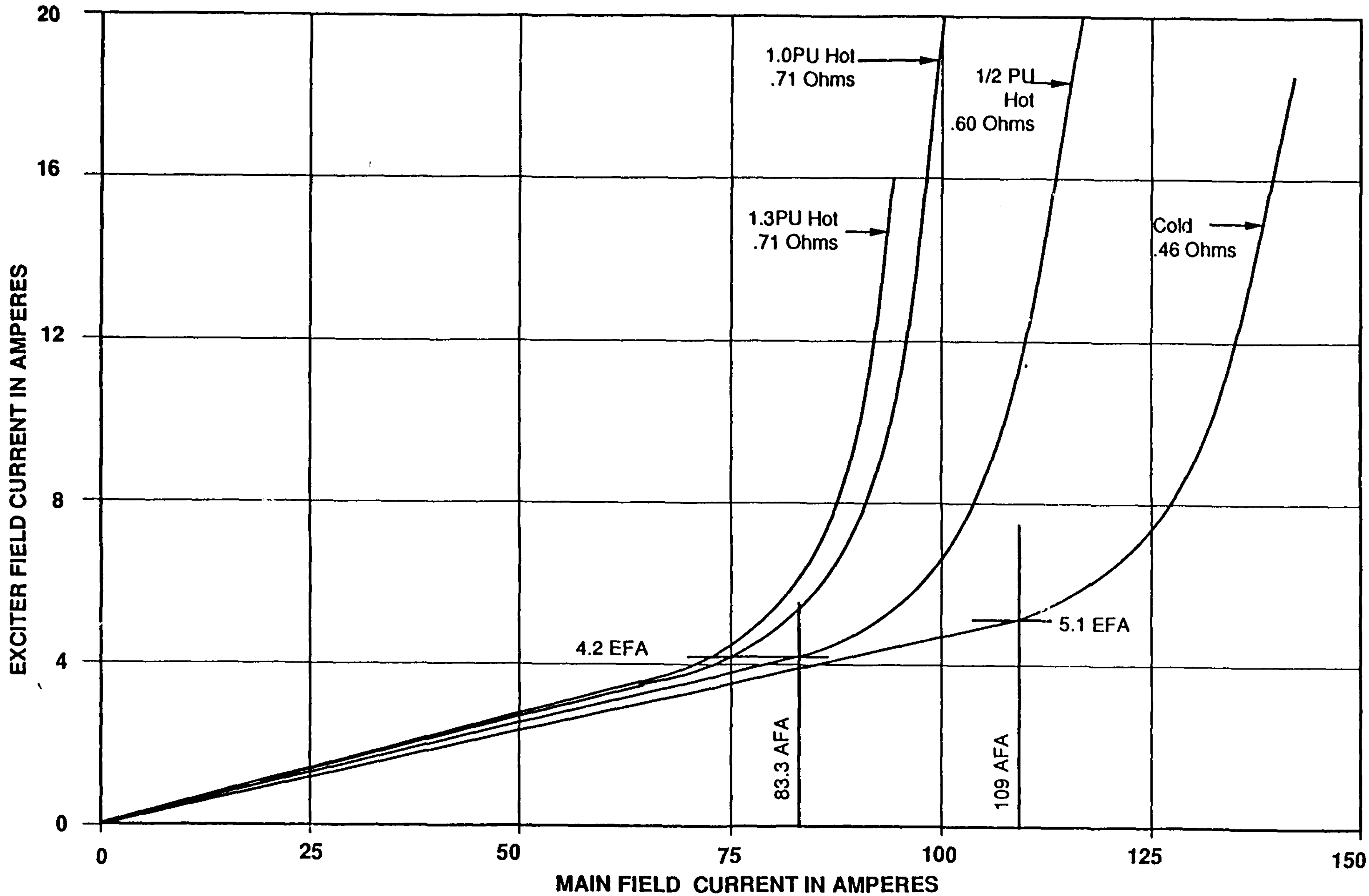

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Figure VI-A-5. Exciter Field Current vs. Main Field Current (4306 RPM - Hipersco 50)

Main Alternator

Figure VI-A-6 shows a schematic and block diagram representation of the model of the main alternator.

The calculation of the field current of the main alternator is done in the same way as the calculation of the exciter field current. At each time step of the model execution, the differential equation of the main alternator field circuit is solved by a fourth order Runge-Kutta numerical procedure. The input voltage in this equation is the output voltage of the exciter which is never negative. The main alternator field current can have only positive values and there is no upper limit imposed in the model.

An "effective" value field current that is equal to the main alternator field current minus a demagnetizing component of the alternator load current is used as the input to a lookup table that is interpolated to obtain a value for the generated voltage within the main alternator. The lookup table values are multiplied by a constant factor and the prime mover speed to account for the variation of generated voltage with alternator speed. The values used in this lookup table have been derived from the curves shown in Figure VI-A-7. The curves show the steady-state relation between the current in the alternator field and the alternator terminal voltage for various load conditions with magnetic saturation and machine temperatures taken into account. This information has been translated into curves of generated voltage versus field current.

A steady-state d-q axis model is used in conjunction with the alternator load current (induction motor input current) to calculate the terminal voltage of the alternator. Figure VI-A-8 shows a curve that is used to account for saturation of the leakage inductance of the main alternator versus the load current. This curve is translated into a lookup table that is interpolated in the model. The d-q axis calculations also provide the value of the demagnetizing component of the load current that is subtracted from the field current to obtain the "effective" field current that is used with the lookup table.

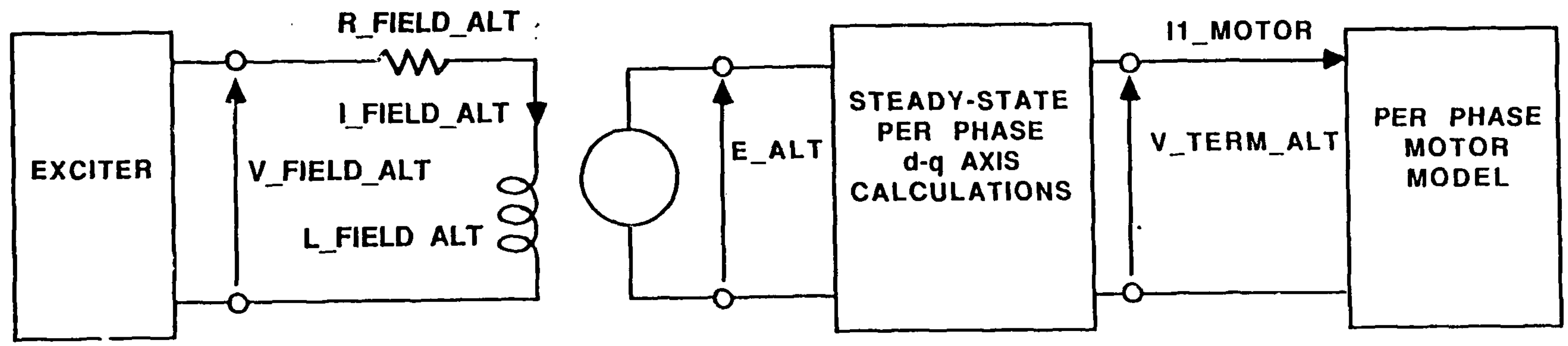

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Figure VI-A-6. Main Alternator Model

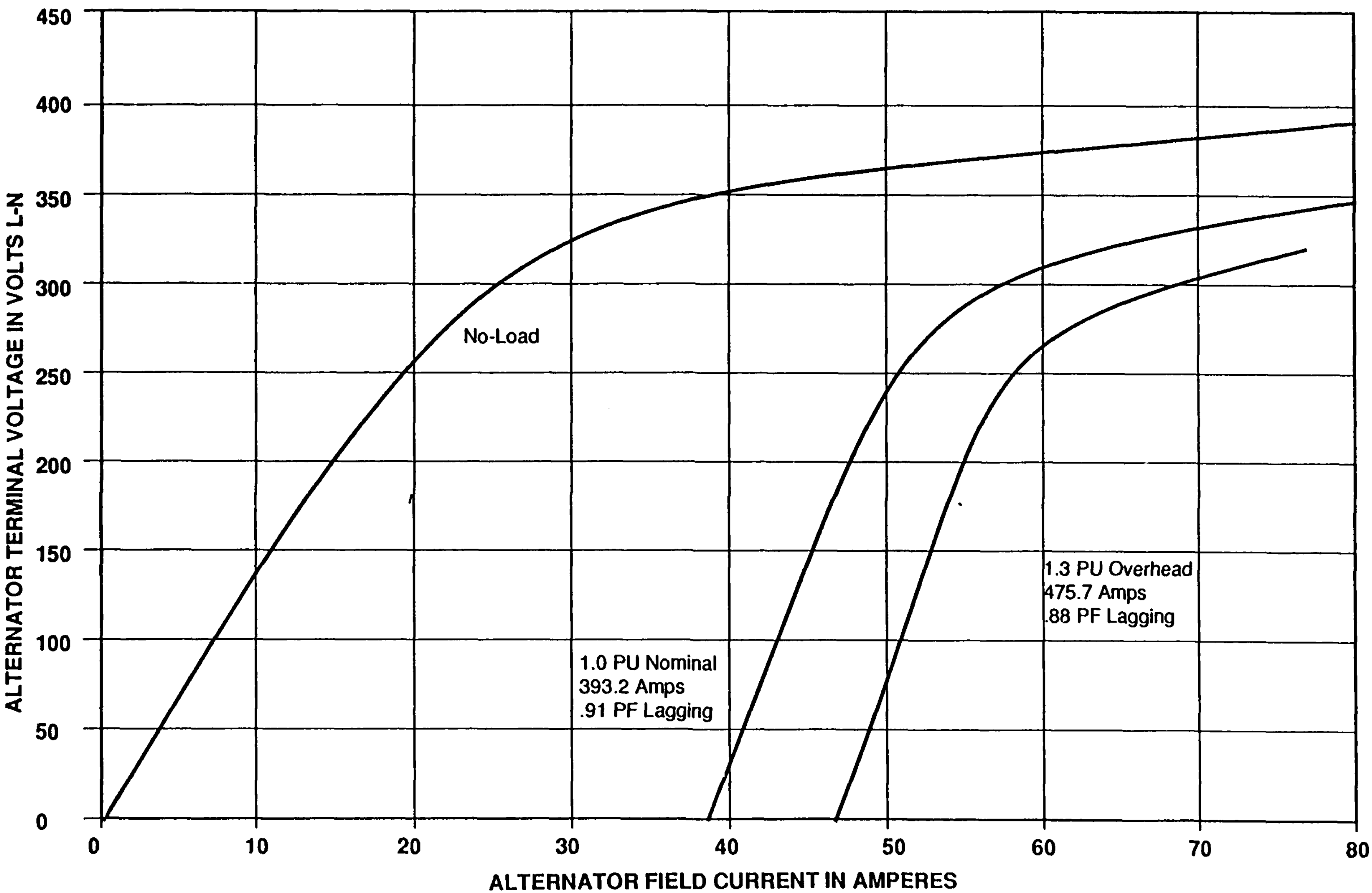

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Figure VI-A-7. Load Saturation Curvers for Main Alternator – 9000 RPM

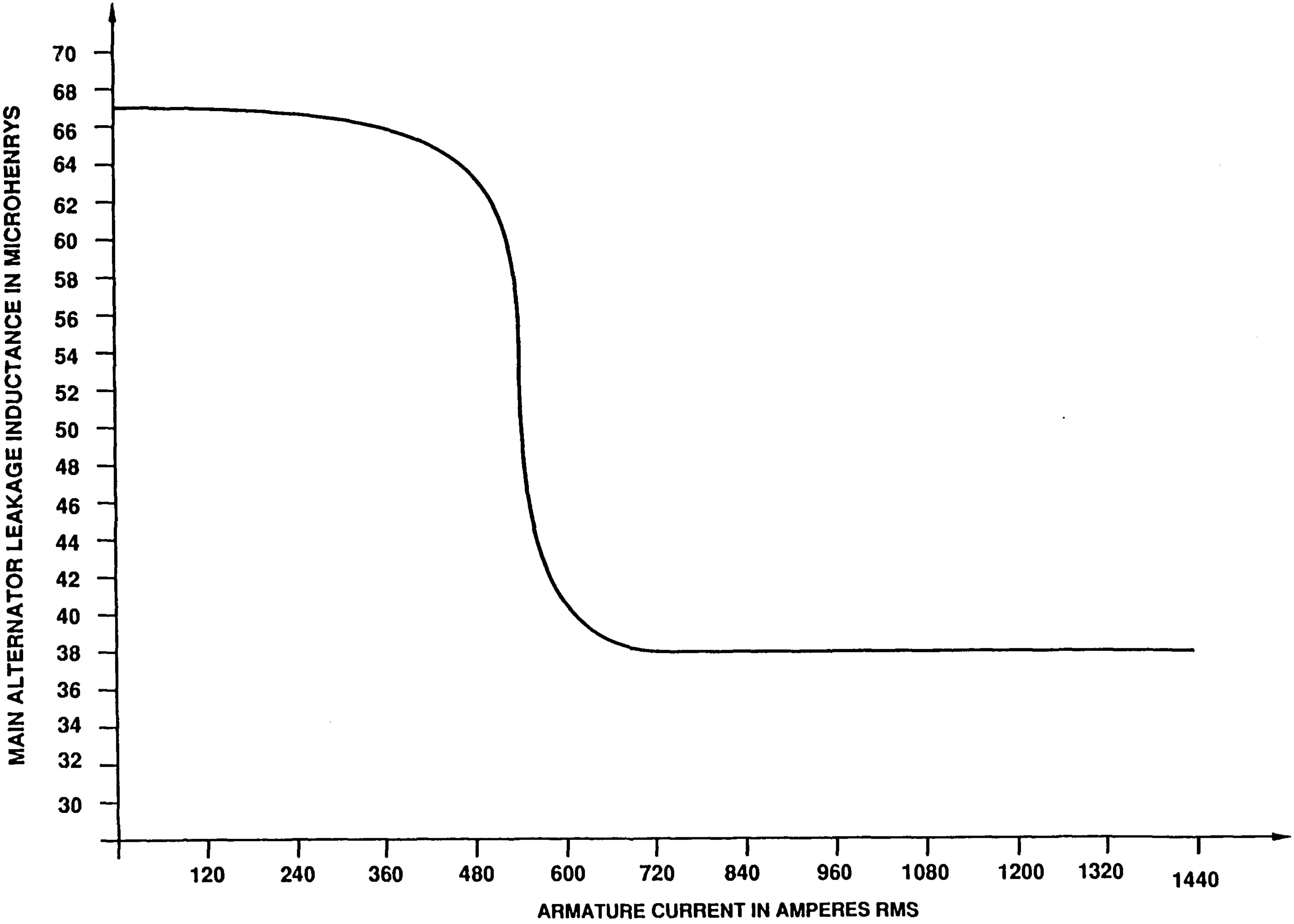

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Figure VI-A-8. Main Alternator Leakage Inductance vs. Armature Current

Induction Motor

Figure VI-A-9 shows the usual steady-state per phase equivalent circuit representation of the induction motor plus the resistance and inductance of the connecting cable from the main alternator to the induction motor.

The induction motor simulation calculations start from an initial value of motor speed which determines the slip at that moment in time. The voltages and currents in the equivalent circuit of the induction motor are calculated for the particular values of terminal voltage of the main alternator and the motor slip.

Figure VI-A-10 shows the magnetic saturation of the magnetizing inductance of the motor versus the value of the volts per hertz at an operating point. Figures VI-A-11 and VI-A-12 show variation of R2_MOTOR and L2_MOTOR versus slip. These curves are used in the model as_interpolated_lookup tables.

The torque produced in the motor is calculated from the equivalent circuit and is used with the model of the load to calculate the speed of the motor.

Load

The model of the load is represented by the block diagram of Figure VI-A-13 and the torque versus speed curve of Figure VI-A-14.

In the model, all load effects are referred to the motor side of the speed reduction gear and the combined equivalent friction and moment of inertia values of the motor, reduction gear, and load are treated as parts of the load. The torque versus speed curve of Figure VI-A-14 is represented as torque equals a constant times speed squared. To account for the efficiency of the speed reduction gear, the constant has been chosen so that the nominal steady-state output power of the motor is 310.3 kilowatts (416 horsepower) at an equivalent prime mover speed of 9000 rpm.

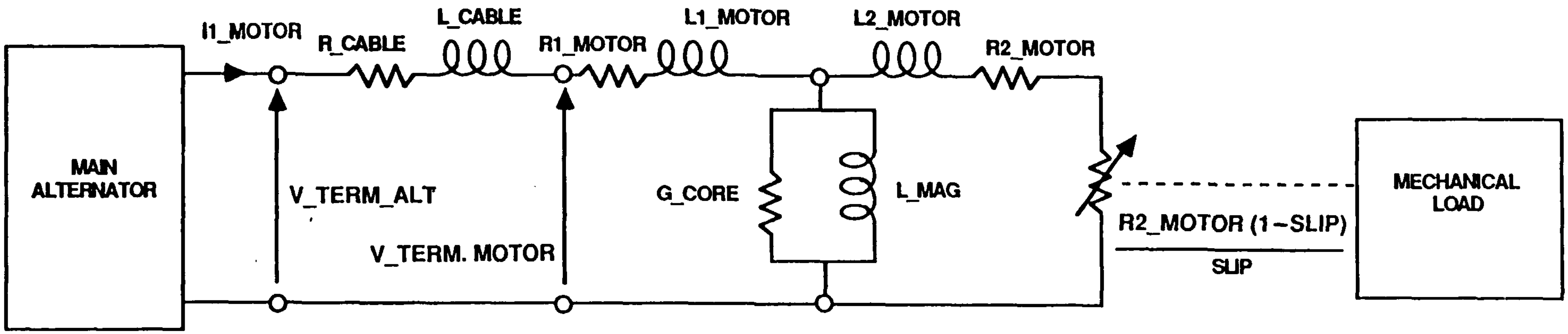

Figure VI-A-9. Induction Motor Model

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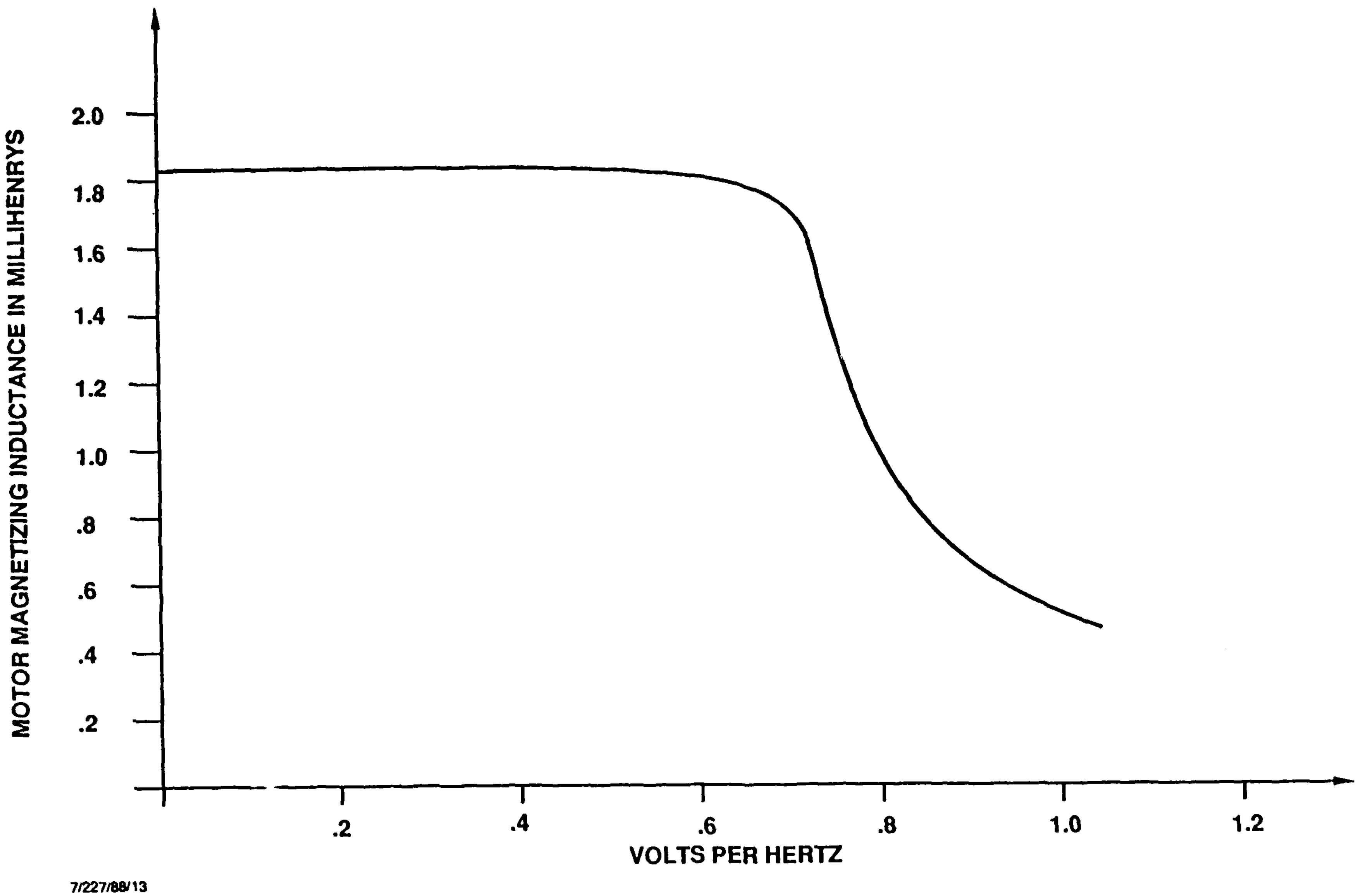

Figure VI-A-10. Motor Magnetizing Inductance vs. Volts Per Hertz

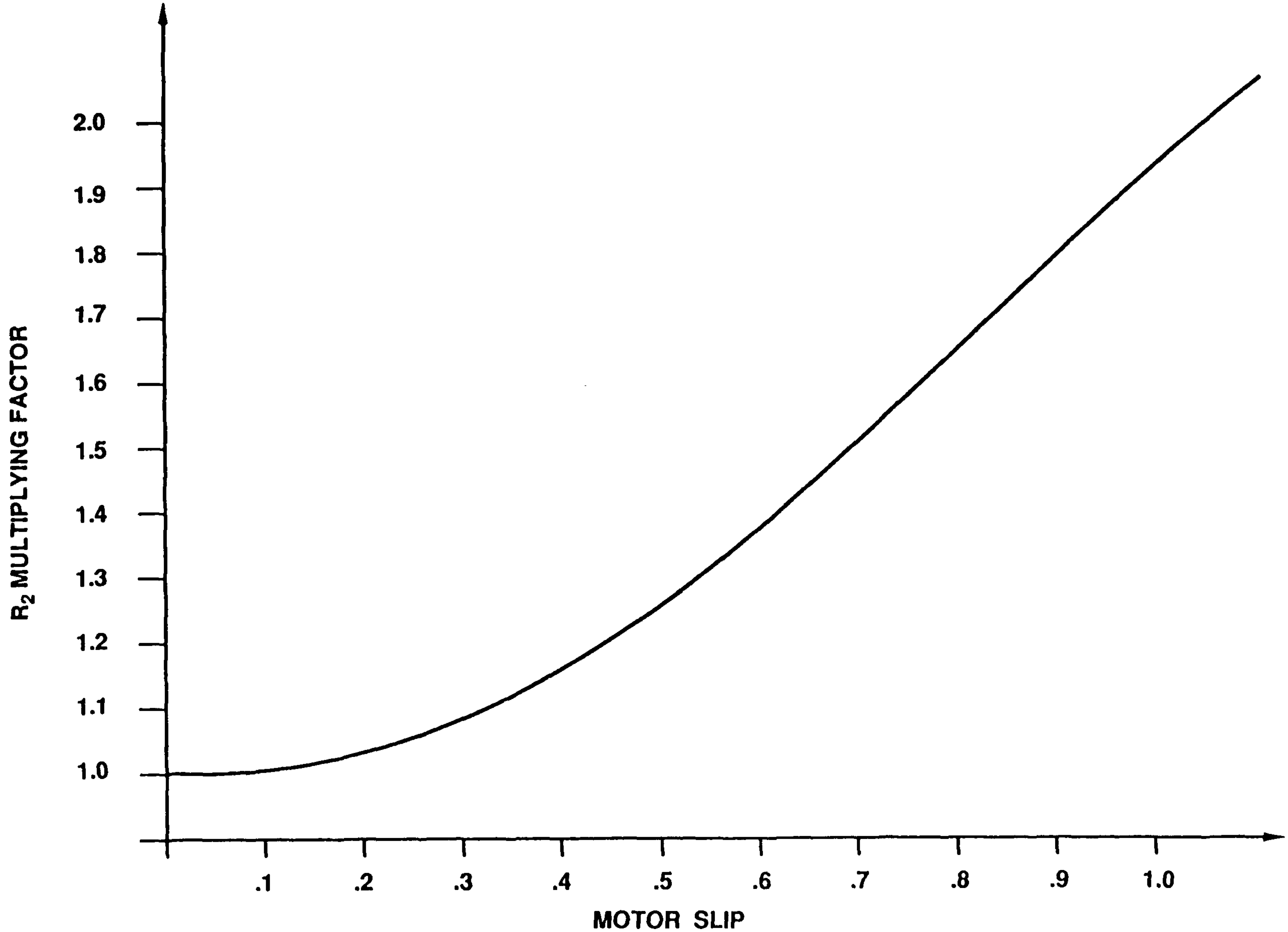

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Figure VI-A-11. Motor Rotor Resistance Variation with Slip

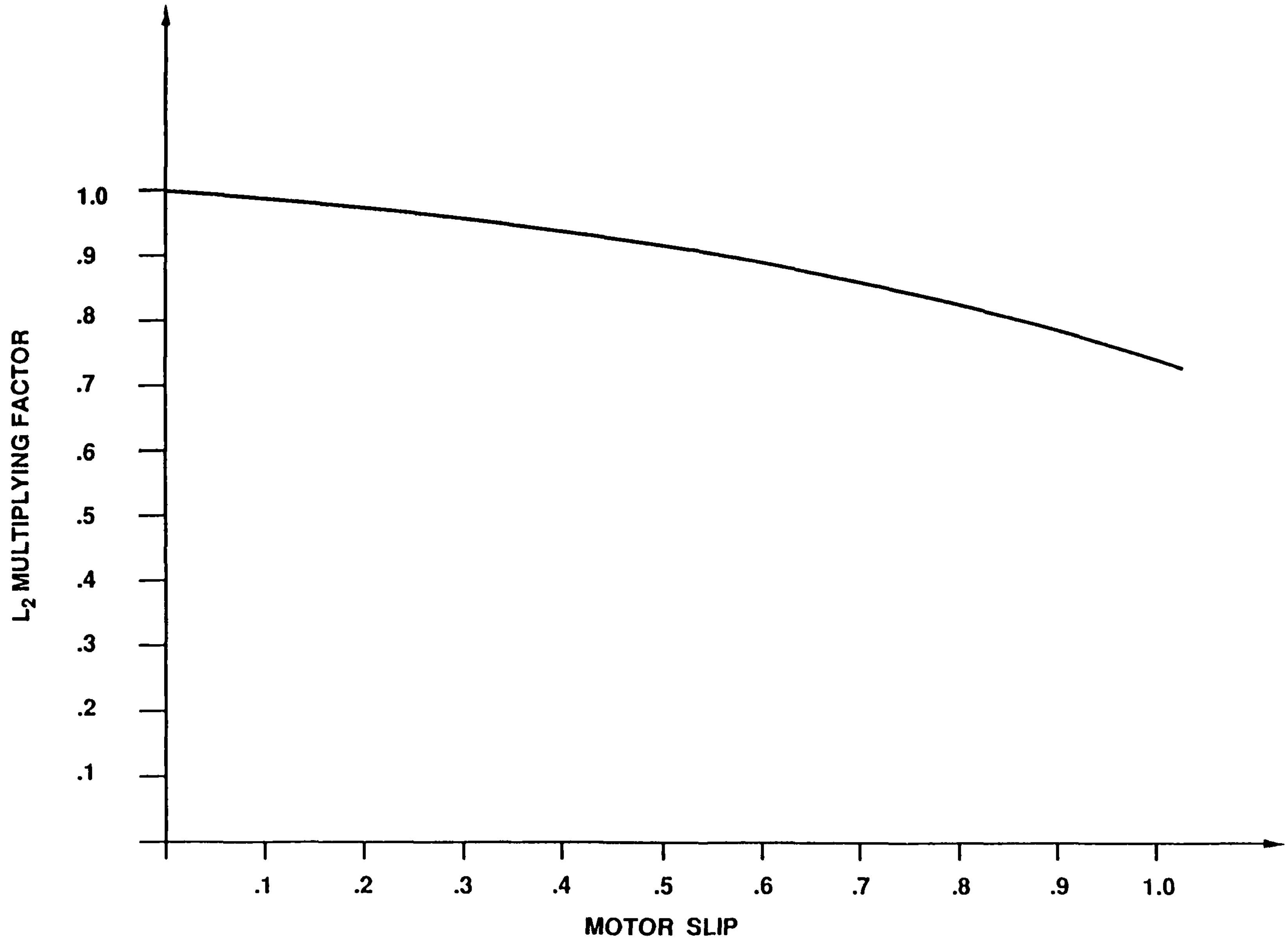

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Figure VI-A-12. Motor Rotor Inductance Variation with Slip

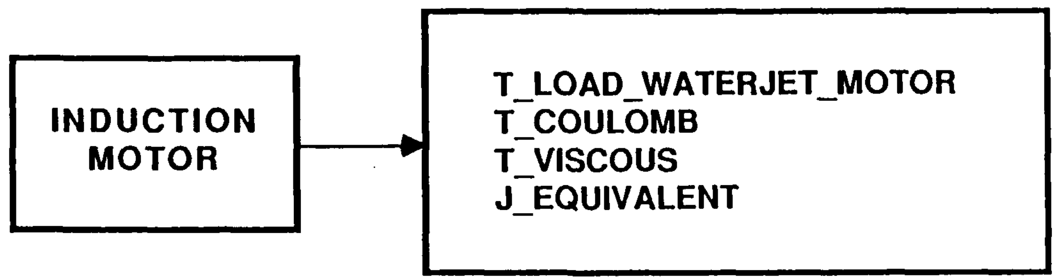

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Figure VI-A-13. Load Model

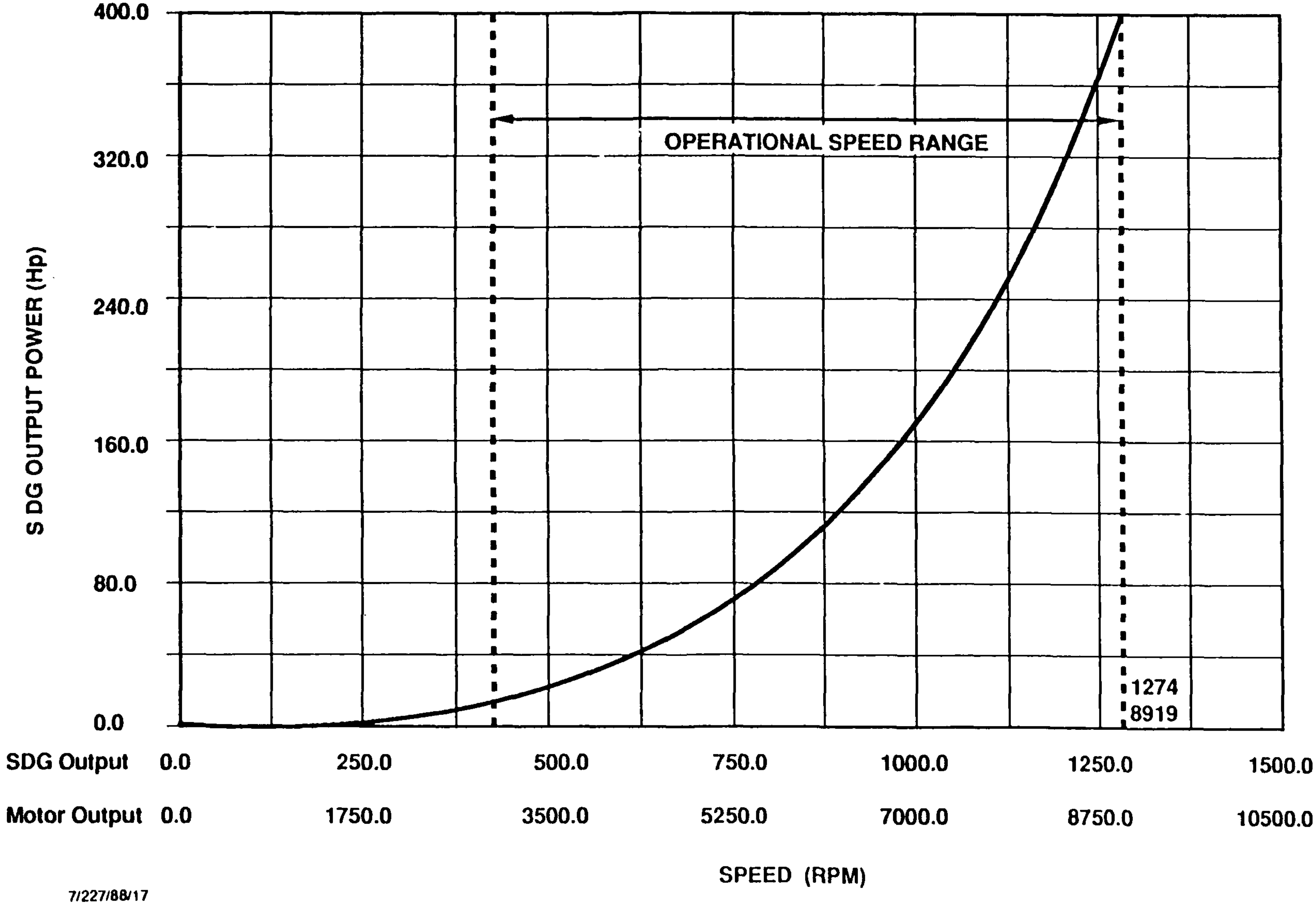


Figure VI-A-14. System Power Versus Speed .

APPENDIX VI-B

The main body of Appendix VI-B is available on request.

Appendix VI-B contains 56 computer plots of the simulation results that were used to investigate the sensitivity of dynamic performance of the David Taylor amphibious vehicle electric propulsion system to variations of the system parameters. Each plot is 11 x 25 inches.

Curves of the following system variables are shown on each plot :

- PERCENT SLIP
  The percent slip of the propulsion motor with respect to the synchronous speed determined by the main alternator speed.

- TERMINAL VOLTAGE PER PHASE
  The rms line to neutral voltage per phase of the main alternator.

- I FIELD ALTERNATOR
  The current supplied by the exciter to the field winding of the main alternator.

- ALTERNATOR CURRENT
  The rms current per phase supplied by the main alternator to the propulsion motor.

- LOAD TORQUE
  The propellor load torque as seen at the motor.

- MOTOR INTERNAL TORQUE
  The torque developed inside the motor at the airgap; equal to the propellor load torque as seen at the motor plus friction torques plus torque to accelerate the moment of inertia.

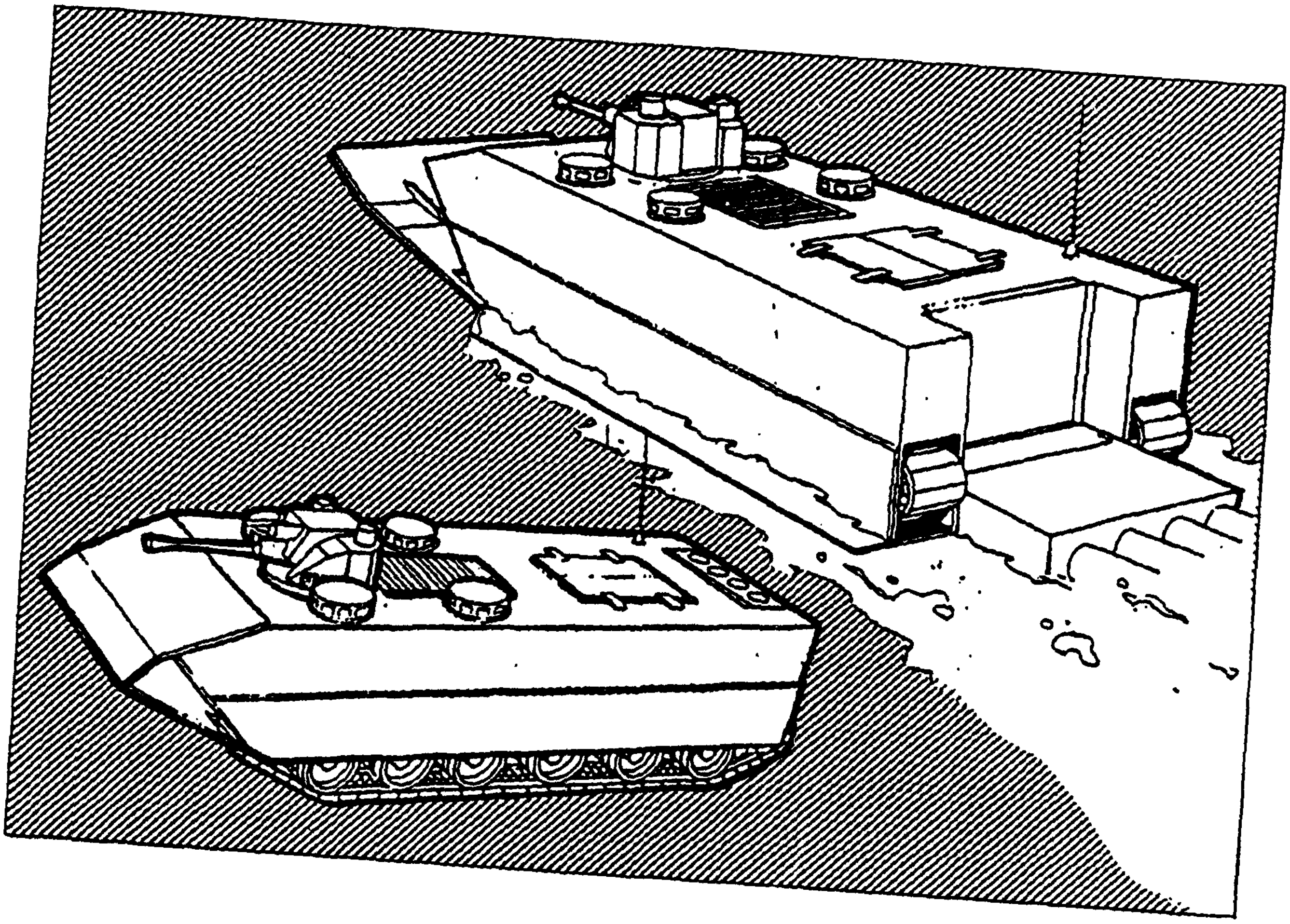
- I FIELD EXCITER
  The current supplied by the regulator to the field winding of the exciter.

- V FIELD EXCITER
  The voltage supplied by the regulator to the terminals of the field winding of the exciter.

Amphibious Vehicle Propulsion System Acceptance Test Report

For a Propulsion System Demonstrator (PSD) Vehicle

December 21, 1989



Prepared under
Contract No. N00167-86-C-0158
for David Taylor Research Center
Bethesda, Maryland

Westinghouse Electric Corporation
Naval Systems Division
18901 Euclid Avenue
Cleveland, Ohio 44117

Clin 0002

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18901 Euclid Avenue
Cleveland, Ohio 44117

William Eastman, Technical Manager

Steven Specht, Program Manager

Table of Contents

Table of Contents

Section 1.0
SYSTEM DESCRIPTION

Advanced Alternator, Inverter, and Motor Technology for Amphibious Vehicle Electric Waterjet Propulsion Applications

ELECTRIC WATERJET PROPULSION SYSTEM

The electric waterjet propulsion system depicted below is currently under development for the Propulsion System Demonstrator project. The components were designed to be powered by either a turbine or rotary engine. Each 400 hp electric waterjet drive system includes its own alternator, alternator controller, microprocessor monitor system, power cable, electric motor and speed decreasing gear.

SYSTEM ADVANTAGES

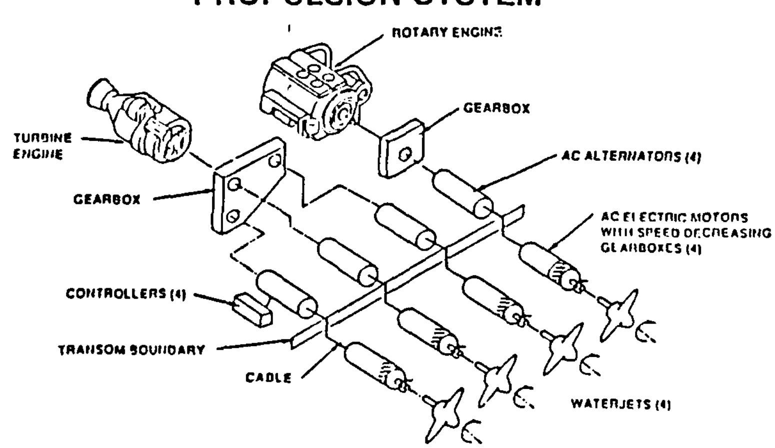
The electric waterjet propulsion offers several advantages over conventional hydraulic systems. The electric system is designed for improved efficiency and electronic control reliability, as well as reduced maintenance when compared to current systems. For advanced system concepts, electric components offer flexibility of placement within the vehicle, can be designed to operate with a common cooling fluid, and would be relatively quiet if oil cooling were to replace air cooling in the alternator system. This facilitates the design of a platform that may use some of the advanced armaments such as electrothermal, or electromagnetic gun weapon systems. Using electric traction drive, a totally electric amphibious vehicle could be developed.

STATUS

The electric waterjet propulsion system has demonstrated the capability to produce the full speed and power rating of 1,250 RPM and 400HP, in brief tests. Motor / SDG design problems have precluded achievement of steady state thermal operation at power levels above 161 HP, or 40% of full power. The motor and SDG are currently being redesigned to meet full power and 1.3 overload conditions. The alternator and alternator control subsystems have demonstrated steady state thermal operation at full power, and the 1.3 overload condition for one minute, at unity power factor, using a resistive load.

This test report covers testing done on the system (as modified during the fabrication and test programs) delivered under the subject contract. For further information on the original design see the "Amphibious Vehicle Propulsion System Design Report", Westinghouse Inc., Oceanic Division, July 8, 1988. For further information on the overall test program and the latest design see the "Amphibious Vehicle Propulsion System Final Rport"' Westinghouse Inc., Naval Systems Division, January 31, 1990.

PROPULSION SYSTEM



Section 2.0
SYSTEM TEST SETUP

The Westinghouse System Test Stand Allows Testing at the Component and System Level to Acceptance Level Standards

TEST STANDS

The test stand used to perform component and subsystem integration tests on the electric waterjet propulsion system includes a controllable 9000 RPM, 500hp electric drive stand to power the alternator, a 0-1250 RPM waterbrake dynamometer stand to load the motor, and control consoles for the stands and instrumentation readouts.

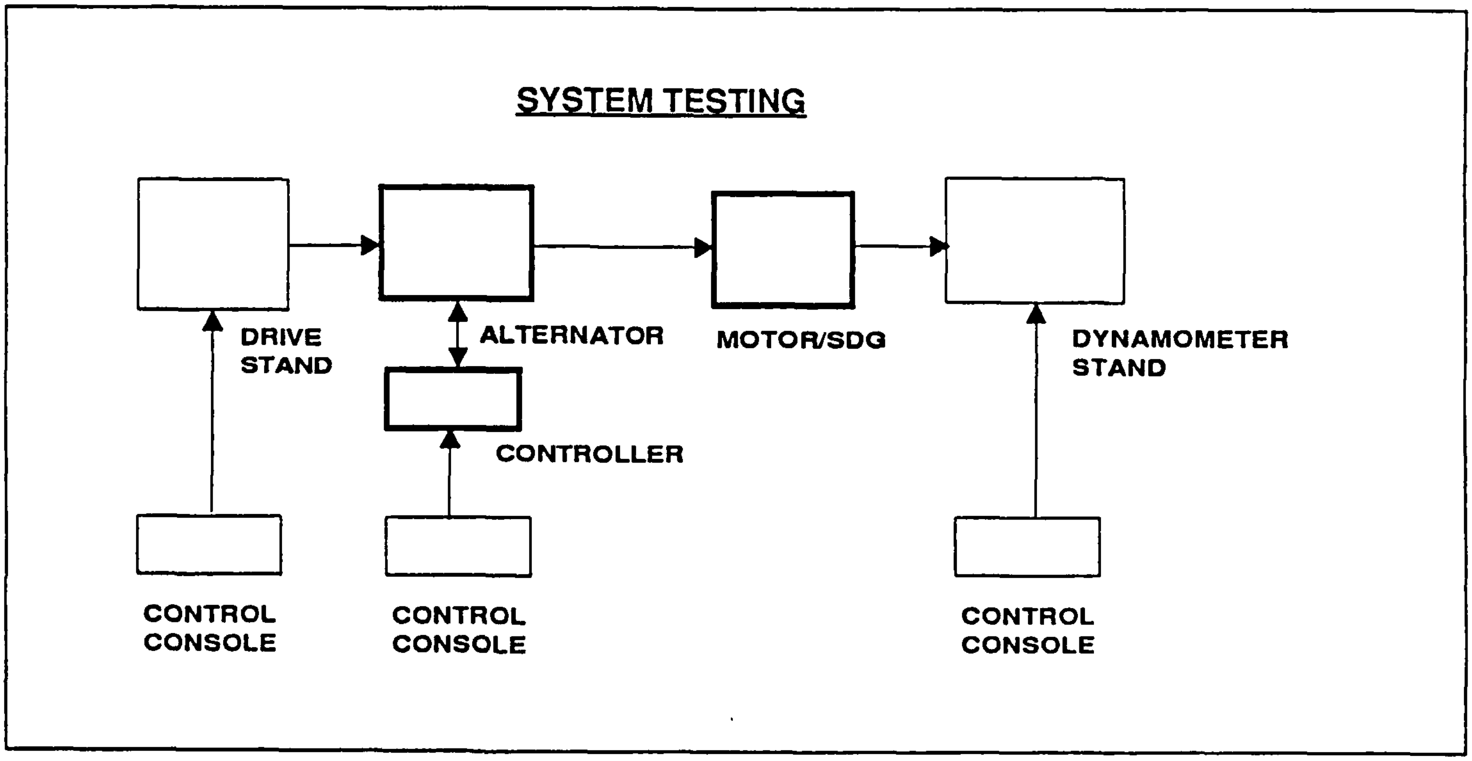
TEST STAND CONTROL

Three independent consoles are used to control, load, and monitor the tests. The drive stand speed is controllable from 0-9000 RPM and monitors the mechanical power being supplied to the alternator.

The waterbrake dynamometer is capable of loading the system from 0 to 532 hp (1.3 Overload). Mechanical power into the dynamometer is monitored with a torque transducer. Total system efficiency (mechanical input/mechanical output) can be obtained for the total electric waterjet drive subsystem.

The electrical operating characteristics are monitored and controlled through the alternator controller. Voltage, current, power, line operating frequency, time varying waveform data, operating temperatures, and control status are obtained through the test facility instrumentation. The controller is used to activate a safety or overload shutdown of the system. The controller is capable of running the system from 610 to 1250 RPM Motor/SDG (output).

A block diagram of the entire test stand is shown below. This test stand is available to support future electric waterjet propulsion component or system level testing.



Section 3.0
SYSTEM TEST RESULTS

COMPONENT TEST RESULTS

Component test results are included for reference purposes to show the areas where the system meets the requirements, and the areas where design changes were implemented.

SYSTEM TEST RESULTS

The results of the system tested are summarized in the figure below. The first test was aborted after 2 minutes due to an excessive rate of rise in the motor winding temperatures. The second test was run at a lower power level to determine a safe operating point. This test was aborted after 6 minutes due to excessive motor winding temperatures. The third test was run after incorporation of design changes which improved the motor cooling system. Acceptable steady state motor winding temperature was reached within 10 minutes in this test. Hardware damage in subsequent higher power level tests indicated that the then tested hardware must be derated to the power level of test 506 described below (161 HP @ 920 RPM).

Because of the severe derating of the system the component test data which follows is included for reference.

Parameter	Requirement	Test/Date			Comments
		202 3/12/89	203 3/12/89	506 5/18/89	
System					
Efficiency (%)	81% Min	80	81	*	* Data not taken due to Transducer failure
Run Time (Min.)	See Note	2	6	10	Achievement of steady state operating temperature was criterion for these tests.
Alternator					
RPM	9,000	8,840	8,005	6,515	
Input Power (HP)	494 Hp Max	496	361	*	
Efficiency (%)	88% Min	93	94	*	
Winding Temp (C)	230 C Max				Data not taken- see Alternator heat run data
Motor/SDG					
RPM	1,250 RPM	1,248	1,126	925	
Output power (HP)	400 HP Min	399	294	161	Steady state not achieved in tests 202 and 203 due to excessive winding temperature rise.
Efficiency (%)	92% Min	86	86	93	
Winding Temp (C)	180 C Max	130	180	120	
Oil flow rate (GPM)	3.5 GPM Min	3.9	3.63	3.5	
Heat rejected (BTU/HR)	54000 Btu/Hr Max	**	**	16,500	** Not a requirement in these tests

Section 3.0
SYSTEM TEST RESULTS

DESCRIPTION OF DESIGN PROBLEMS

The design problems encountered in the test program were primarily isolated to the Motor/SDG. A brief summary of the problems follows.

ROTOR

The end rings had shifted on the rotor during operation, which disrupted the sprayed oil cooling flow path, resulting in severe overheating of the entire rotor. The laminations were not insulated from each other, contributing additional losses which had to be carried away by the sprayed oil cooling.

STATOR

Inadequate lamination insulation and circulating currents in the windings produced additional thermal losses. The lamination anneal did not develop optimum magnetic properties requiring higher magnetizing current than desired to reach the operating point. These higher currents resulted in higher losses.

HOUSING

The housing, which contains an integral heat exchanger, did not exhibit the anticipated heat transfer coefficient as a result of distortion problems in manufacturing and from the nickel plating (added to improve corrosion resistance). The oil suction path restricted the flow, which starved the inlet to the pump at maximum flow conditions.

SDG

The oil lubrication/cooling furnished did not adequately remove the heat from the gears. The heat buildup increased the gear blank temperatures to the point that damage in the gear meshes occurred.

DESCRIPTION OF REDESIGNS

The follwing design changes have been incorporated into the component parts of a second motor/sdg but have not been tested.

ROTOR IMPROVEMENTS

A new end ring concept was devised which will maintain centering of the ring and cannot interfere with the sprayed oil cooling. The laminations have been double adhesive coated to provide interlamination insulation. Bonding of the laminations can be accomplished by replacing the brazing of the brass with soldering. The new end ring design provides the mechanical strength for the bar support so that the solder joint is only an electrical connection.

STATOR REDESIGN

The laminations were annealed a second time to produce optimum magnetic properties. The laminations were then double adhesive coated to provide interlamination insulation. The winding was not changed.

HOUSING IMPROVEMENT

The heat exchanger was redesigned to eliminate all welding and consequently eliminate distortion. The oil suction path was increased in area to avoid flow restriction.

SDG REDESIGN

The oil spray system was redesigned to spray oil on the gear teeth upon exiting the mesh so that positive heat removal is ensured. Changes in the oil supply path within the SDG were made to accommodate the new spray nozzles. The oil inlet passage to the lubrication pump was increased to match the larger passage in the housing.

Section 4.0
COMPONENT TESTING

The 322 kW Alternator was Tested at Full Power With a Resistive Load

ELECTRIC WATERJET COMPONENTS

Four major subsystems were developed to realize a 400 Hp electric waterjet propulsion drive system. They are a 322 Kw alternator; an alternator controller with system control, protection, and monitoring; a 400 Hp induction motor; and a speed decreasing gearbox. The system has been designed to meet a 1.3 overload condition for one minute. System speed is a direct function of prime mover speed.

ALTERNATOR SUBSYSTEM

The 322 Kw alternator subsystem is a modification of an existing Westinghouse design. The alternator is actually three electric machines on a common shaft. These include the main machine which supplies electrical power directly to the motor, an exciter which produces field current for the main machine, and a permanent magnet generator (PMG) which supplies a frequency reference to the control system. Voltage and current information is supplied by the power sensing box (PSB).

CONTROLLER

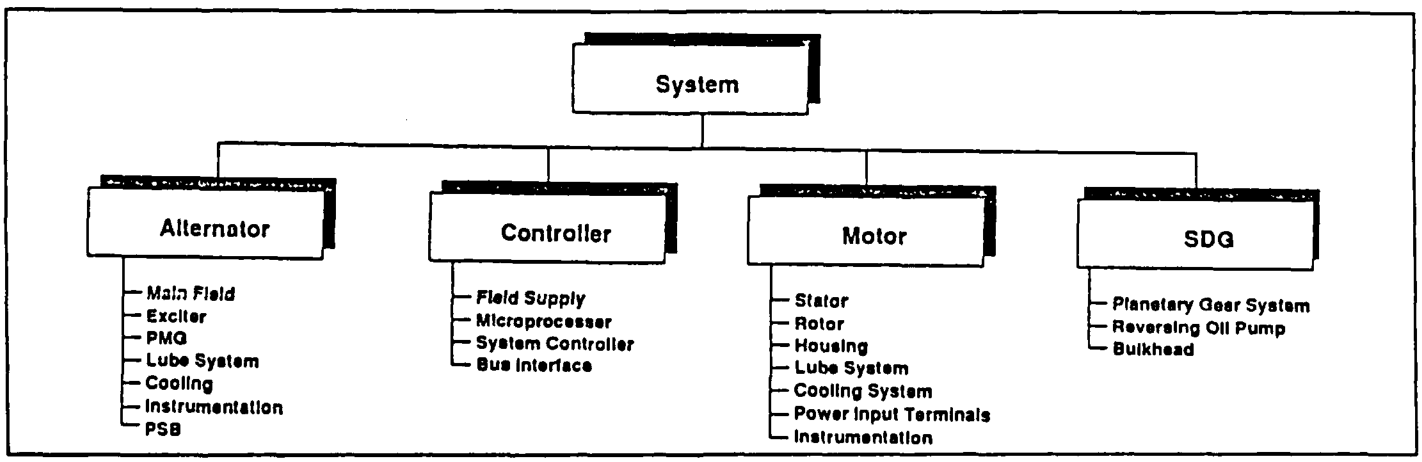
The exciter is controlled by the high frequency power converter (2.5 Amps continuous, 7.0 Amps for 1 minute) which maintains a constant Volts per Hertz ratio on the alternator output to the motor. Overall system control is achieved with hard wired logic. Monitoring functions and communication of system status are handled by an embedded microcontroller.

MOTOR

The 400 Hp motor includes the electromagnetic structure (stator and rotor); an integral lubrication and cooling system; and sensors for temperature, oil pressure, and shaft speed. The three phase electrical power is supplied to the motor through sealed cable connections.

SPEED DECREASING GEAR (SDG)

The single stage planetary gear system provides a 7:1 reduction ratio. The oil pump for the motor/SDG unit is driven by the planet carrier within this unit. The motor and SDG share a common bulkhead for mechanical and lubrication functions.



Section 4.1
ALTERNATOR TEST SETUP

PURPOSE OF TEST

The initial factory acceptance testing, limited to 65% full power (drive stand capacity) was performed at the Westinghouse Electrical Systems Division in Lima, Ohio. The Westinghouse Chardon Facility testing was conducted to demonstrate full power and overload conditions. Performance testing was conducted over the entire operating temperature range of the unit. After completion of this test the unit was ready for system integration testing.

TEST CONFIGURATION

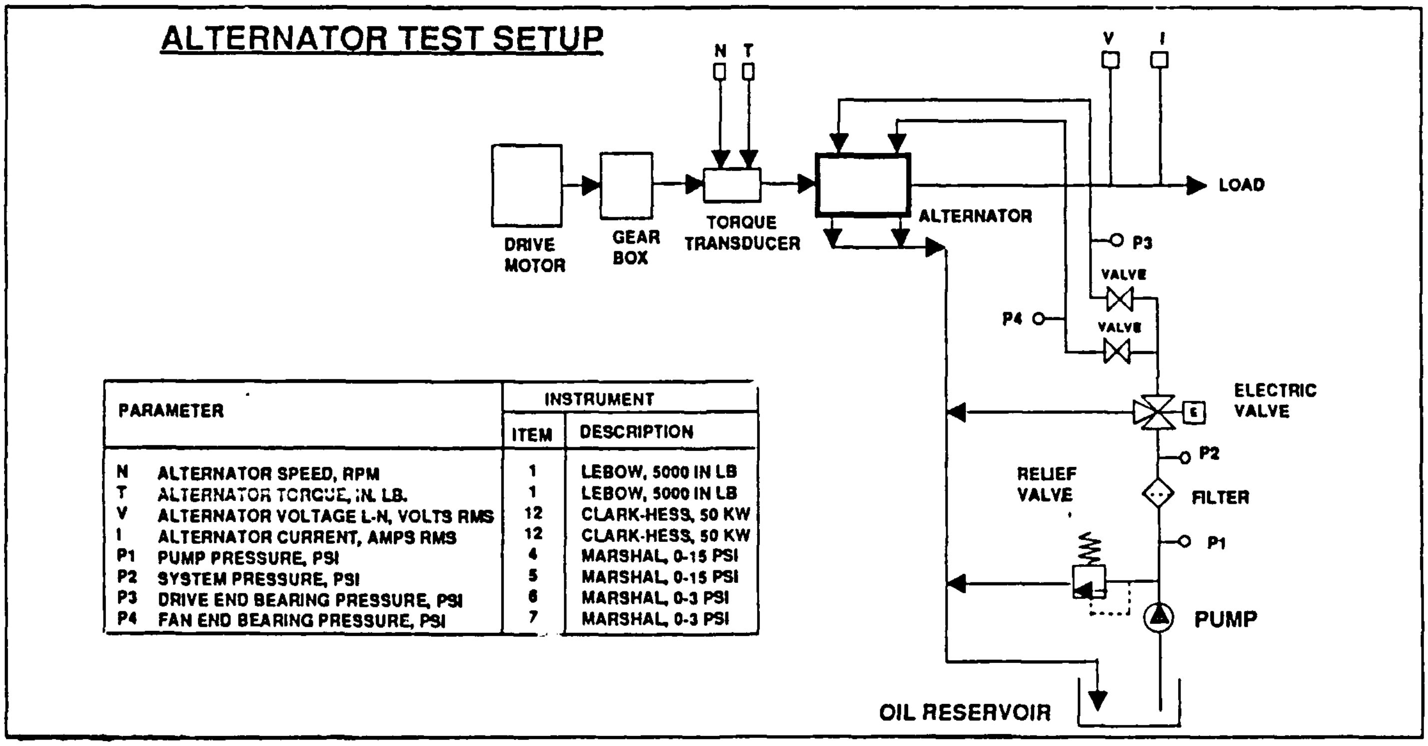
The test stand configuration for the alternator is shown in the figure below. The high speed alternator was driven by a direct drive DC motor through a speed increasing gearbox. Input torque to the alternator was measured using a torque transducer. Cooling air was supplied by an internal fan. Lubricating oil was supplied by a circulating filtered oil system in the facility. A resistive load bank was used to obtain the operating characteristics of the alternator and to test the performance under overload conditions.

INSTRUMENTATION

The instrumentation used is summarized below. A torque transducer provided input speed and torque data and a wattmeter provided output power, voltage and current data. Pressure gauges in the lubrication system were used to monitor the system for proper function.

FACTORY ACCEPTANCE TEST

For further information on the alternator factory acceptance testing, see "Test Report CDRL T-807" Westinghouse Electric Corporation, Electrical Systems Division, October 12, 1988.



PARAMETER		INSTRUMENT ITEM	INSTRUMENT DESCRIPTION
N	ALTERNATOR SPEED, RPM	1	LEBOW, 5000 IN LB
T	ALTERNATOR TORQUE, IN. LB.	1	LEBOW, 5000 IN LB
V	ALTERNATOR VOLTAGE L-N, VOLTS RMS	12	CLARK-HESS, 50 KW
I	ALTERNATOR CURRENT, AMPS RMS	12	CLARK-HESS, 50 KW
P1	PUMP PRESSURE, PSI	4	MARSHAL, 0-15 PSI
P2	SYSTEM PRESSURE, PSI	5	MARSHAL, 0-15 PSI
P3	DRIVE END BEARING PRESSURE, PSI	6	MARSHAL, 0-3 PSI
P4	FAN END BEARING PRESSURE, PSI	7	MARSHAL, 0-3 PSI

Section 4.1
ALTERNATOR TEST RESULTS

DIELECTRIC TESTS

Dielectric tests were performed on the alternator during fabrication and factory acceptance testing with the vendor's instrumentation and in accordance with prescribed fabrication and test procedures. Westinghouse, Chardon repeated the tests after receiving the machine, to verify the insulation integrity of the machine and to provide a baseline with Chardon instrumentation for evaluation of the machine condition during and after testing. The Westinghouse, Chardon results are shown below.

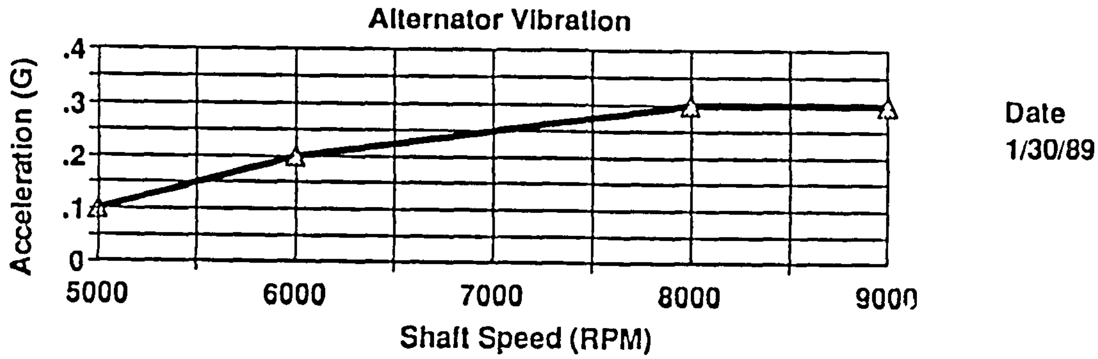
Date: 10/21/88

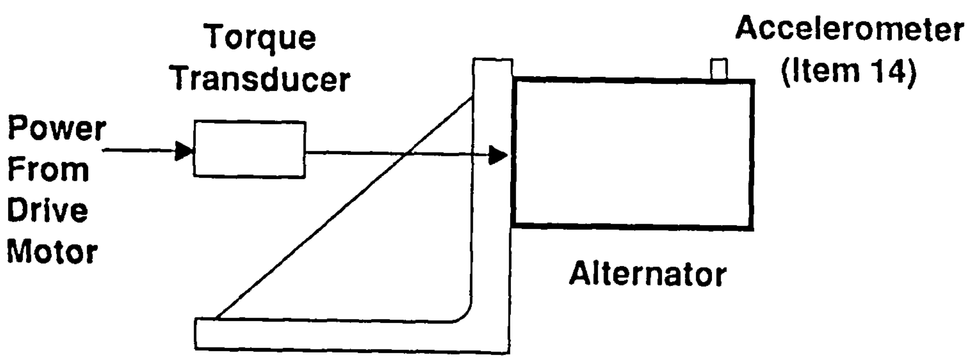
Parameter	Result	Comments
Winding to Frame (Meg Ohm)		
T1	10,000	Data taken with a Hipotronics Series 300 Megohmeter (ITEM 16) at 500 VDC
T2	12,000	
T3	10,000	
Winding to winding (Meg Ohm)		
T1 - T2	15,000	
T2 - T3	15,000	
T1 - T3	15,000	
Connector P1 to Frame (Meg Ohm)		
Pin A	100,000	
Pin B	30,000	

Section 4.1
ALTERNATOR TEST RESULTS

ALTERNATOR MOUNTING/VIBRATION ASSESSMENT

Initial alternator testing on the Westinghouse, Chardon drivestand was terminated due to excessive vibration levels on the alternator. The source of vibration was traced to the alternator mounting bracket which was resonating within the operating speed range. A new, stiffer bracket was fabricated and vibration tests were performed to assure that the alternator drivestand provided suitable mounting conditions. Alternator baseline vibration levels were recorded to evaluate machine conditions during testing. The test setup and vibration levels at various speeds are shown below.



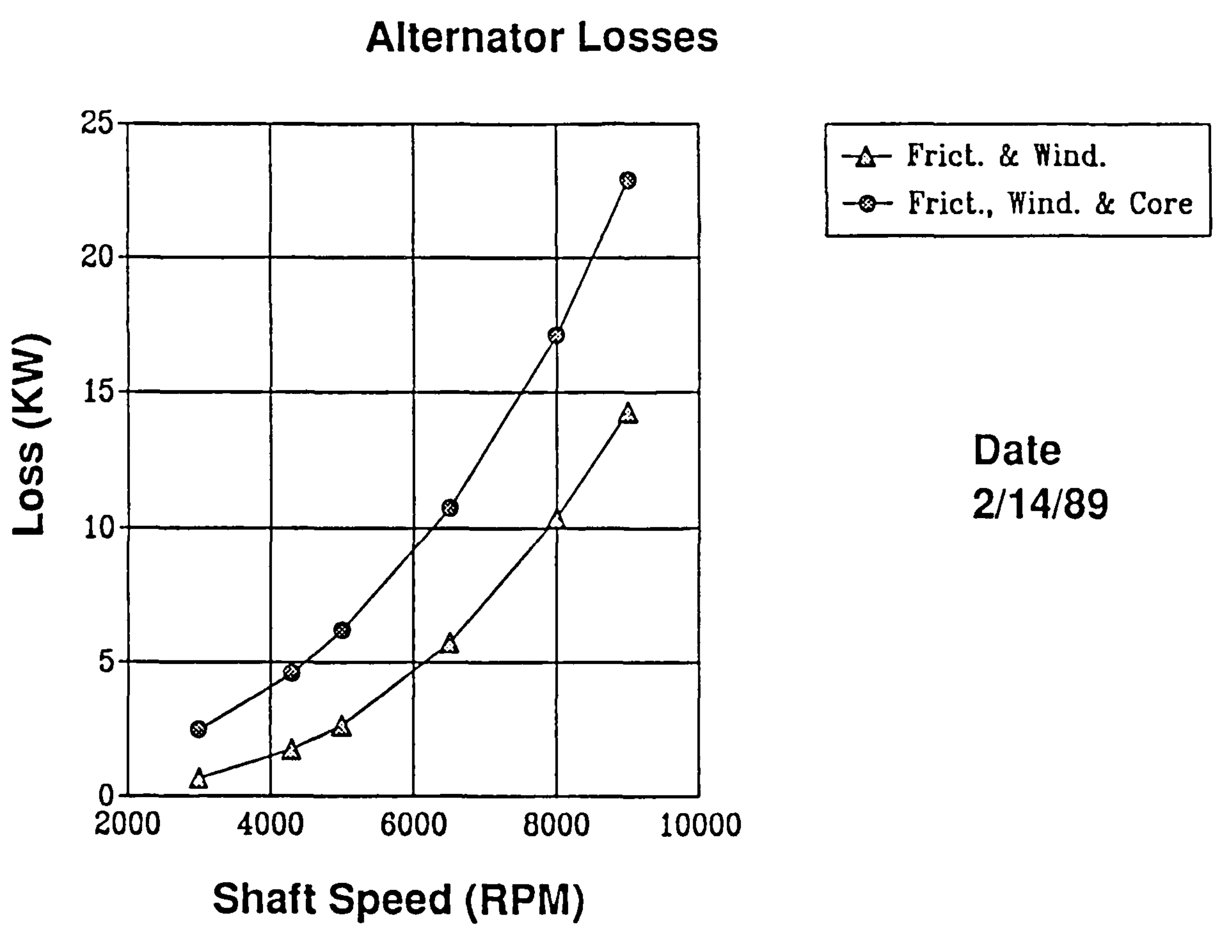


TEST SETUP

Section 4.1
ALTERNATOR TEST RESULTS

ALTERNATOR LOSSES

The test results from the alternator friction and windage loss tests are shown below. The test setup is shown in the beginning of section 4.1. The friction and windage curve shows all mechanical losses. With no load attached the exciter field was energized with a 2.0 Amp current to obtain the additional effect of core loss.



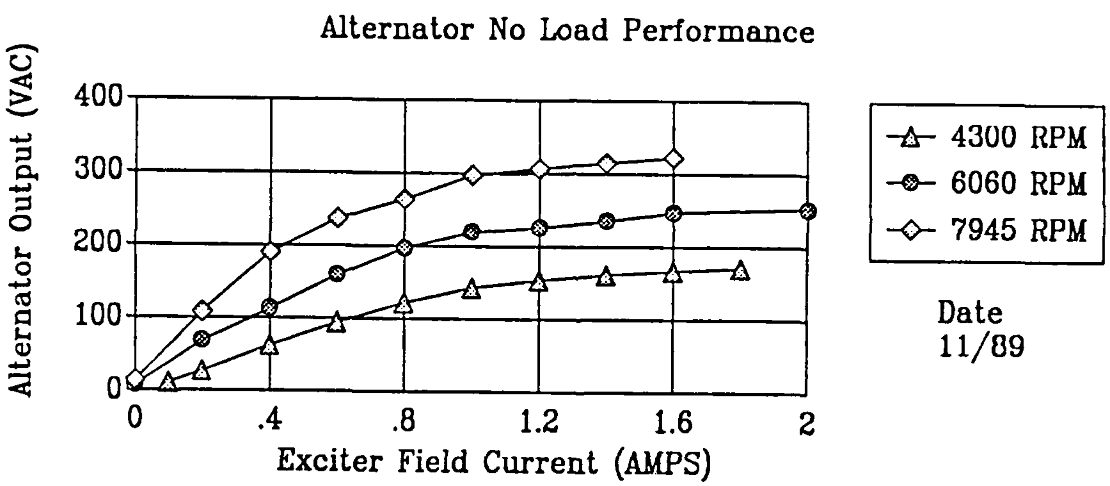
Section 4.1
ALTERNATOR TEST RESULTS

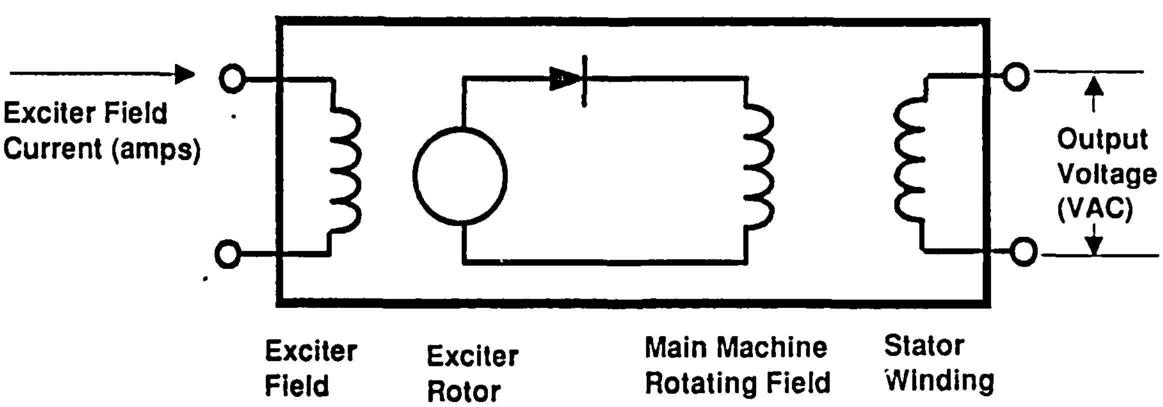
ALTERNATOR NO LOAD PERFORMANCE

The test results and schematic for alternator no load testing are shown below; the test setup is shown at the beginning of this section. The purpose of this test was to determine the output voltage as a function of input current and shaft speed. Shaft speed was limited to the maximum demonstrated in Lima tests so as to minimize risk to the alternator. These curves show the effect of magnetic saturation on the machine output.

Since this machine was to be used in a constant Volts per Hz mode (which differs from the original design requirements of the machine) this data was needed to verify suitable performance.

Final adjustments to the controller were made on the basis of these results.





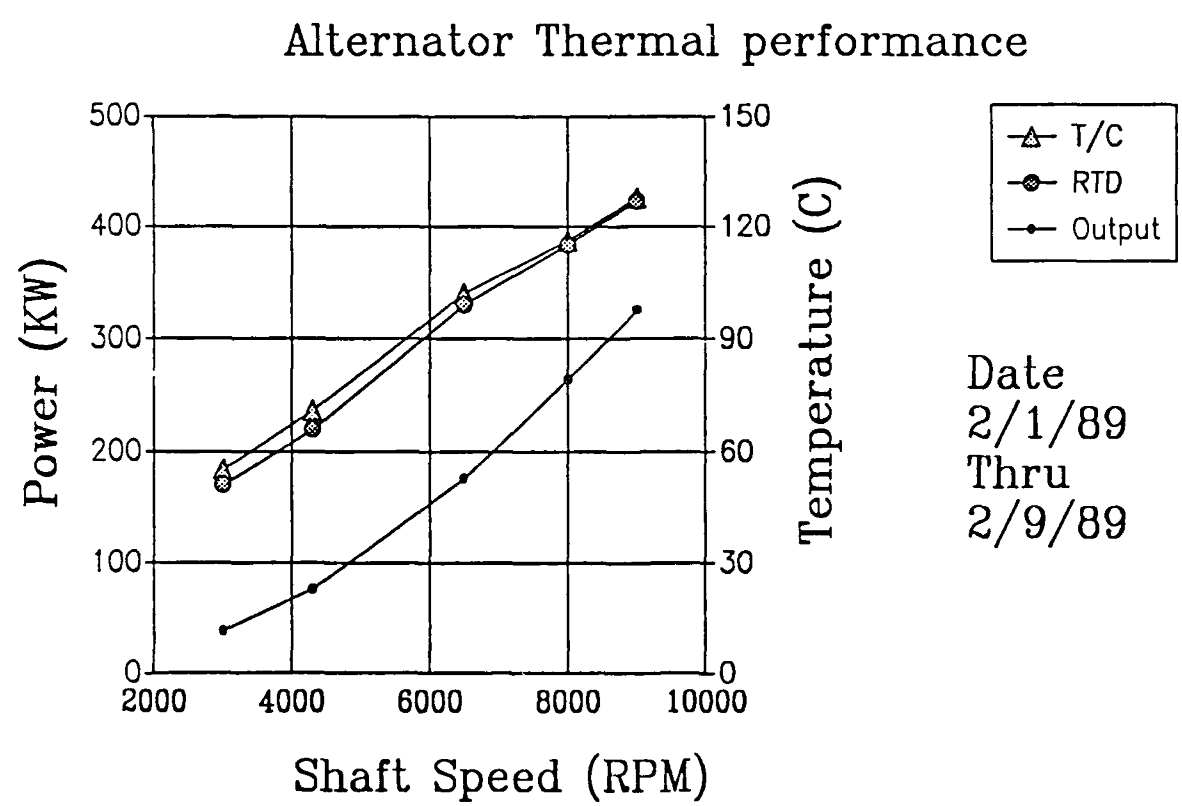
TEST SCHEMATIC

Section 4.1
ALTERNATOR TEST RESULTS

ALTERNATOR THERMAL PERFORMANCE

The test results of the thermal performance tests are shown below. The test setup is shown in the beginning of section 4.1 Several tests were run at various speeds at the operational power level until steady state temperatures were achieved. The purpose of this test was to verify that the machine would function properly at the maximum operating condition (this was not done in the factory acceptance test at ESD) and to determine if the data from the resistance temperature devices (RTD's) mounted in the frame correlated with the thermocouples mounted on the main stator winding.

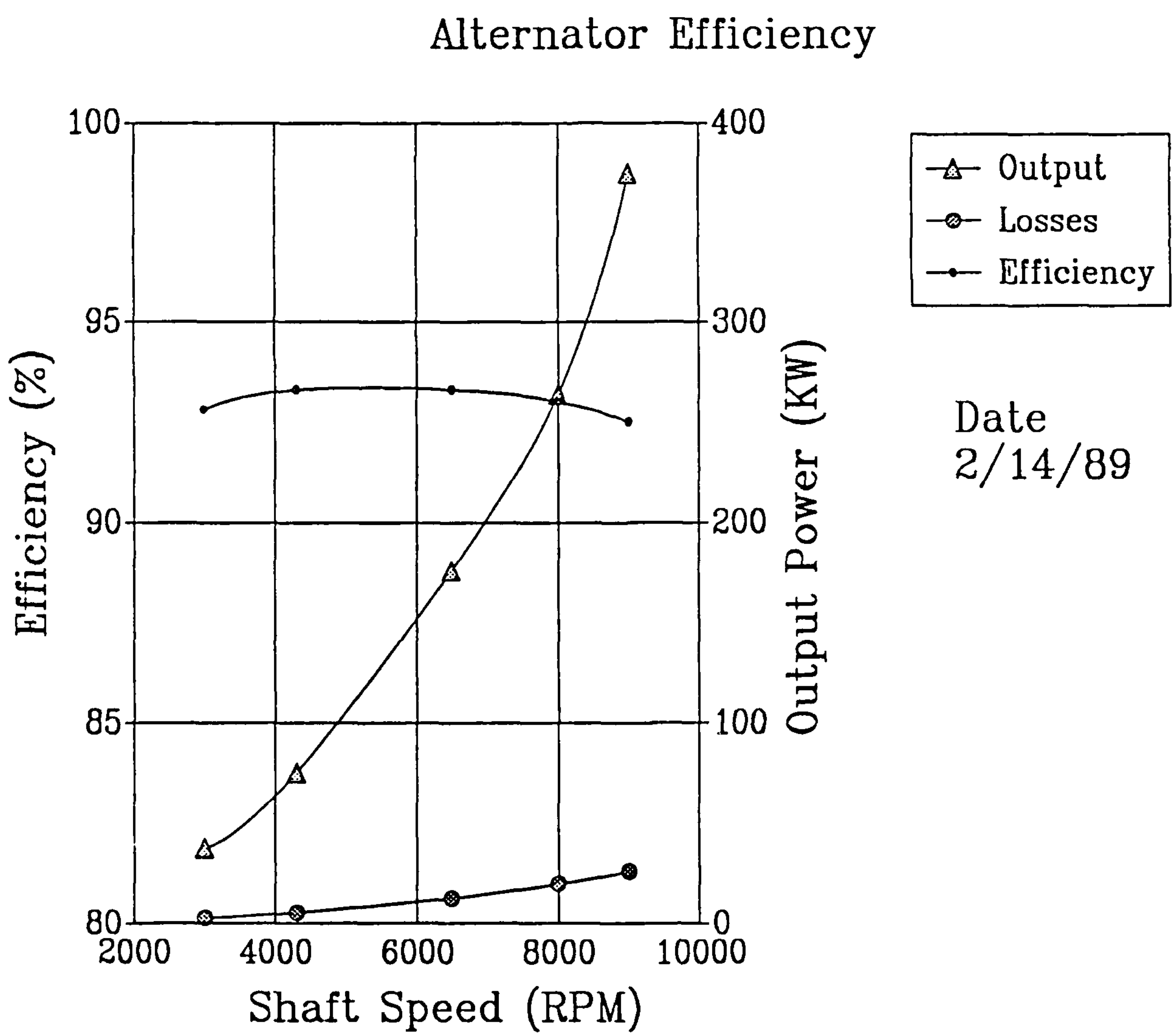
The maximum operating temperatures observed are well within the 300C operating limit for the stator insulation system and the RTD's are shown to have excellent correlation with the thermocouples. This shows that the RTD's are suitable for the purpose of sensing an overtemperature condition in the alternator.



Section 4.1
ALTERNATOR TEST RESULTS

ALTERNATOR EFFICIENCY

The alternator efficiency calculations are graphed below. The test setup is shown in the beginning of section 4.1. The total losses were added to the output power to determine input power so that machine efficiency could be calculated. The efficiency at the



Section 4.2
CONTROLLER TEST SETUP

PURPOSE OF TEST

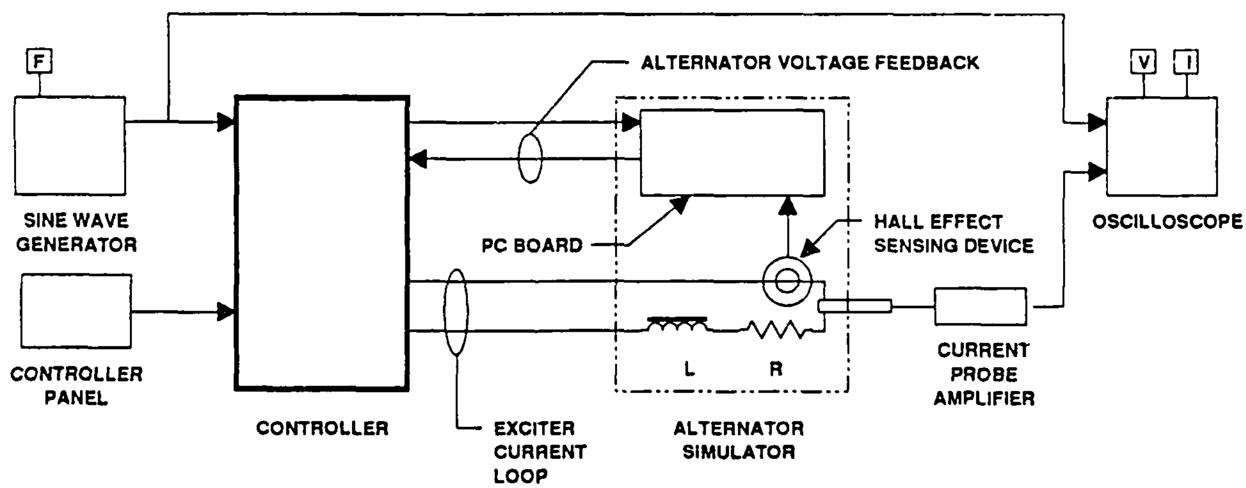
The following controller tests were conducted to verify the: current limit function; steady state current regulation; thermal performance; and fault/protection features. An alternator simulator was built and utilized during the controller development/integration testing to minimize risk of damage to the alternator.

TEST CONFIGURATION

The controller testing was configured in accordance with the figure shown below. The controller was connected to the front panel, the alternator simulator and sine wave generator. The sine wave generator simulated the alternator speed pickup signal. The oscilloscope monitored exciter field current and Wavetek voltage.

INSTRUMENTATION

The instrumentation used for this test is summarized below. the sine wave generator was set to 2KHZ, 10V peak to peak, thus simulating the alternator speed signal. The oscilloscope was a dual trace type, to observe current through the current probe amplifier and voltage.



PARAMETER		INSTRUMENT ITEM	INSTRUMENT DESCRIPTION
F	FREQUENCY (KHZ)	17	WAVETEK, .01 - 4 MHZ
V	INPUT VOLTAGE (V)	19	TEKTRONIX, 200 MHZ, 200V
I	OUTPUT CURRENT (A)	18	TEKTRONIX, 1ma - 20A

Section 4.2
CONTROLLER TEST RESULTS

CURRENT LIMIT TEST
The purpose of this test was to verify that the peak controller current is limited to 7 amps, the value established as the maximum safe limit for the controller.

STEADY STATE FIELD CURRENT
The purpose of this test was to verify that the controller regulates the field current within allowable limits.

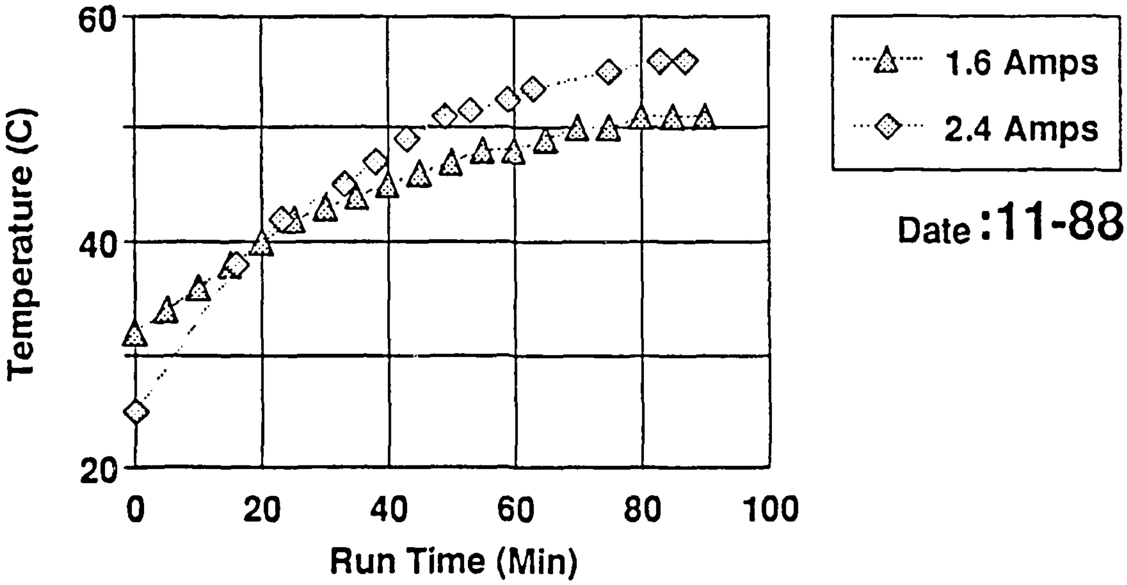
These tests were setup in accordance with the description at the beginning of section 4.2. The tests were performed concurrently. The switch on the controller panel was turned to the "On" position, the current rose to just under 7 Amps for less than one second, and then fell to a steady state value of 1.8 Amps. The tests were passed and the results are shown below.

DATE	TEST DESCRIPTION	INPUT		OUTPUT, AMPS		COMMENTS
		FREQ., KHZ	LEVEL, V P-P	EXPECTED	ACTUAL	
10–88	CURRENT LIMIT	2.0	10	7 MAX	<7	1 SECOND
	STEADY STATE PERFORMANCE	2.0	10	1.8 +/- 5%	1.8	

Section 4.2
CONTROLLER TEST RESULTS

HEAT RUNS

The purpose of this testing was to verify that the maximum operating temperature inside the controller does not exceed component maximum ratings. A thermocouple was placed inside the box to monitor local internal ambient temperature. The controller was connected to the alternator simulator as in the previous test and run at 1.6 Amps to obtain a level of confidence. A resistor was then changed in the simulator to obtain a steady state current of 2.4 Amps (the highest value expected). Steady state temperatures were reached in both tests in less than 90 minutes. A maximum temperature of 56C was recorded while the outside ambient temperature was 25C. Since the maximum allowable ambient temperature is 50C the corrected internal temperature is 81C. This result is below the maximum allowable temperature of 85C (maximum rating of some capacitors). The results of the tests are graphed below.



Section 4.2
CONTROLLER TEST RESULTS

FAULT/PROTECTION TESTING

The results of the fault/protection system testing are shown below. Bench testing was conducted to verify that the controller would provide adequate protection for the alternator and motor/SDG when integrated into the system for system testing and to test conditions that are not desirable to test in the system mode. Some functions were also retested at the system level as shown to demonstrate that critical functions continued to work in the operational environment. All tests performed were passed.

Dates: 1/89 thru 4/89

Function	Mode	System Status	Front Panel Command	Expected Result	Test results		Comments
					Bench Test	System Test	
Overcurrent	Prestart	Fault level current (1400 A)	Select Start	Fault	Passed	Passed	Tests conducted on both phase currents
	Prestart	Fault level current (1400 A)	Select Run	Fault	Passed	Passed	
Over Temperature	Prestart	RTD simulator adjusted to fault value	None	Fault	Passed	Not tested	Tests repeated for each RTD
	Run	RTD simulator adjusted to fault value	None	Fault	Passed	Not tested	Fault limits; Alternator 275 C Motor 200 C
Low Oil Pressure	Run	Reduce pressure transducer output to fault value (5 PSI)	None	Fault	Passed	Not tested	
Alternator Speed	Prestart	Adjust alternator speed to low limit threshold (2500 RPM)	Select Run	No start	Passed	Passed	
	Prestart	Adjust alternator speed to high limit threshold (4400 RPM)	Select Run	No start	Passed	Passed	
Supply Voltage	Prestart	Adjust supply voltage to high limit threshold (30 V)	Select Run	No start	Passed	Passed	
	Prestart	Adjust supply voltage to low limit threshold (22 V)	Select Run	No start	Passed	Passed	
Ground Fault	Any	Apply threshold voltage between OV1 and OV3 (100 v)	None	Alarm	Passed	Not tested	
Slip	Prestart	Set PMG simulator and motor speed sensor simulator to establish threshold slip (5%)	Select Start	Shutdown	Passed	Not tested	
	Run	Set PMG simulator and motor speed sensor simulator to establish threshold slip (5%)	None	Shutdown	Passed	Passed	

Section 4.3
ALTERNATOR/CONTROLLER TEST SETUP

The Alternator/Controller Provided Constant Volts Per Hertz Control Over the Entire Operating Range

PURPOSE OF TEST

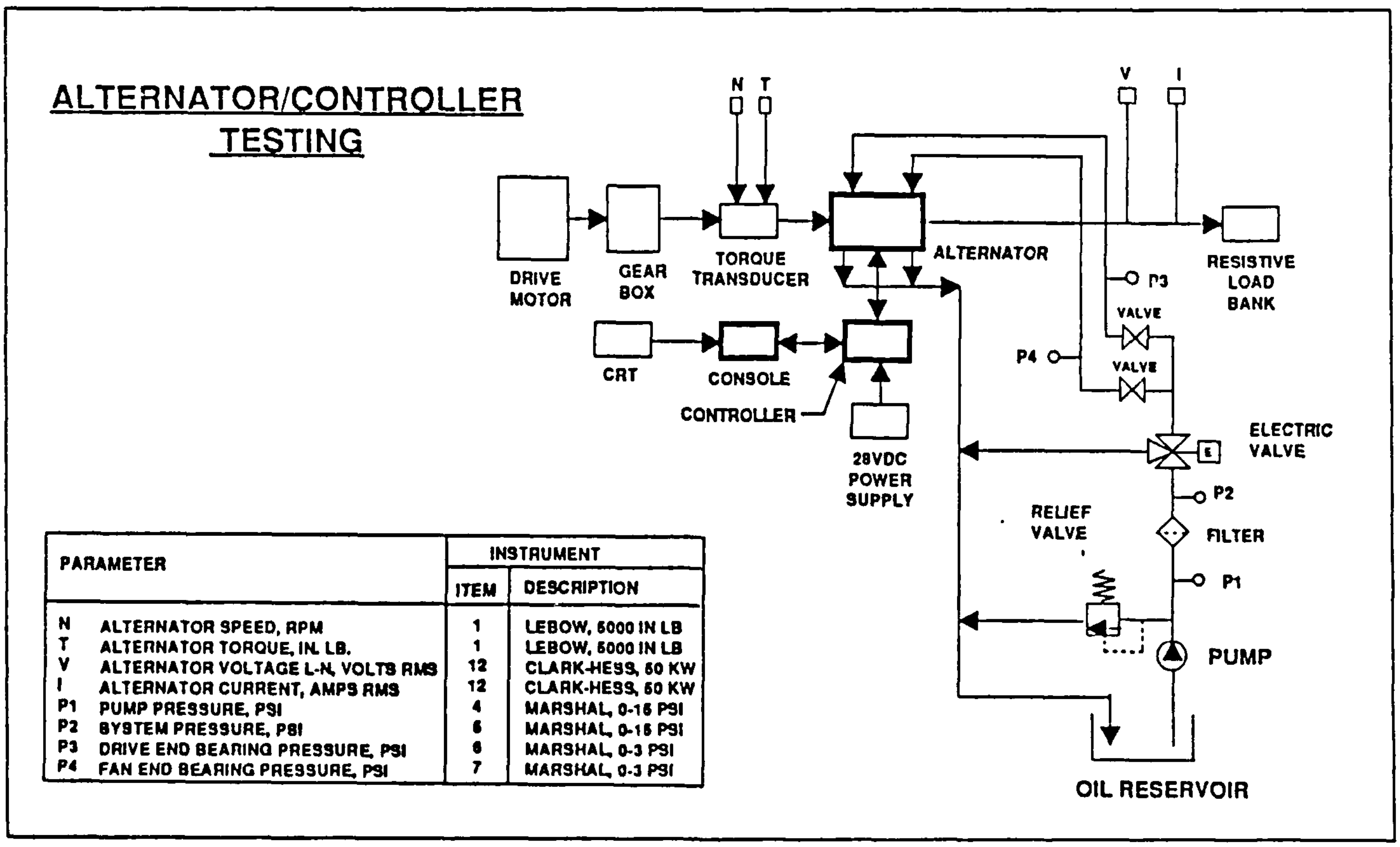
The alternator/controller was tested to demonstrate constant volts per hertz control, system protection modes, and monitoring functions over the entire operating envelope.

TEST CONFIGURATION

The test stand configuration for alternator/controller is shown in the figure below. The high speed alternator was driven by a direct drive DC motor through a speed increasing gearbox. Input torque to the alternator was measured using a torque transducer. Cooling air was supplied by an internal fan. Lubricating oil was supplied by the circulating, filtered, oil system in the facility. A resistive load bank (unity power factor) was used to obtain the operating characteristics of the alternator/controller and to test the performance under overload conditions. The controller was powered by a separate 28 VDC supply.

INSTRUMENTATION

The instrumentation used on this test configuration is summarized below. A torque transducer was used to measure the torque and speed of the alternator. Line to neutral voltage and line current was measured during all tests. Pressure gauges in the lubrication system were used to monitor the system for proper function. Instrumentation output from the microprocessor system was read on the CRT directly through the RS 232 bus.



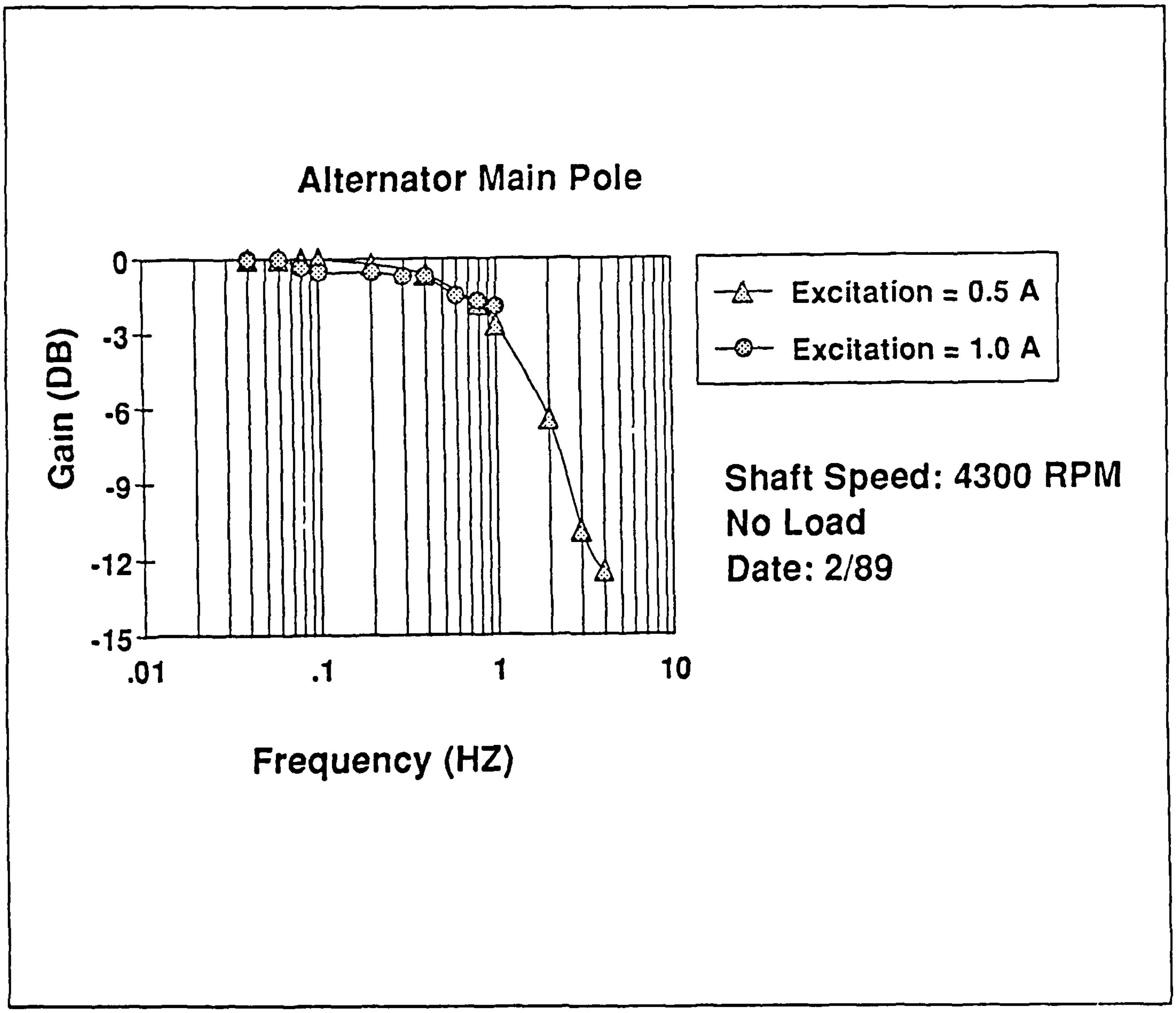
PARAMETER		INSTRUMENT ITEM	INSTRUMENT DESCRIPTION
N	ALTERNATOR SPEED, RPM	1	LEBOW, 5000 IN LB
T	ALTERNATOR TORQUE, IN. LB.	1	LEBOW, 5000 IN LB
V	ALTERNATOR VOLTAGE L-N, VOLTS RMS	12	CLARK-HESS, 50 KW
I	ALTERNATOR CURRENT, AMPS RMS	12	CLARK-HESS, 50 KW
P1	PUMP PRESSURE, PSI	4	MARSHAL, 0-15 PSI
P2	SYSTEM PRESSURE, PSI	5	MARSHAL, 0-15 PSI
P3	DRIVE END BEARING PRESSURE, PSI	6	MARSHAL, 0-3 PSI
P4	FAN END BEARING PRESSURE, PSI	7	MARSHAL, 0-3 PSI

Section 4.3
ALTERNATOR/CONTROLLER TEST RESULTS

MAIN FIELD FREQUENCY RESPONSE

The results of frequency response testing are shown below. The purpose of this test was to determine the main machine time constant so that adjustments could be made on the controller to establish a slightly underdamped loop prior to coupling of the two units.

The time constant was shown to be approximately 1.2 Hz (intersection of the curve with the -3 DB Gain value). Based on this data the necessary adjustments were made in the controller for closed loop testing.



Section 4.3
ALTERNATOR/CONTROLLER TEST RESULTS

CONTROLLER/ALTERNATOR SYSTEM TRANSIENT RESPONSE

The purpose of this test was to verify that the transient response of the system did not exceed 20% overshoot and one second recovery time. The test setup for this test was the same as the test setup for the closed loop Volts/Hz test. The system was run closed loop at 6,000 RPM with a resistive load bank connected to the alternator.

The load bank was set to the equivalent waterjet load produced at 6,000 RPM. The load was stepped off and then fully on again with toggle switches on the load bank. The alternator output voltage as a function of time is shown below. Overshoot and undershoot are approximately 10% of the set point and recovery time is about 1 second, satisfying the stated requirements. The gain of the system could be increased if faster response and/or less overshoot were desired.

DATE: 02/89

RPM	VOLTS, AC EXPECTED	VOLTS, AC ACTUAL	VOLTS/HZ	
			EXPECTED +/- 5%	CALCULATED ACTUAL
4,300	142	140	.033	.0326
5,045	166	166	.033	.0329
6,020	199	200	.033	.0332
7,005	231	234	.033	.0334
8,030	265	268	.033	.0334
9,055	299	303	.033	.0335

Section 4.3
ALTERNATOR/CONTROLLER TEST RESULTS

CONTROLLER/ALTERNATOR SYSTEM TRANSIENT RESPONSE

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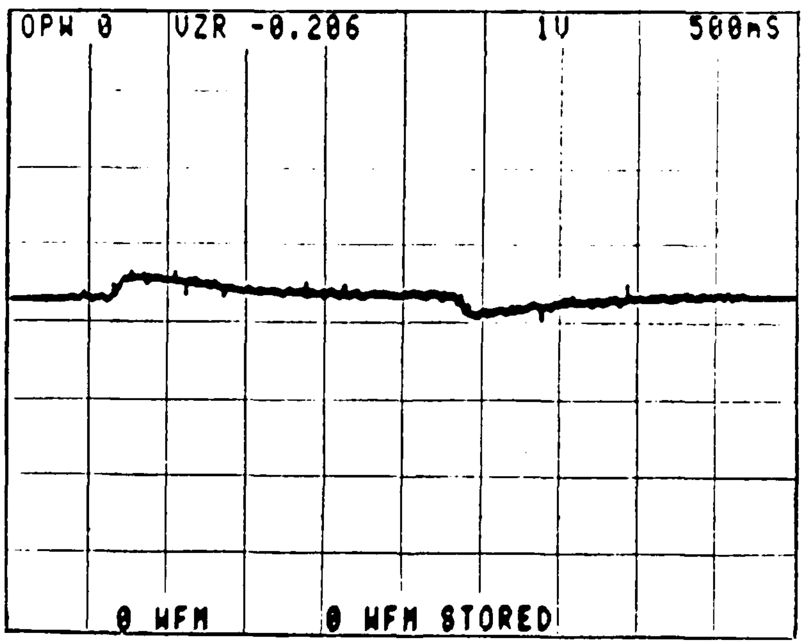
The load bank was set to the equivalent waterjet load produced at 6,000 RPM. The load was stepped off and then fully on again with toggle switches on the load bank. The alternator output voltage as a function of time is shown below. Overshoot and undershoot are approximately 10% of the set point and recovery time is about 1 second, satisfying the stated requirements. The gain of the system could be increased if faster response and/or less overshoot were desired.



Section 4.4
MOTOR/SDG TEST SETUP

PURPOSE OF TEST

Fixturing was not available to test the motor and SDG individually, so the motor/SDG was tested as one unit. Overall efficiency, oil system performance, heat flow out of the unit, start up characteristics, vibration signature, and overall system performance were determined.

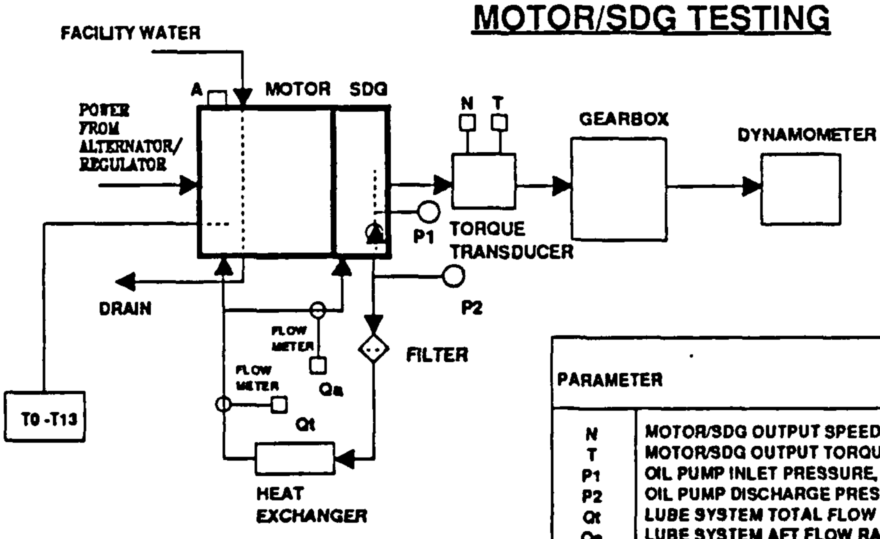
TEST CONFIGURATION

The test stand configuration for the motor/SDG is shown in the figure below. The motor was driven electrically from the alternator. Power produced by the motor/SDG was coupled through a torque transducer and speed increasing gearbox to a waterbrake dynamometer load. Lubricating oil was circulated by the internal lube pump. Oil cooling and filtering was provided by the facility equipment. Cooling water was also supplied by the facility.

INSTRUMENTATION

The instrumentation used on this test configuration is summarized below. A torque transducer was used to measure the torque and speed at the SDG output shaft. Operating pressures and oil flow rate for the pump, and input power to the motor/SDG were measured and recorded. The frequency signature for the two components was monitored to determine if the machine was experiencing any changes in balance during operation.

MOTOR/SDG TESTING



PARAMETER		INSTRUMENT ITEM	DESCRIPTION
N	MOTOR/SDG OUTPUT SPEED, RPM	2	LEBOW, 27,500 IN LB
T	MOTOR/SDG OUTPUT TORQUE, IN. LB.	2	LEBOW, 27,500 IN LB
P1	OIL PUMP INLET PRESSURE, IN. HG	8	PACIFIC SCIENTIFIC, 0-30 IN HG
P2	OIL PUMP DISCHARGE PRESSURE, PSI	9	ASHCROFT, 0-400 PSI
Qt	LUBE SYSTEM TOTAL FLOW RATE, GPM	10	HOFFER, 9.5 GPM
Qa	LUBE SYSTEM AFT FLOW RATE, GPM	11	HOFFER, 9.5 GPM
A	ACCELERATION, G	14	PIEZOTRONICS, 10 MV/G
T0 - T13	TEMPERATURE, C	15	FLUKE

Section 4.4
MOTOR/SDG TEST RESULTS

STATOR TESTING

The first purpose of these tests was to verify the insulation integrity of the stator after shipment from the vendor and to establish a baseline of data for determination of stator condition after completion of assembly and subsequent testing. The tests were repeated after assembly of the motor to verify that no damage occurred in the assembly process. All results were within specified values as shown in Table 1 below.

The second purpose of these tests was to verify that the winding resistance and inductance matched design criteria, which they did, as shown in Table 2 below.

Table 1

Parameter	Acceptable value	As recieved	Installed	Comments
Date		1-18-89	2-18-89	
Resistance				
Winding to stack (Mohms)	*500 Min.*	*25,000*	*25,000*	Hypotronics megohmeter 500 VDC
Winding to RTD's (Mohms)	500 Min.	>100k	>100k	Hypotronics megohmeter 500 VDC
Stack to RTD's (Mohms)	500 Min.	>100k	>100k	Hypotronics megohmeter 500 VDC
Leakage current (microamp)	1.0 Max.	0.05	0.05	Hypotronics Hypot 1500 VDC

Table 2 Date 1-18-89

Parameter	Expected value	As recieved	Comments
Resistance			
Phase 1-2	10.2	11.5	Valhalla 4300B micro-ohmeter
Phase 1-3	10.2	11.6	10 Amp test current
Phase 2-3	10.2	11.5	
Inductance (microH)			
Phase 1-2	Equal to	149	Hewlet-Packard impedance
Phase 1-3	each other	149	bridge 1000 Hz
Phase 2-3	within 5%	149	

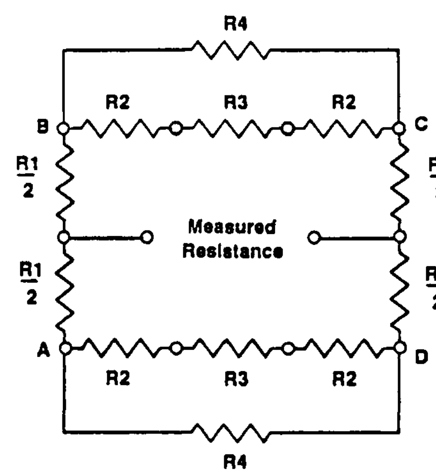
Section 4.4
MOTOR/SDG TEST RESULTS

ROTOR BAR RESISTANCE

The test results are shown in the table below. The purpose of this test was to determine if the resistance in the bars and brazed joints to the shorting rings were within acceptable limits. To meet the design requirements of the machine each bar must have a maximum resistance of 72 microohms (including the shorting ring brazed joints at each end). To obtain this data the resistance from the center of one bar to the center of an adjacent bar was measured with Valhalla Model 4300 B. This method produced a circuit as shown in the figure below. This circuit can be broken down into two parallel circuits consisting of two half bars, two braze joints and one shorting ring segment. If the joints are within limits the total resistance of this circuit is 36 microohms max. If all of the joints and bar segments are of equal resistance then both shorting rings are at the same potential and the other bars (not shown) do not have a significant influence on the circuit. Since four joints are simultaneously measured a bad joint cannot be identified directly. However, the bar in which a bad joint occurs can be identified by taking data to adjacent bars on either side.

Date 5-8-89

Rotor bar resistance (micro Ohm)	
Actual	Req'd
70.4	72 Max



R1 Rotor Bar resistance
R2 Joint Resistance
R3 End Ring Resistance
R4 Resistance Of All Other Bars, Joints And The Portion Of The End Ring Which Is Outside The Current Path Of The Inner Loop.

Notes:

1. Although R4 is shown as two elements, it is actually one large network.

2. Due to the symmetry of the inside loop, nodes A through D have the same Potential and no current passes through R4. As a result of this the only elements of the circuit that effect the measurement are those elements that are of consequence to the test results (provided the elements are all within acceptable limits).

Section 4.4
MOTOR/SDG TEST RESULTS

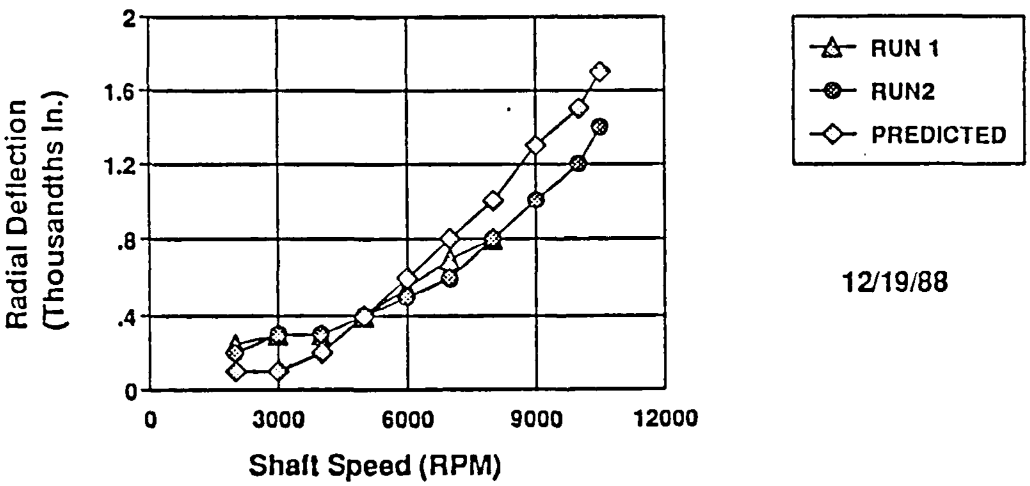
ROTOR SPIN TESTING

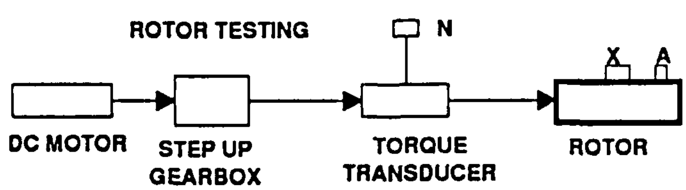
The test setup and results of rotor spin testing are shown below. The purpose of these tests was to verify that the rotor radial deflection, due to centrifugal force, was within expectations and that the rotor could safely run to the overspeed requirement.

The test setup consisted of a rotor mounted in a test housing, driven by a DC motor through a stepup gearbox and an in-line torque transducer; a proximity sensor and accelerometer were mounted to the test housing. The motor was used to gradually bring the rotor up to speed. The torque transducer was used strictly for speed sensing and the proximity sensor was used to measure rotor radial deflection. The accelerometer was used as a monitor only, to provide an early indication for test termination, should vibration levels change.

After completion of the first test (up to 8000 RPM) the rotor was removed from the fixture and examined for damage prior to testing at overspeed.

Measured deflection showed a reasonable correlation with predictions, vibration levels were extremly low, and the rotor was run to overspeed (10,500 RPM) without any evidence of damage.





PARAMETER		INSTRUMENT	
		ITEM	DESCRIPTION
N	INPUT SHAFT SPEED, RPM	3	LEBOW, 200 IN LB
X	RADIAL DEFLECTION, IN.	13	ELECTROMIKE
A	ACCELERATION, G	14	PIEZOTRONICS, 10 MV/G

Section 4.4
MOTOR/SDG TEST RESULTS

SPRAY NOZZLE TESTING

The results of spray nozzle testing are shown in Table 1 below. The purpose of this test was to verify that the nozzles provide the apprpriate design flow characteristic. Since the nozzles in the motor are connected in parallel with the nozzles in the SDG the flow characteristic determines how the total oil flow splits between the motor and SDG. The motor flow rate was shown to be acceptable (see section 4.5 for SDG nozzle performance).

During the test a range of flows was delivered to the nozzles with an external pump and visual observations were made of the spray pattern. An acceptable flow pattern was observed over the entire operational flow range.

ROTOR RESONANCE TESTING

The results of rotor resonance testing are shown in Table 2 below. The purpose of this test was to verify that the rotor first critical speed was higher than any operating speed of the machine. During this test the rotor was assembled in the motor and the motor was resting on a concrete block. A Fast Fourier Transform (FFT) analyzer was used in conjunction with an accelerometer mounted to the rotor shaft to obtain the frequency spectrum of the system. A Piezotronics impulse hammer which produces a broad band of frequencies was used to produce excitation in the shaft. The results were acceptable and demonstrated that the rotor was ready for further testing.

Table 1. Spray Nozzle Testing

Test Date	Pressure, PSI	Rotor Flow Rate, Per End, GPM		Comments
		REQUIRED	ACTUAL	
4-13-89	10	.5 MIN.	0.64	Test conducted to verify performance of rotor spray nozzles.

Table 2. Rotor Resonance Testing

Test Date	Rotor CritICAL Speed (RPM)		Comments
	Actual	Required	
12/11/88	18,000	10,500	Test results based on Dynamic resonance tests using an impulse hammer, accelerometer and FFT analyzer.

Section 4.4

MOTOR/SDG TEST RESULTS

LOCKED ROTOR TESTING

The results of locked rotor testing are shown below. The purpose of this test was to determine the rotor resistance, the leakage inductance and the starting torque of the machine. For this test rotation of the output shaft was prevented by mechanical means and the stator was excited with safe current levels (for locked rotor testing) at the starting frequency of 215 Hz. As in the stator performance testing, the core loss in this test is virtually negligible and the measured loss is almost purely copper loss.

Since the stator AC resistance was known from measurements, the rotor resistance was obtained by subtracting the stator resistance from the total resistance calculated in this test. Based on the calculated data from this test the torque at 900 Amps is expected to be 43 Ft. Lb minimum; the design analysis predicted 40 Ft. Lb..

Parameter	Test 406 4/30/89	Comments
Line current, amps	200	Data taken at 215 HZ (4300 RPM)
Line voltage, V	37.9	
Power, KW	2.8	
Leakage Inductance, micro H		
Actual	79.2	
Expected	76.2	
Rotor Resistance (OHM)		
Actual	.0106	
Expected	.0110	
Starting Torque, Ft. Lb.		
Actual (Calculated)	43	
Expected	40	

Section 4.4
MOTOR/SDG TEST RESULTS

STATOR AC RESISTANCE MEASUREMENTS

The purpose of this test was to verify the AC resistance of the stator winding. For this test the stator was installed in the heat exchanger without the rotor. The stator cavity was insulated and the stator was excited with 200 and 450 Amps at 450 Hz. A Wattmeter was used to measure the stator dissipation. The results of the testing are shown below.

Test No. Date	Line Current, Amps	Dissipation, KW		AC Resistance/Phase, MOHMS		DC Resistance/Phase, MOHMS
		Expected	Actual	Expected	Actual	Actual
304 4/89	200 400	1.52 7.72	1.6 7.9	12.7 12.7	13.3 13.0	5.76 5.76

Section 4.4
MOTOR/SDG TEST RESULTS

STATOR HEAT RUNS

The purpose of this test was to verify the winding thermal resistance to the stator core. Since relatively high current levels can be attained with low voltage levels, the magnetic core loss is assumed to be isolated in the copper windings. The test setup was similar to the AC resistance measurement tests, with the exception that temporary thermocouples were installed to obtain core temperatures. The data was taken at steady state temperature.

Using slot geometry, insulation values and wire details, the thermal resistance of the copper wire to the core was calculated to be 15C/kw of winding dissipation. Tolerances and manufacturing variations permit the resistance to vary from 12 to 20C/Kw of winding dissipation. A summary of the results is shown below.

Test No. Date	Current (AMPS)	Heat dissipation, Input KW	Run time, MIN	Copper Temperature Rise Above Core, C	
				Expected	Measured
302 4-20-89	300	2.17	41	33	35
303 4-21-89	350	3.2	32	48	51

Section 4.4
MOTOR/SDG TEST RESULTS

START-UP TEST

The results of the motor start-up tests are shown below. The test setup is described in the beginning of section 4.4. For this test the SDG pinion was removed to eliminate the acceleration of the dynamometer. Since the starting torque of an induction machine is reasonably constant over the majority of the acceleration time, this relationship was used to calculate the torque during motor start-up. Using recorded motor start-up time and calculated rotor polar moment of inertia, the starting torque was calculated.

Test Date	Speed, RPM	Start Time, Seconds	Torque, LB FT, Calculated		Comments
			From Design Report	From 2 Sec. Start and Inertia	
2/26/89	4,300	2	40	48	Rotor Inertia, 902 LB-IN^2

Section 4.4
MOTOR/SDG TEST RESULTS

MOTOR FRICTION AND WINDAGE

The friction and windage test results are shown below. The SDG pinion was left out of the assembly for these tests to eliminate the SDG dynamometer loss from the data. The motor speed was recorded as a function of time after the machine was run to the design speed and then shutoff. The rate of decceleration was calculated from the data and used with the calculated rotor angular momentum to determine the loss figure.

Tests were conducted with three different setups to obtain the effects of the minimum and maximum rotor oil spray flow rates. In the first test the bearings were packed with grease to enable operation of the machine without an oil supply. Subsequent tests were conducted with the minimum and maximum system oil flow rates respectively. The filtered oil supply was furnished at the specified flows in tests 500 and 501 by an external facility pump.

Test No. Date	Speed, RPM	Total Oil flow, GPM	Loss, Hp		Comments
			Expected	Actual	
402 4-27-89	9000	0	.18	.45	Friction and windage only
500 5-15-89	8900	3.75	.38	.94	Oil drag added. Test conducted at minimum expected flow rate.
501 5-16-89	8900	5.32	.38	1.33	Oil drag added. Test conducted at maximum expected flow rate.

Section 4.5
SDG TEST SET-UP

PURPOSE OF TEST

Since the SDG was beyond the test capabilities of the manufacturer the unit was tested at Westinghouse. Component testing was conducted to determine friction and windage losses and oil flow rate of the lubrication system. Efficiency was to be evaluated during the motor/sdg integration testing.

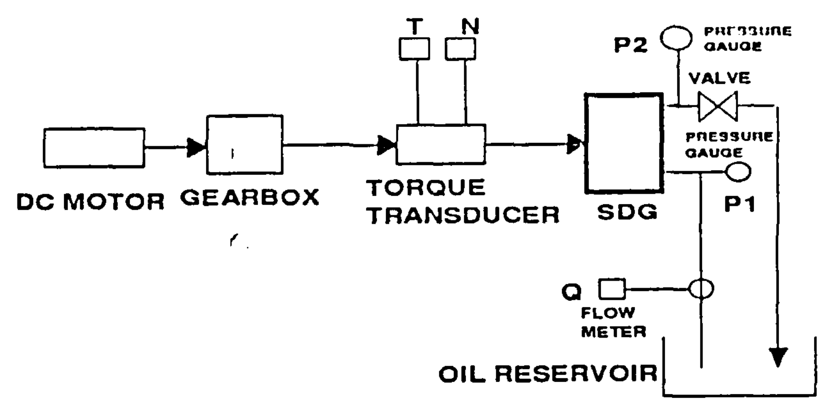
TEST CONFIGURATION

The test stand configuration for the speed decreasing gear (SDG) is shown in the figure below. The high speed pinion of the SDG was driven by a DC motor through a speed increasing gear. Input torque to the SDG was measured using a torque transducer. The internal lube pump was used to supply lubricating oil as in the final motor/SDG configuration. External facility plumbing was used to simulate operating environment for the lube system.

INSTRUMENTATION

The instrumentation used on this test configuration is summarized below. A torque transducer was used to measure the torque and speed of the SDG. Operating pressures for the pump, oil flow rate, and input power to the pump were measured and recorded.

SDG TESTING



PARAMETER		INSTRUMENT	
		ITEM	DESCRIPTION
N	INPUT SHAFT SPEED, RPM	3	LEBOW, 200 IN LB
T	INPUT SHAFT TORQUE, IN. LB.	3	LEBOW, 200 IN LB
P1	OIL INLET PRESSURE, IN. HG	8	PACIFIC SCIENTIFIC, 0-30 IN HG
P2	OIL OUTLET PRESSURE, PSI	9	ASHCROFT, 0-400 PSI
Q	OIL FLOW RATE, GPM	10	HOFFER 9.5 GPM

Section 4.5
SDG TEST RESULTS

SDG Friction and Windage Test Results Indicate Additional Margin Available for Gear Mesh Losses to Meet Design Goal of 96% Efficiency.

SDG Losses

SDG losses in the gearbox consist of friction and windage losses, as well as additional gear mesh losses under load. As a preliminary check on the gearbox design, friction and windage losses were measured as a function of pump discharge pressure. A maximum total friction and windage loss of .3% was measured. The data is summarized in Table 1 below.

SDG NOZZLE PERFORMANCE

The purpose of oil flow in the gearbox is to provide lubrication of the gear meshes, and to conduct heat away from the gear surfaces. The flow rate of the oil nozzles was checked to ensure that they would deliver the proper flow to the gear meshes in the SDG. The results of the nozzle tests are summarized in Table 2 below.

Table 1. SDG Friction and Windage Losses

Test Date	Input speed. RPM	Pump discharge pressure, PSI	Total Oil flow, GPM	Power loss, HP		Comments
				Allowed	Actual	
7-28-89	9050	20	3.9	8.0	0.92	Losses due to friction and oil churning
7-28-89	8950	50	3.5	8.0	0.99	Losses including pump operating at expected steady state pressure and flow.
7-28-89	9030	100	3.8	8.0	1.26	Losses including pump operating at expected startup flow and pressure.

Table 2. SDG Nozzle Oil Flow Test Results

Test Date	Pressure, PSI	SDG Flow Rate, GPM		Comments
		Required	Actual	
4-13-89	10	2.5 +/-0.5	2.1	Test conducted to verify SDG nozzle performance.

Appendix A
DETAILED EQUIPMENT LIST

Item	Description	Model
1	Torque transducer, Lebow, 5000 In. Lb.	1605-5K
2	Torque transducer, Lebow, 27,500 In. Lb.	1606
3	Torque transducer, Lebow, 200 In. Lb.	1604
4	Pressure gauge, Marshal, 0-15 PSI	88880
5	Pressure gauge, Marshal, 0-15 PSI	88880
6	Pressure gauge, Marshal, 03 PSI	90278
7	Pressure gauge, Marshal, 03 PSI	90278
8	Pressure gauge, Pacific Scientific, 0-30 In. Hg vacuum, 0-30 PSI	
9	Pressure gauge, Ashcroft, 0-400 PSI	
10	Flow meter, Hoffer, 9.5 GPM	HO 1/2 X 1/2 -1.25 - 9.5 - B - 1M
11	Flow meter, Hoffer, 9.5 GPM	HO 1/2 X 1/2 -1.25 - 9.5 - B - 1M
12	Wattmeter, Clark-Hess, 50 Kw	259
13	Proximity sensor, Electro Mike	PAC 300A43
14	Accelerometer, Piezotronics, 10 Mv/G	
15	Fluke Data Logger	2240B
16	Megohmeter, 500VDC, Hipotronics	Series 300
17	Sine Wave Generator, Wavetek	
18	Current Probe Amplifier, Tektronix	AM503
19	Oscilloscope, 250 Mhz, Tektronix	Model 7854

CRDL E - 202

Design Disclosure Package

Submitted to:

Gould Defense Systems, Inc.
Ocean Systems Division

As Partial Completion of

RFP-MIS-13-87

by

Westinghouse Electric Corporation
Electrical Systems Division
Lima, Ohio

CRDL E - 202

Design Disclosure Package

Submitted to:

Gould Defense Systems, Inc.
Ocean Systems Division

As Partial Completion of

RFP-MIS-13-87

by

Westinghouse Electric Corporation
Electrical Systems Division
Lima, Ohio

Design Disclosure Package ---- CDRL E-202

The following three pages, Items 1 through 19 and Appendix complete the response to SOW Section 7.0. The drawings have been forwarded under separate cover in a cardboard tube to satisfy Section 7.1. Item 0 is a copy of the letter to your Subcontracts Administrator, Mr. Shero, indicating that the Design Disclosure Package, CDRL E-202, is completed.

Section 7.2 Alternator Data

1: Machine Constants Section 7.2.a

Item 1 is supplied from Attachment I of a letter from David Dunlavy of ESD Marketing to Don Solar of January 23, 1987. Item 2 is a FAX transmittal from Mark Runkle of ESD Engineering to Dr. Vanek of Gould Engineering on May 8, 1987.

In addition to the Items, the Appendix is a copy of the PHM Electrical System Verification & Qualification Test Report, LY15075, Part II. This document describes the electrical test of a completed machine for its machine characteristics. It is an unclassified report prepared for Boeing, who was the prime contractor for the PHM to the Department of the Navy.

2: Alternator Excitation Section 7.2.b

Items 3, 4a and 4b are provided from the Boeing /PHM Qualification Report to indicate temperatures at the nominal 250 kVA and overload conditions, respectively, of a standard PHM without a Hiperco 50 exciter.

It can be seen on Item 4b that the 1PU load of 322 kW for the Gould application is very close in power requirement to the 150% load. However, the temperatures in this case are suspect, and the 125% values are used for 322 kW. The 1.3PU or 1.3 * 322 kW = 418.6 kW load is near the 200% case, so its temperatures are used for the analysis. Note that these values give optimistic efficiencies, since they were measured at a fixed time interval under a still transient rise. They are not equilibrium values.

Thus, the temperatures assumed for the excitation study and the saturation curves , adjusted to 38 deg. C air in, are:

	Temperature (deg. C) 1.0 PU	1.3 PU
Main Generator Armature	241.	296.
Main Generator Field	167.	180.

In both cases the exciter field and armature were studied at 92 degrees C per Item 3 for lack of better information.

2: Alternator Excitation (continued) Section 7.2.b

Item 5 defines the main and exciter excitations at 1PU and 1.3PU, as well as efficiencies and a separation of the losses. The machine constants are provided above, and the saturation curves are provided below.

1 ampere of alternator field current will create 10.09 amps of balanced three-phase short-circuit current. (3PU AFA at 411.2 amp 1PU current is 122.2 amps.)

3: PMG Rectifier Characteristics Section 7.2.c

Items 6 and 7 are previously transmitted documents showing the DC Load Characteristics of the PMG feeding a resistive load through a full-wave, single-phase bridge, and the AC Load Characteristics feeding the bridge from the DC curve and also feeding a salt bath directly (no rectifiers).

Detailed information regarding the test data begins on page 23 of the Appendix to this report.

Dr. Vanek requested that we provide the cold resistance of the wound armature for this device. The 25 degree Celsius resistance is .10 Ohms +/- 10%.

4: Saturation Curves -- 9000 RPM Section 7.2.d

This requirement is satisfied by tabulation of the data in Item 8, and plots of the data for Vl-n vs. AFA and Vl-l vs. AFA in Items 9 and 10, respectively. The values shown are for a hot machine as defined in Section 7.2.b above.

Consideration was given to displaying a cold machine and slight variations in power factor, but the results were not materially different from what is shown.

5: Saturation Curves -- 3000 RPM Section 7.2.e

Item 11a, 11b and 12 represent the tabulations and plot of the saturation curves at this speed.

This RPM is so far off the original PHM design speed that there is no data to extrapolate. Since it is known that this is a starting configuration, a cold machine at 25 degrees Celsius is assumed.

Three saturation curves and a no-load curve are provided, based on an impedance of .0205 + j .0784, or .08104 /_75.3 ohms. The values of 50, 75 and 100 Ohms/phase were construed to mean saturation curves at 617, 925 and 1234 amps at cos(75.3)=.25 PF lagging.

5: Saturation Curves -- 3000 RPM (continued) Section 7.2.e

Note:

The presentation of the 925 and 1234 amp saturation curves in no way expresses or implies that we assure meeting Item 3.c on page IV-1 of the SOW. They are presented only to satisfy this data item of the SOW. Per a letter to David Dunlavy from Bill Yates (Section Manager of Power Electronics and Dynamics) of February 20, 1987, we still hold that the best the cold machine can do is 740 amps, and this will fall rapidly due to heating.

6: EFA versus AFA -- 9000 RPM Section 7.2.f

Items 13 and 14 represent the tabular data and plot for this set of curves.

Note that "Cold" is defined to be 25 degrees C, and "Hot" is 92 degrees C for both the armature and field copper.

7: EFA versus AFA -- 3000 RPM Section 7.2.g

Items 15 and 16 are the tabular data and plot of the saturation curves for 3000 RPM exciter performance.

The definitions of "Hot" and "Cold" are the same as in Section 7.2.f above.

8: Miscellaneous

8.1: Bearing Lubrication

Item 17 was prepared by Dick Nisonger at the request of Don Solar. It defines options available to Gould for the lubrication of the machine's bearings without modification to the existing device.

8.2: Connector Reference

It became apparent during our conversations that the Chardon site may not provide easy access to Mil. Std. documentation. An excerpt from the "Encyclopedia of Connectors", Vol. I, Book 1 is included for your convenience regarding the definition of an MS3402D-16S-1P connector. This appears as Item 18.

8.3: Oil Fitting Reference

Item 19 answers questions from Don Solar regarding the dimensions of the Mil. Std. 33649-4 holes related to the lubrication system on our Outline 947F038. This hole is specified on Sheet 1 of 2 of the Frame drawing 977J243 (provided under the drawings in 7.1), and is redefined in this Item from the Parker O-Ring Handbook.

Item Ø

Westinghouse
Electric Corporation

Electrical Systems Division

Lima Plant
Box 989
Lima Ohio 45802
419 226 3121

August 10, 1987

Gould Defense Systems, Inc.
Ocean Systems Division
18901 Euclid Avenue
Cleveland, Ohio 44117

Attention: Mr. Joseph B. Shero
Subcontracts, Building #1

Dear Mr. Shero:

The Drawings and Generator Data Package, and the tube of sepia drawings sent under separate cover, required under Section 7, page IV-5, of our SOW are complete and have been forwarded to Mr. Don Sòlar at the Chardon facility.

This completes the requirements of our contract under Design Disclosure Package, CDRL #E-202, of page V-II of RFP-MS-13-87.

Sincerely,

WESTINGHOUSE ELECTRIC CORPORATION

Mark A. Runkle

MARK A. RUNKLE, PROGRAM MANAGER
SENIOR ELECTRICAL ENGINEER
POWER ELECTRONICS & DYNAMICS

MAR/brr

cc: Mr. Tim Swick, Contracts Department

000146/ENGM

ATTACHMENT I

MACHINE CONSTANTS
250 KVA PHM GENERATOR
P/N 977J031-3

The following constants at 8000 rpm are based on computer calculations (Prog. E331) and some test results.* Per unit is based on 250 kVA, 262 V/ph, 318 A/ph.

		Per Unit	Ohms/Phase
Synchronous react.	X_d (unsat)	1.43	1.18
Syn react (quad. axis)	X_q	.52	.44
Trans. react	X'_d	.14	.115
Subtransient react.	X''_d	.12	.10
Subtrans. react.	X''_q	.086	.071
Neg. sequence react.	X_2	.10	.082
Zero seq. react.	X_0	.0106	.009
Neg. seq. resist.	R_2 @ 25°C	.017	.014
Zero seq. resist.	R_0 @ 25°C	.008	.007

	Time Const.	Res. 25°C
Open cct. time const. main fld, 25°C, T'_{do}	.348 sec	(.455)
Trans. time const. main fld, 25°C, T'_d	.03 sec	(.455)
Arm. time const. main gen 25°C, T_a	.006 sec	(.0067)
Exc. open cct time const., 25°C, T'_{do}	.125 sec	(7.12)
Exc. trans. react, 25°C, T'_d	.021 sec	(7.12)

*NOTE: To evaluate possible tolerances, computer X'_d and X''_d were .106 and .096 ohms, respectively; vs. test of .126 and .109 ohms.

Telefax Number: (216) 285-1689

To: Dr. Larry Vanek
Gould Inc.
Oceanic Systems Div.

From: Mark Runkle
Westinghouse ESD

Date: May 8, 1987

Subject: Constants for the Hiperco 50 Exciter for Gould's Variation of the PHM Alternator

Per your telephone request of this morning, the constants for the Hiperco 50 exciter are as shown below. These values are calculated, and determined at a base speed of 8000 RPM for the 8 pole exciter.

Xd = 3.4761 Ohms		
X'd = 0.5811 Ohms		
Xq = 1.8601 Ohms		
Xplo = 0.4321 Ohms	Potier	Reactance
Ra = 0.0727 Ohms	Armature	Resistance
Rf = 7.1204 Ohms	Field	Resistance
T'do = 0.1253 seconds		Open circuit.
T'd = 0.0209 seconds		Short circuit.

We have moved around our 3rd floor office space, and I am now at a new number. In the future, I can be reached at (419) 226-3163.

Sincerely,

Mark Runkle

TABLE IV

PHM - SUMMARY OF EFFICIENCY & TEMPERATURE TEST RESULTS

Load	50%	100%
RPM	8000	8000
KVA	124	251
Volts (L-L)	450	451
Amps	159	322
P.F. Lag	.8	.8
*"Q2" Temperature Rise (case), ^{o}C	-	2
Alternator Field Volt, AFV (Rotating)	22.6	35.8
Alternator Field Amps, AFA (Rotating)	36.1	52.5
Rotating Field Avg. Temperature, ^{o}C	122	154
Exciter Field Volts	9.3	14.3
Exciter Field Amp	1.12	1.73
**Exciter Field Temp, ^{o}C	92	90.3
Main AC Winding Hot Spot, ^{o}C	152	210
Air In Temp, ^{o}C	40	42
Air Out Temp, ^{o}C (Avg)	73	86
Air Flow, CFM (@ 70F 14.69 psia)	940	924
Static Press Head at Air Out in H_2O	5.89"	5.89"
Time	1 hr.	2 hrs.
Tork. inch-lbs.	1325	2375
KW Input	125.5	225
Efficiency (KW out ÷ KW input)	79.7	90.1%

*Stabilized in 20 minutes

**Rotating Field Resistance at 25^{o}C was .455 ohms. Excitor Field 25^{o}C was 6.6 ohms.

Test Procedure & Expected Results:

All applicable Test Record Sheets and Oscillographs were reviewed relative to Voltage Regulation. L-L voltage at the P.O.R. shall be within ± 1% (± 4.5V) up to rated load and within ± 3% (13.5V) at 2.0 P.U. load.

Test Results:

Review of all applicable data showed the system to be well within the required limits.

- Overload

Specification Requirement:

Boeing 312-80173, Para. 4.3.4.1.2.14

References:

Test Record Sheets: AA12160, AA12162 Curve 601527

Note: AA12160 and Curve 601527 are included with the Efficiency and Temperature data.

Test Procedure and Expected Results:

This test was conducted following the Efficiency and Temperature tests. With the generator stabilized at full load from the above tests, run the system at 125%, 0.8 P.F. lagging load for 10 minutes. Return to rated load for a short time and then run at 150%, 0.8 P.F. lagging load for 2 minutes. Return to rated load for 1 hour and then run at 200%, 0.8 P.F. lagging load for 50 seconds.

Voltage regulation to 200% load shall not exceed ± 3% and the maximum generator temperature shall not exceed the intermittent duty values for the materials as they are used in the generator when extrapolated to a 54°C ambient.

Test Results:

As can be seen from the test data, the L-L voltage changed a maximum of 3V which is well under the ± 3% (± 13.5V) allowed by the specification.

As far as the Efficiency and Temperature tests, winding temperatures were determined by thermocouple in the stator and by resistance change on the rotating field. Results were as follows:

kilowatts	250 kw	300 kw	400 kw
Load	125%	150%	200%
Time at Overload	10 min	2 min	50 Sec
Hot Spot Temp			
AC Winding	243°C	240°C	296°C
Rot. Field Volts	45	46.5	63
Rot. Field Amps	63.5	68	86.7
*Rot. Field Resis. (hot)	.709 ohm	.684	.727
Avg. Rot. Field Temp	169°C	155°C	180°C
Air In Temp	40°C	40°C	38°C

*Rot. field was .455 ohms @ 25°C

As is seen above, the hot spot temperature was on the stator wire.

These temperatures are not excessive as can be seen by the following analysis. Refer to curve 601527. First assume the max. temp reached occurs for the whole time the overload is applied instead of just at the end of the loading. Then calculate the per cent of insulation life used up by each application. The following results:

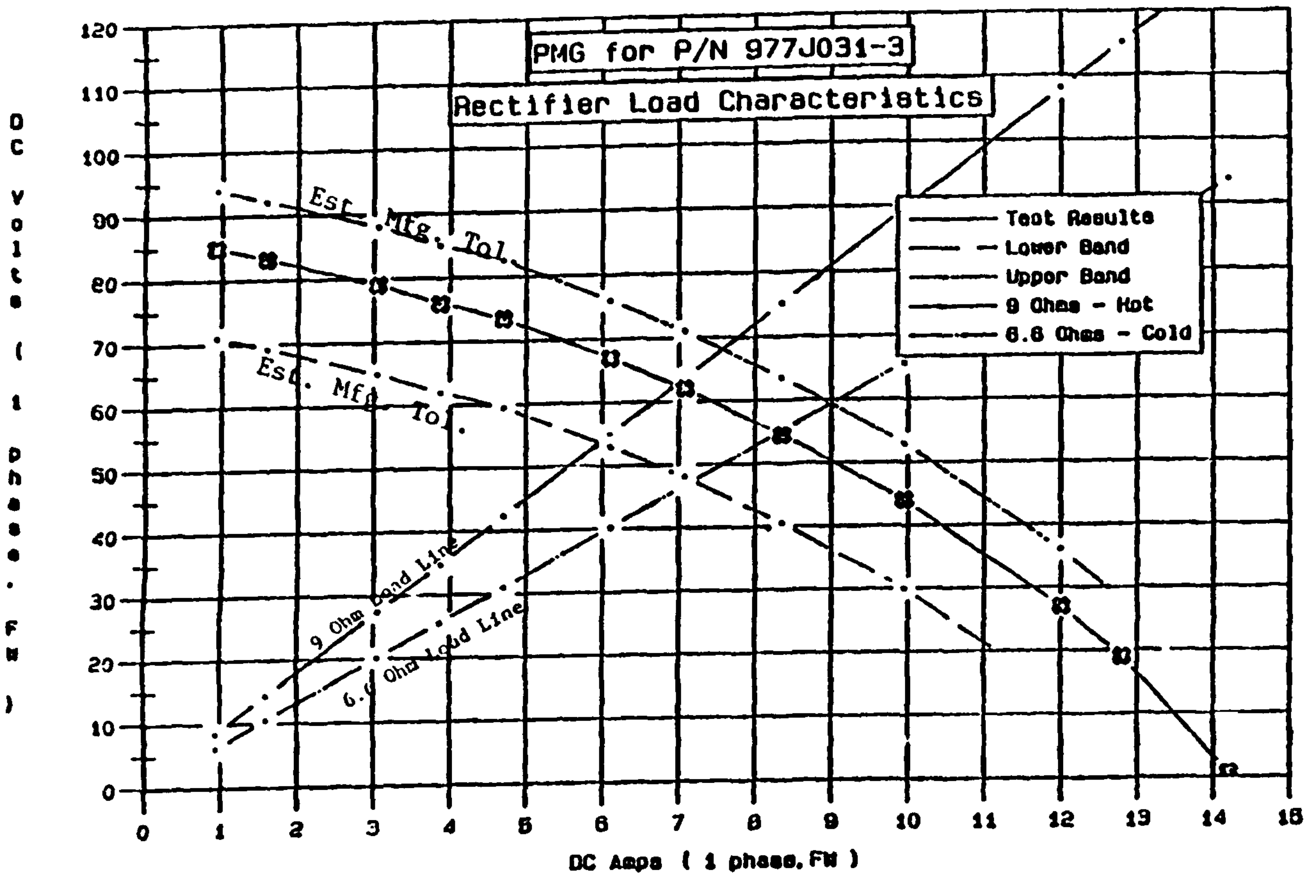
Load	125%	150%	200%
Time	10 min	2 min	50 sec.
Max Winding Temp	240°C	240°C	296°C
Air In Temp	40°C	40°C	38°C
Max Wdg Temps			
Adjusted for 54°C air in:	257°C	254°C	312°C
Insul. life at temp	5400 hrs	6200 hrs	510 hrs
Per Cent Insul. life for			
one application	.0031%	.0053%	.0027%

Efficiency and Separation of Losses for Gould PHM 977J031-6

M. Runkle
08/10/87

	1PU Hot	1.3PU Hot
Generator		
Vln	300.00	300.00
Iln	392.90	528.54
kVA	353.61	475.69
PF	.91	.88
kW	322.00	418.60
RPM	9000.00	9000.00
Excitation		
Main Fld. Amps	58.80	70.30
Exc. Fld. Amps	2.42	2.91
Loss-Main		
AC Cu	5961.00	9727.00
Iron	5923.00	6107.00
Fld Cu	2475.00	3660.00
PF+DB	2896.00	3019.00
Tot. Main	17255.00	22513.00
Rectifiers	68.00	81.00
Air Losses		
Windage	3638.00	3638.00
Fan	12100.00	12100.00
Loss-Exc		
AC Cu	301.00	430.00
Fe+PF	106.00	155.00
Fld Cu	52.00	75.00
Tot. Exc	459.00	660.00
Main+Rect+ +Exc+PMG	33520.00	38992.00
3% Stray	1005.60	1169.76
TOTAL LOSS (W)	34525.60	40161.76
Output+Loss(kW)	356.53	458.77
% Efficiency	90.32	91.25

Iron losses are based on 3 x Epstein losses for .014" silicon steel
= 3 * 91.8 lbs. * 2.06 * (B/100)^2 * (f/100)^1.6



8000 RPM -- 4800 Hz

Test Data AA12158,12159

Reference Engineering Data

6.5 Turns/Coil
Stack 1"
Alnico VIA
"Poles" = 72
SOD = 7.00"
SID = 3.527"
ROD = 3.5"
RID = 2.57"

Rotor Punching
.014 10501BC
920B546

Diagram 955C405

Acceptance Test 857246

Magnet 920B682-1
Stator 939D822-1

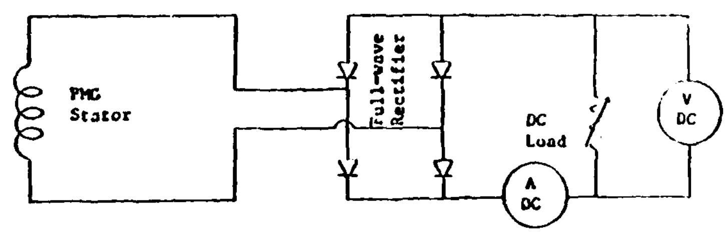
Based on Figure 9 of
PHM Report LY15075,
Part II, Addendum

No-Load AC output tolerance of PMG Stator is 90VAC - 106 VAC per ATP 857246. Rectified voltage conversion ratios vary from 1.13 - 1.27 VAC/VDC based on prior test data.

Highest DC voltage near No-Load = 106/1.13 = 94 V DC
Lowest DC voltage near No-Load = 90/1.27 = 71 V DC

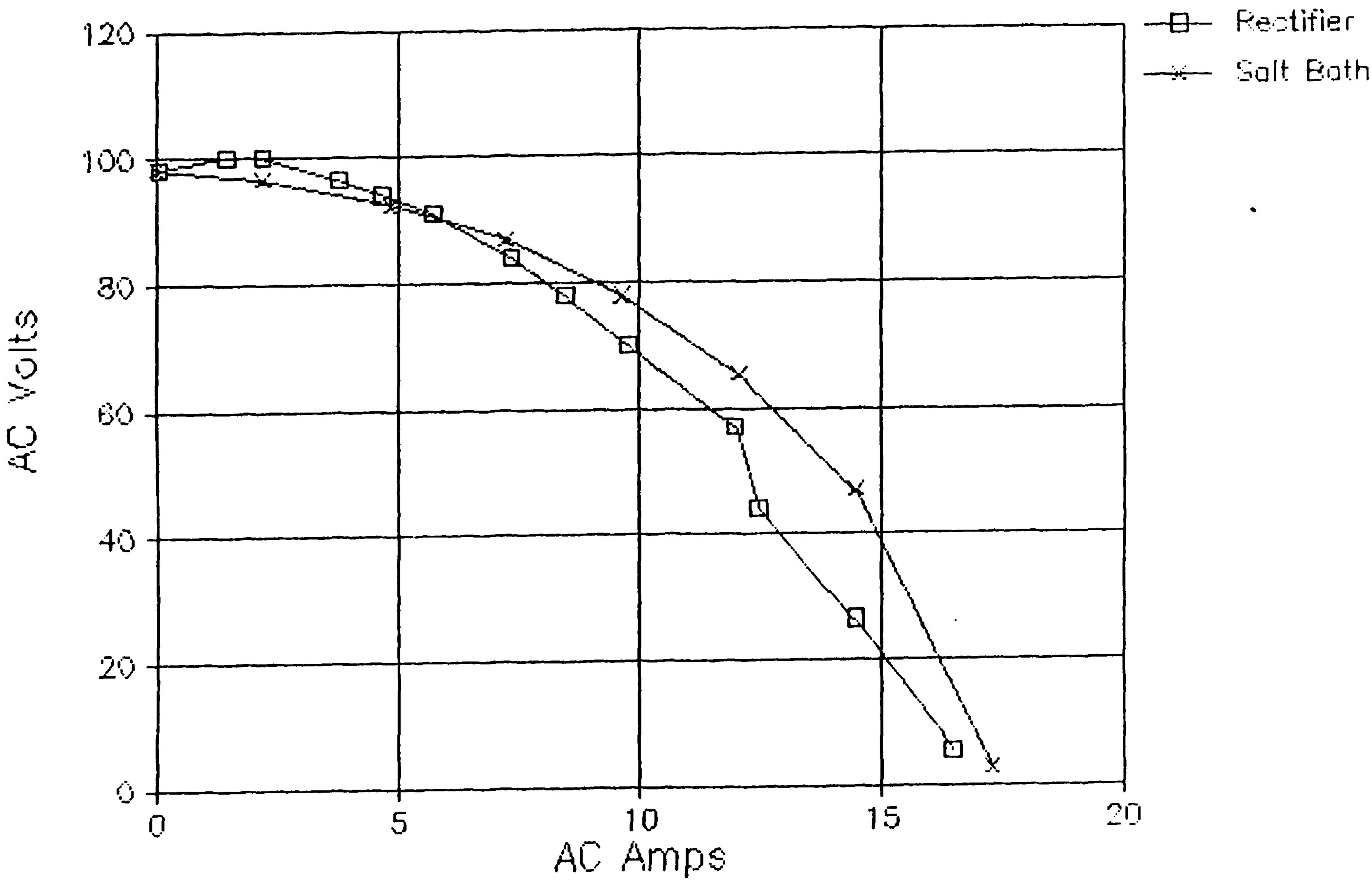
Create tolerance bands based on variation about the DC data near No-load, or the 1 A DC, 85 V DC point.

Lower Band = 85 - 71 = 14 V DC below test.
Upper Band = 94 - 85 = 9 V DC above test.



Flux Switch Permanent Magnet Generator

for Generator P/N 977J031-3



Item 8

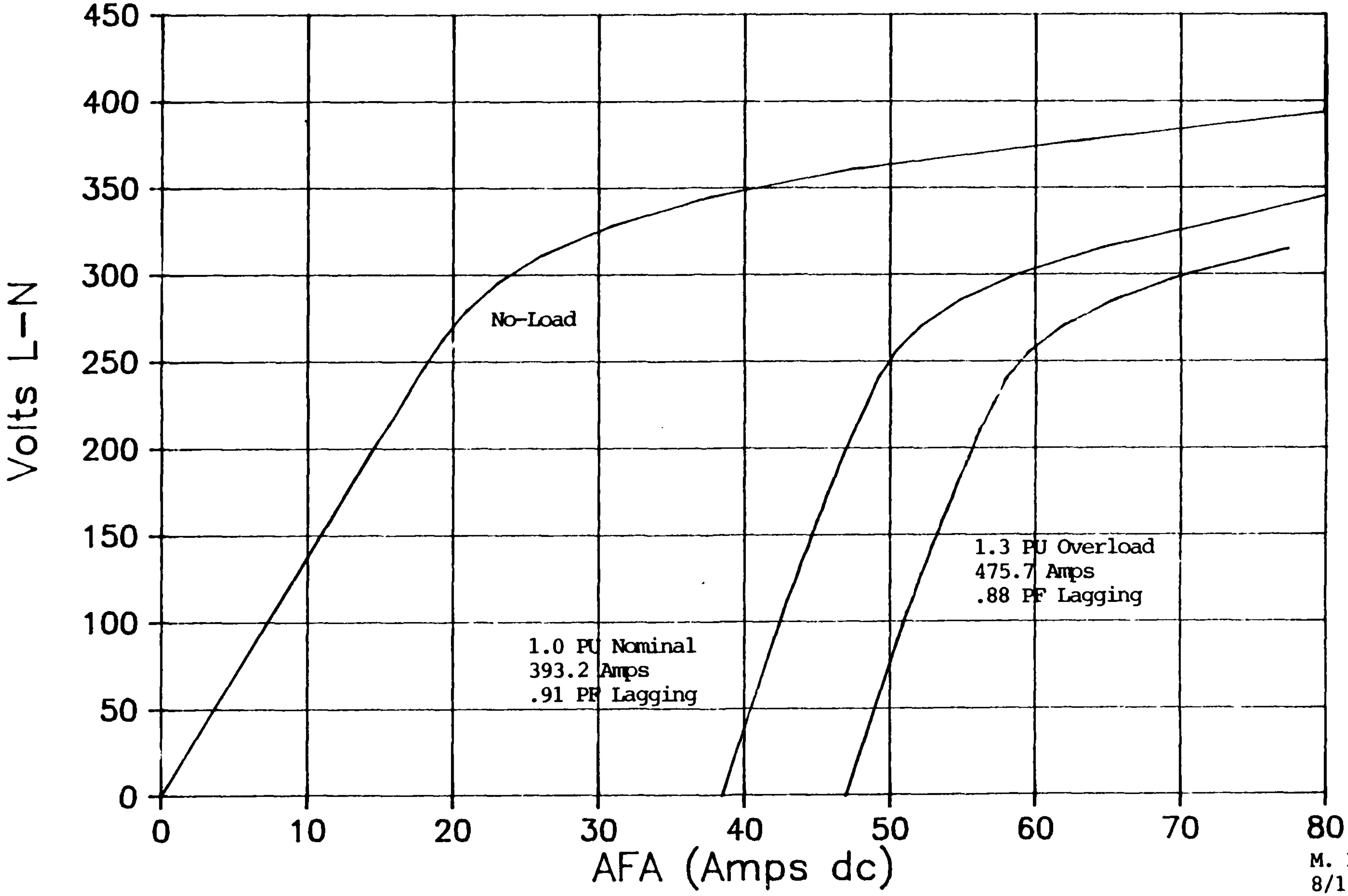
Load Saturation Curves for Main Generator -- 9000 RPM

		Alternator Field Amps		
V 1-n	V 1-1	No-Load	1. PU	1.3 PU
.0	.0	.0	38.4	46.9
90.0	155.9		42.0	50.5
97.5	168.9		42.3	50.8
105.0	181.9		42.6	51.1
112.5	194.9		42.9	51.5
120.0	207.8		43.3	51.8
127.5	220.8		43.6	52.1
135.0	233.8		43.9	52.5
142.5	246.8		44.3	52.8
150.0	259.8		44.6	53.2
157.5	272.8		44.9	53.5
165.0	285.8		45.3	53.9
172.5	298.8		45.6	54.3
180.0	311.8		46.0	54.6
195.0	337.7		46.7	55.4
196.8	340.9	14.3		
210.0	363.7		47.5	56.1
213.2	369.3	15.6		
225.0	389.7		48.3	57.0
229.6	397.7	16.8		
240.0	415.7		49.1	57.9
246.0	426.1	18.0		
255.0	441.7		50.3	59.4
262.4	454.5	19.3		
270.0	467.6		52.1	61.8
278.8	482.9	20.9		
285.0	493.6		54.8	65.3
295.2	511.3	23.1		
300.0	519.6		58.8	70.3
311.6	539.7	26.2		
315.0	545.6		64.5	77.5
328.0	568.1	30.9		
330.0	571.6		72.5	87.4
344.[illegible]	596.5	37.6		
345.0	597.5		84.4	100.9
360.0	623.5		99.5	120.3
360.8	624.9	47.5		
375.0	649.5		121.0	152.1
377.2	653.3	63.1		
390.0	675.5		169.6	228.3
393.6	681.7	81.1		
405.0	701.5		267.5	360.9
410.0	710.1	112.2		
420.0	727.4		464.2	616.4
426.4	738.5	219.7		
442.8	766.9	501.7		

Item 9

Load Saturation Curves

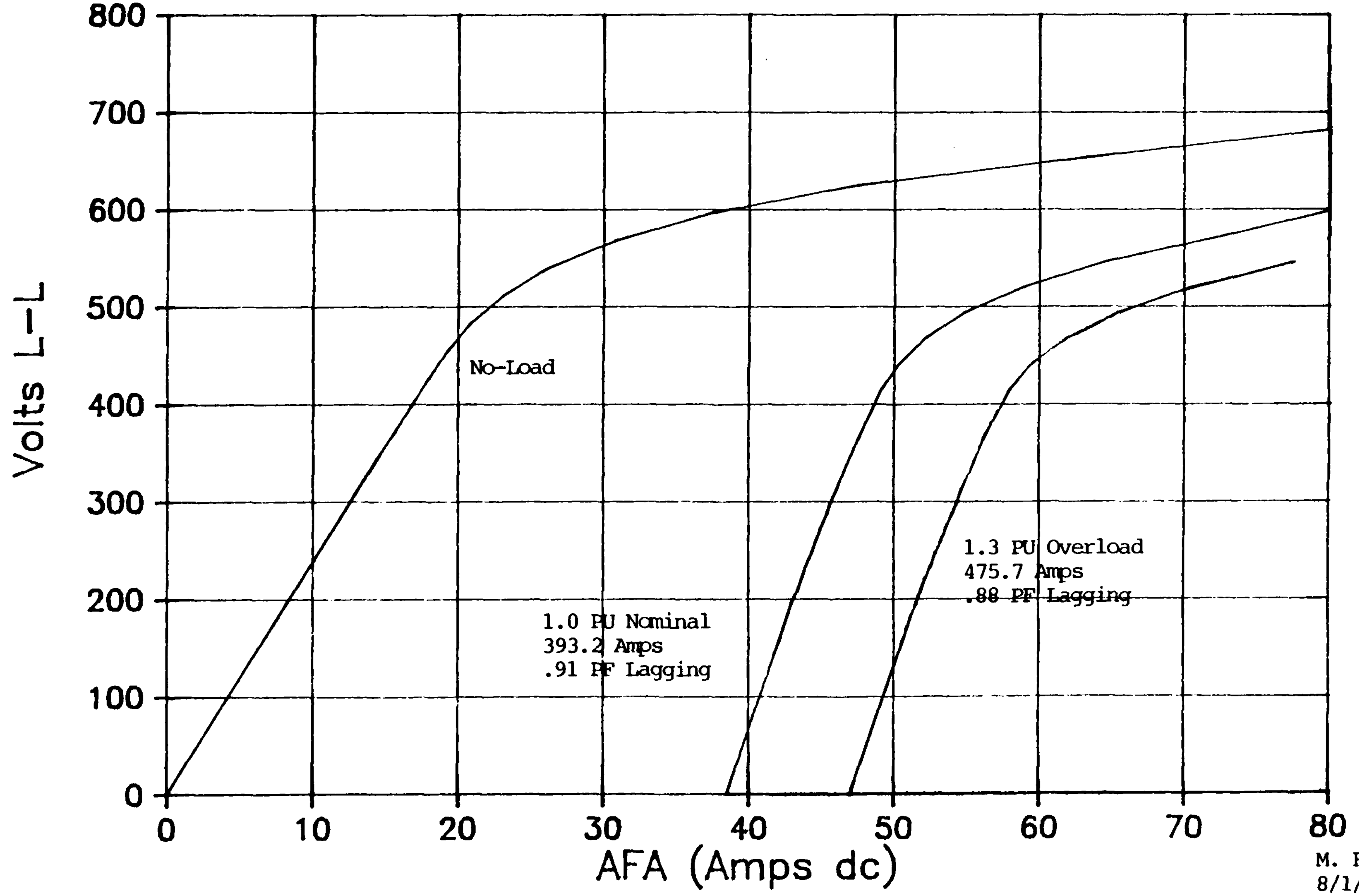
for Main Generator --- 9000 RPM



M. Runkle
8/1/87

Load Saturation Curves

for Main Generator -- 9000 RPM



M. Runkle
8/1/87

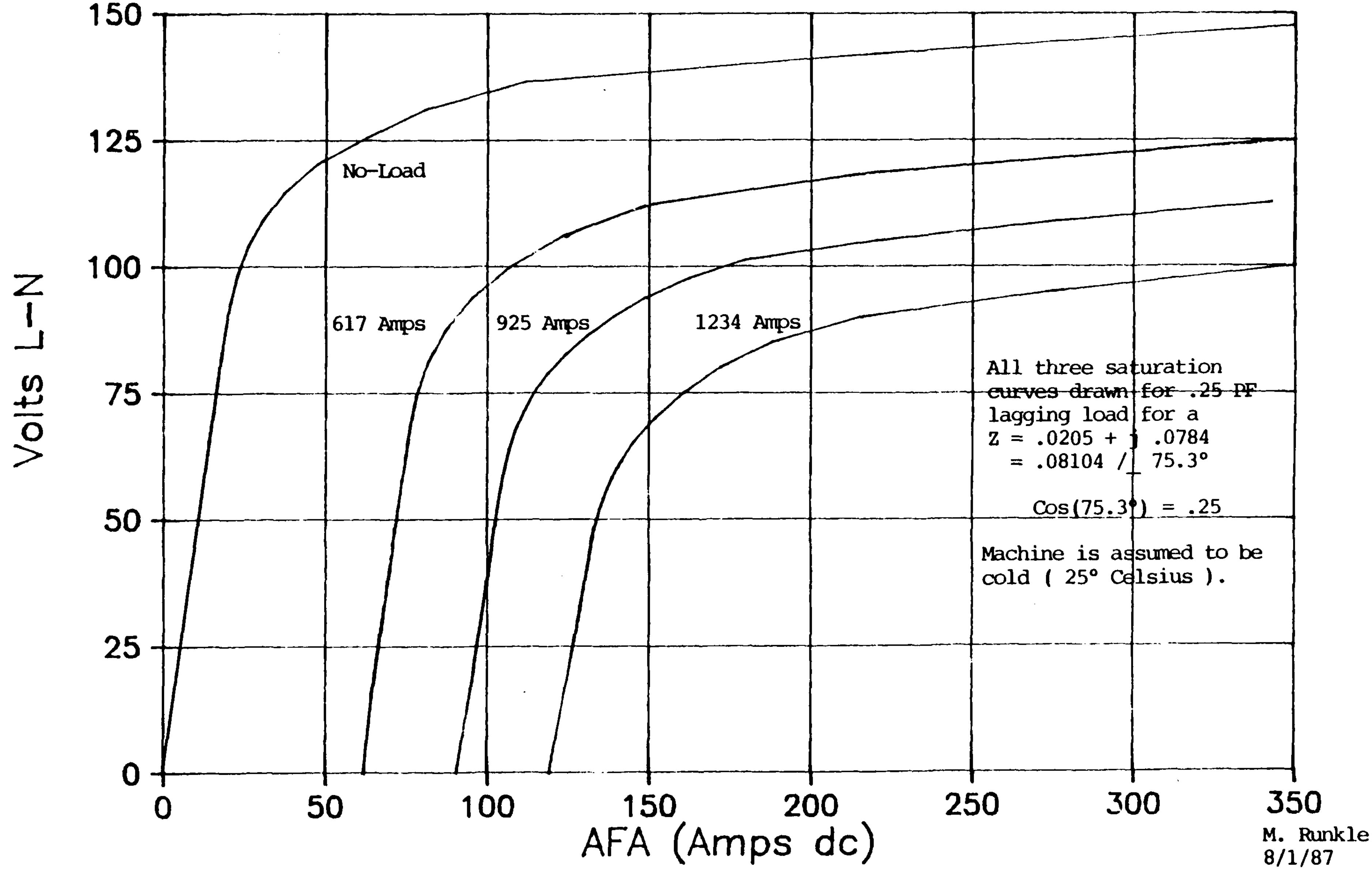
Load Saturation Curves
for Main Generator -- 3000 RPM
Starting Z = .0205+j.0784

			Alternator Field Amps for		
V l-n	V l-l	No-Load	50 V/ph	75 V/ph	100 V/ph
.0	.0	.0	61.6	90.2	119.2
15.0	26.0		64.1		
16.2	28.1		64.3		
17.5	30.3		64.6		
18.0	31.2			95.0	
18.7	32.4		64.9		
19.5	33.8			95.4	
20.0	34.6		65.2		
21.0	36.4			95.7	
21.2	36.7		65.4		
22.5	39.0		65.7	96.0	
23.7	41.0		66.0		
24.0	41.6			96.4	126.4
25.0	43.3		66.3		
25.5	44.2			96.7	
26.0	45.0				127.0
26.2	45.4		66.5		
27.0	46.8			97.1	
27.5	47.6		66.8		
28.0	48.5				127.6
28.5	49.4			97.4	
28.7	49.7		67.1		
30.0	52.0		67.4	97.8	128.1
31.5	54.6			98.1	
32.0	55.4				128.7
32.5	56.3		67.9		
33.0	57.2			98.5	
34.0	58.9				129.2
34.5	59.8			98.8	
35.0	60.6		68.5		
36.0	62.4			99.2	129.8
37.5	65.0		69.0	99.5	
38.0	65.8				130.3
39.0	67.5			99.9	
40.0	69.3		69.6		130.9
40.5	70.1			100.2	
42.0	72.7			100.6	131.5
42.5	73.6		70.1		
43.5	75.3			100.9	
44.0	76.2				132.0
45.0	77.9		70.7	101.2	
46.0	79.7				132.6
47.5	82.3		71.2		
48.0	83.1				133.3
48.7	84.3			102.1	
50.0	86.6		71.8		134.1
52.0	90.1				135.0
52.5	90.9		72.3	103.0	
54.0	93.5				136.1
55.0	95.3		72.9		
56.0	97.0				137.3
56.2	97.3			104.0	
57.5	99.6		73.4		
58.0	100.5				138.7

60.0	103.9		74.0	105.1	140.2
62.5	108.3		74.6		
63.7	110.3			106.5	
65.0	112.6		75.2		145.1
65.6	113.6	14.3			
67.5	116.9		75.8	108.4	
70.0	121.2		76.5		151.9
71.1	123.1	15.6			
71.2	123.3			111.0	
72.5	125.6		77.3		
75.0	129.9		78.1	114.2	160.8
76.5	132.5	16.8			
78.7	136.3			118.4	
80.0	138.6				172.1
81.2	140.6		81.5		
82.0	142.0	18.0			
82.5	142.9			123.9	
85.0	147.2				188.2
86.2	149.3			130.6	
87.5	151.6	19.3	86.8		
90.0	155.9			138.7	216.0
92.9	160.9	20.9			
93.7	162.3		94.9	148.6	
95.0	164.5				275.0
97.5	168.9			161.7	
98.4	170.4	23.1			
100.0	173.2		106.9		357.3
101.2	175.3			179.6	
103.9	180.0	26.2			
105.0	181.9			220.3	471.8
106.2	183.9		123.4		
108.7	188.3			273.8	
109.3	189.3	30.9			
110.0	190.5				607.8
112.5	194.9		150.9	342.3	

Load Saturation Curves

for Main Generator -- 3000 RPM

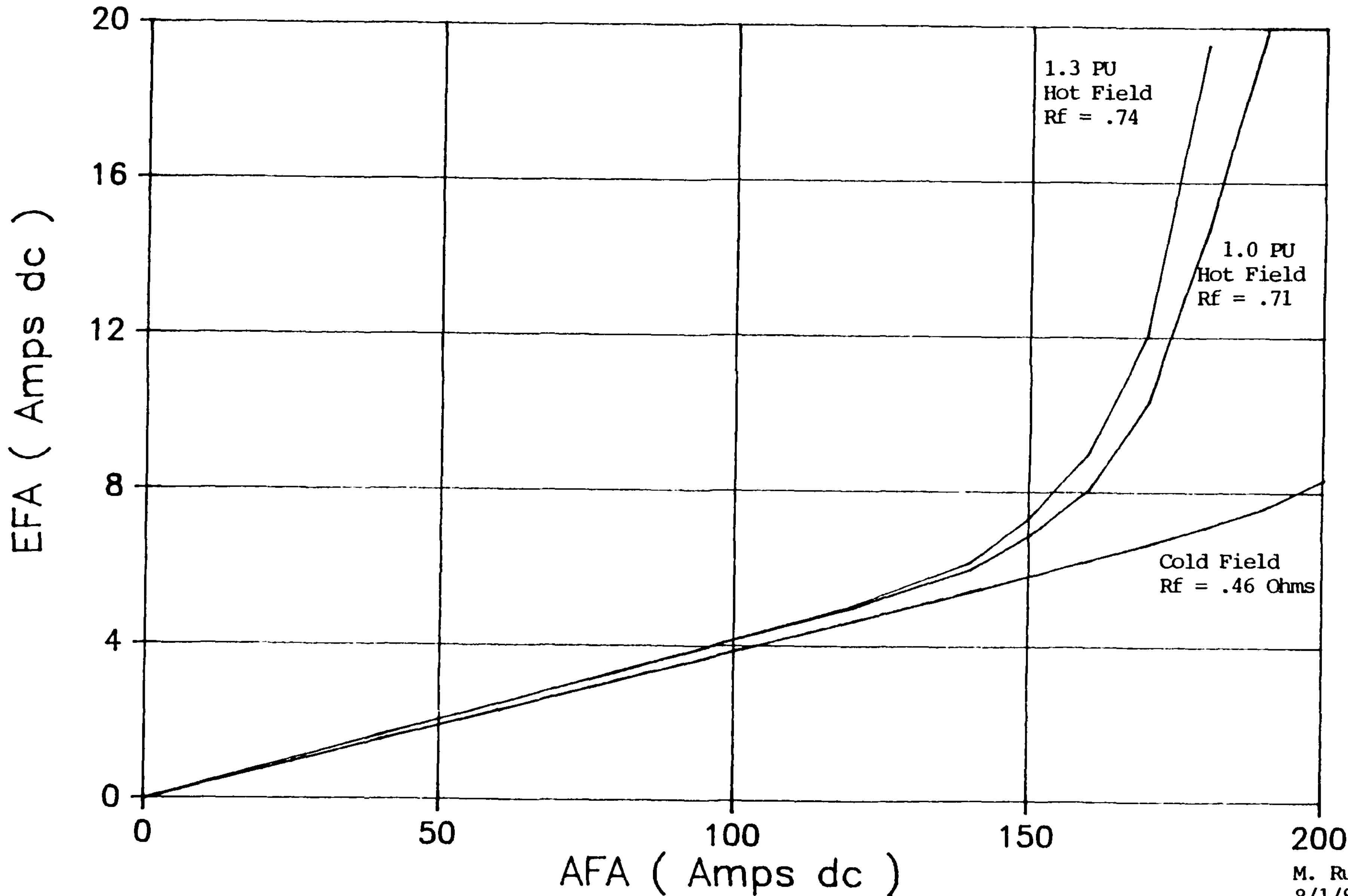


Exc. Field Amps vs. Main Field Amps
9000 RPM - Hiperco 50

AFA	COLD	1PU HOT	1.3PU HOT
0	0	0	0
20	.779		
40	1.551	1.647	1.66
60	2.325		
70	2.711		
75	2.905		
80	3.098	3.288	3.314
85	3.292		
90	3.485		
95	3.679		
100	3.872		
120	4.649	4.971	5.023
140	5.432	5.975	6.161
150	5.829	6.853	7.291
160	6.234	8.036	8.978
170	6.649	10.325	12.015
180	7.103	14.765	19.541
190	7.604	25.726	39.183
200	8.334	50.565	73.426

Exc. Field Amps vs. Main Field Amps

9000 RPM – Hiperco 50



M. Runkle
8/1/87

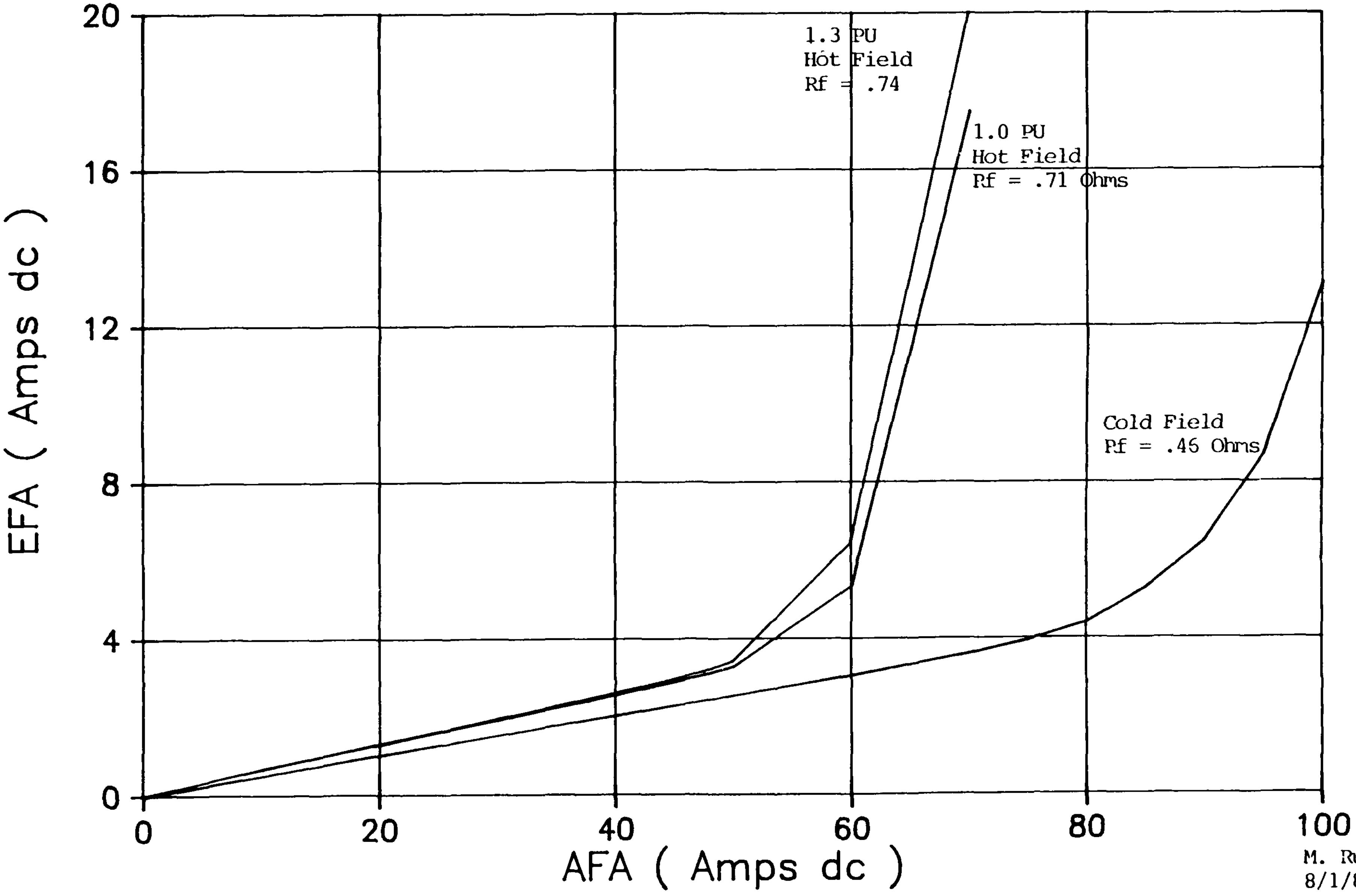
Item 14

Exc. Field Amps vs. Main Field Amps
3000 RPM - Hiperco 50

AFA	COLD	1PU HOT	1.3PU HOT
0	0	0	0
10		.666	.682
20	1.04	1.288	1.319
30		1.91	1.956
35		2.225	2.28
37.5		2.383	2.442
40	2.041	2.544	2.61
42.5		2.708	2.781
45		2.88	2.965
47.5		3.062	3.163
50		3.269	3.415
60	3.058	5.319	6.422
70	3.609	17.456	29.84
75	3.945		
80	4.401		
85	5.277		
90	6.471		
95	8.698		
100	13.075		

Exc. Field Amps vs. Main Field Amps

3000 RPM – Hiperco 50



M. Runkle
8/1/87

Item 16

BEARING LUBRICATION

REFERENCE GENERATOR P/N 977J031-1 THRU -4
OUTLINE P/N 947F038, 947F871

The attached sketch shows a portion of the generator layout with an exhaust shroud and gearbox added for reference.

In most applications, the generator is driven through a gearbox by a turbine engine. The engine, gearbox, and generator share a common oil supply. A number of variations can be made to the oil system, however, without adversely affecting the generator operation or requiring changes to the generator design.

It is recommended that lubricating oil be supplied to the generator at a pressure of 1 ± .5 psig measured at the generator inlet (reference points "A" and "B" on the attached sketch). At 1.5 psig, approximately 115 cc/minute is supplied to each bearing. Oil is typically supplied from a higher pressure line and regulated down to the 1 ± .5 psig pressure. The oil supply line for the drive-end bearing must be separate from the line for the fan-end bearing. If the two lines are common one bearing can be starved. The oil exits at the bottom of the generator (reference points "F" and "G").

The bearing cavities are enclosed by close-clearance seals. To prevent leakage the bearing cavity pressure must be lower than the surrounding ambient pressure. On the fan end, the pressure head developed by the fan is sufficient and this cavity may be gravity drained back to the supply reservoir or gearbox provided they are vented to atmospheric pressure.

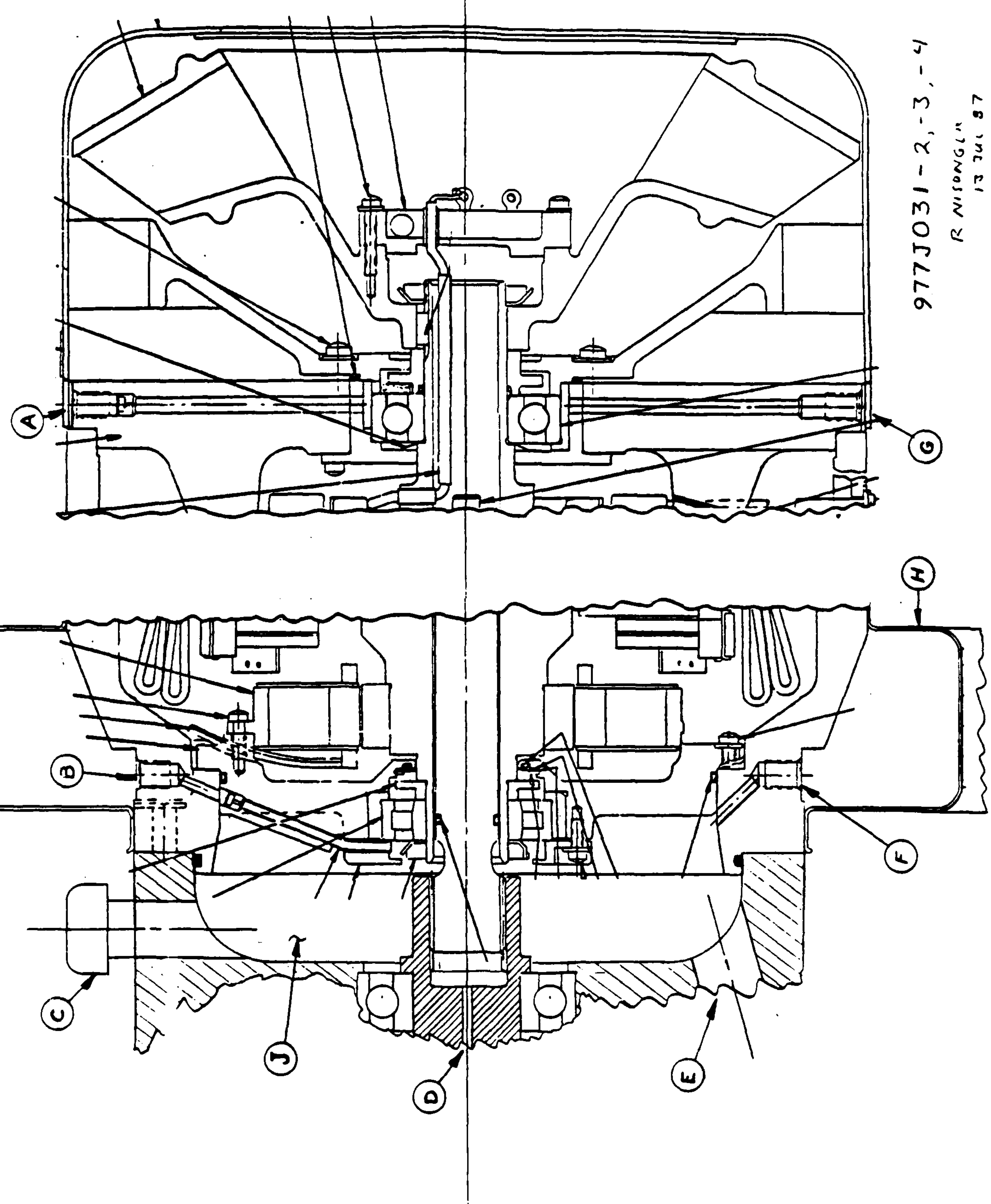
The drive-end bearing lubricating oil dumps into the cavity between the generator and gearbox (reference location "J"). An exhaust ("H") shroud is typically employed and the exhaust is restricted to provide a back pressure of approximately 3 inches of water. If the cavity between the gearbox and generator is sealed, the oil must be evacuated thru port "F". The recommended sump line pressure is 1.0 ± .5 psig vacuum measured at port "F".

An alternate method is to provide a drain directly back into the gearbox through port "E" in conjunction with a gearbox pad vent "C". The exhaust shroud is still required but the drive-end bearing drain port "F" can be plugged.

Spline lubricant is typically provided from the gearbox through a hole "D" in the drive shaft.

000088/ENGM

Item 17b



THE ENCYCLOPEDIA of CONNECTORS VOLUME I

BOOK 1

MILITARY AND COMMERCIAL CYLINDRICAL CONNECTORS

EDWARD'S PUBLISHING COMPANY, INC.
14115 Chadron Avenue, P.O. Box 1668
Hawthorne, CA 90250-1668

MIL-C-5015
CRIMP, FRONT RELEASE

MIL-C-5015F

Shortly after revision E of MIL-C-5015 was released (this revision created the first removable crimp contact connector design in MIL-C-5015), it was deemed additional service classes of connectors, unified thread dimensions, and a rear release type connector were required.

Instead of further revising MIL-C-5015E, revision F was created. The following items resulted:

a. A new front release MIL-C-5015 connector with rear threads common to those in the latest revisions of MIL-C-26482 Series 2, and MIL-C-83723 Series I and III. These threads and anti-rotation teeth are defined in MS3155.

b. The following classes were specified in MIL-C-5015 for crimp, front release connectors:

    D 175°C high impact shock.
    DJ 175°C high impact shock, cable sealing gland.
    K 175°C hermetic seal.
    L 200°C fluid resistant.

c. A newly designed rear release removable crimp contact connector (which was the Navy's version of the Air Force's MIL-C-83723, Series II connector) was included. These rear threads and anti-rotation teeth were also in accordance with MS3155.

MIL-C-5015G

Revision G was issued on March 23, 1976 and incorporated all the amendments of Revision F. These amendments were a clarification of language, testing, operating requirements, etc. Revision G did not contain any major dimensional changes in the connectors.

ORDERING INFORMATION

Item 18c

MS 3406 D S 28 - 21 P Y

- **MS** — MILITARY PREFIX
- **3406** — SHELL STYLE
- **D** — SERVICE CLASS
- **S** — SHELL MATERIAL
- **28** — SHELL SIZE
- **-** — BACKSHELL SEALING RANGE (CLASS DJ ONLY)
- **21** — INSERT CONFIGURATION
- **P** — CONTACT STYLE
- **Y** — ALTERNATE POSITION

SHELL STYLE

3400 Wall mount receptacle
3401 In-line receptacle.
3402 Box mount receptacle.
3404 Jam nut receptacle.
3406 Straight plug.
3408 90° plug.
3409 45° plug.
3412 Box mount receptacle with threaded rear skirt.

SERVICE CLASS

D High impact shock, 175°C. See pages 40 thru 43.
DJ High impact shock, cable sealing gland, 175°C. See pages 44 thru 53.
K Firewall seal, 175°C. See pages 40 thru 43.
L Fluid resistant, 200°C. See pages 40 thru 43

SHELL MATERIAL

BLANK Aluminum.
S Stainless steel.
T Ferrous alloy, class K only.

SHELL SIZE

See detail drawings on pages 40 thru 53 for available sizes.

BACKSHELL SEALING RANGE
(CLASS DJ ONLY)
A, B, D, E, F, G or H. See 'ASSEMBLY NO.' column and 'CABLE ENTRY' column in tables on pages 44 thru 53 for designators and sealing ranges.

INSERT CONFIGURATION

See pages 73 thru 106.

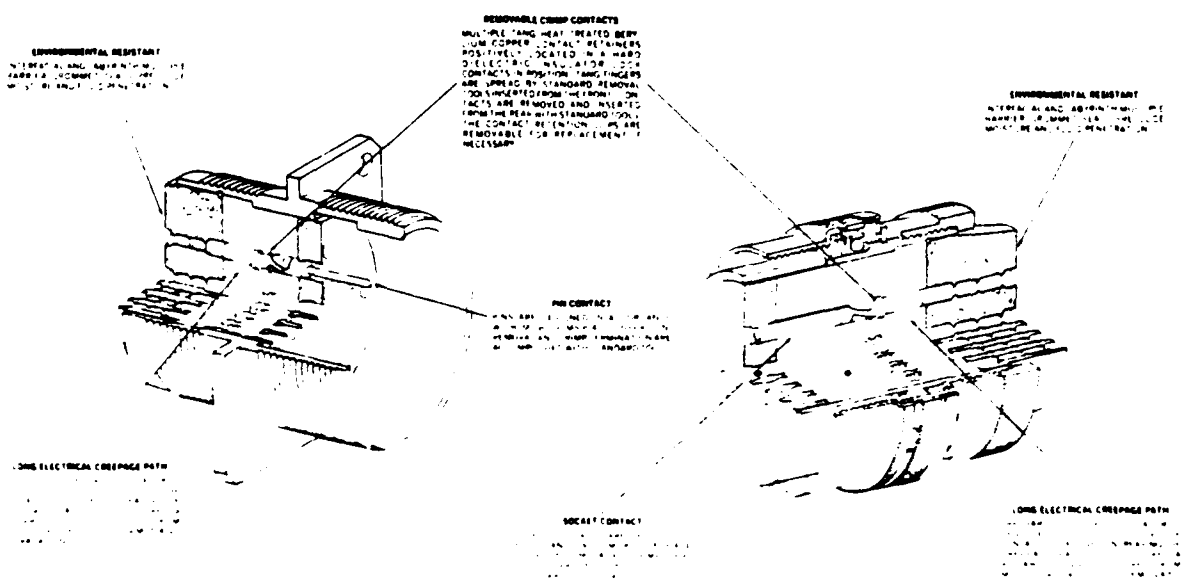
CONTACT STYLE

D 16-22 pin contacts in lieu of 16-16 or 12-16 pin contacts in lieu of 12-12. Class D connectors only.
E 16-22 socket contacts in lieu of 16-16 or 12-16 socket contacts in lieu of 12-12. Class D connectors only.
P Pin contacts.
S Socket contacts.

ALTERNATE POSITION (POLARIZATION)

BLANK (normal), W, X, Y or Z. See pages 73 thru 81.

TYPICAL CONNECTOR DESIGN FEATURES



AVAILABLE SOURCES

DATA DERIVED FROM MILITARY QPL AND MANUFACTURER'S CATALOGS. SEE PAGE 1. ONLY BASIC PART NUMBERS ARE SHOWN. FOR COMPLETE PART NUMBER REFER TO SPECIFIC MANUFACTURER'S ORDERING INFORMATION ON PAGES 124 THRU 261.

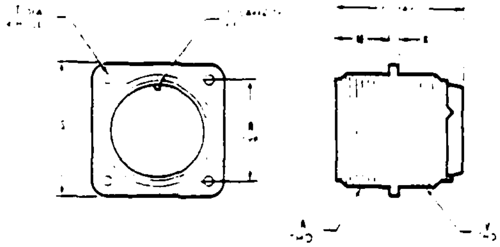
PART NUMBER	FLIGHT CONNECTOR	ITT CANNON	MATRIX SCIENCE	SAE
MS3400D	FF00D	WFS3400D	MFR0D	M00D
MS3400DJ	FF00DJ	—	MFR0DJ	M00DJ
MS3400DJS	FF00DJS	—	—	M00DJS
MS3400DS	FF00DS	WFS3400DS	—	M00DS
MS3400KS	—	—	—	M00KS
MS3400KT	—	—	—	M00KT
MS3400K	—	—	—	M00K
MS3401D	FF01D	WFS3401D	MFR1D	M01DI
MS3401DJ	FF01DJ	—	MFR1DJ	M01DJ
MS3401DJS	FF01DJS	—	—	M01DJS
MS3401DS	FF01DS	WFS3401DS	—	M01DS
MS3402D	FF02D	WFS3402D	MFR2D	M02D
MS3402DS	FF02DS	WFS3402DS	—	M02DS
MS3404D	FF04D	WFS3404D	MFR4D	M04D
MS3404DS	FF04DS	WFS3404DS	—	M04DS
MS3406D	FF06D	WFS3406D	MFR6D	M06D
MS3406DJ	FF06DJ	—	MFR6DJ	M06DJ
MS3406DJS	FF06DJS	—	—	M06DJS
MS3406DS	FF06DS	WFS3406DS	—	M06DS
MS3406KS	—	—	—	M06KS
MS3406KT	—	—	—	M06KT
MS3406K	—	—	—	M06K
MS3408D	FF08D	WFS3408D	MFR8D	M08D
MS3408DJ	FF08DJ	—	MFR8DJ	M08DJ
MS3408DJS	FF08DJS	—	—	M08DJS
MS3408DS	FF08DS	WFS3408DS	—	M08DS
MS3409D	FF09D	WFS3409D	MFR9D	M09D
MS3409DJ	FF09DJ	—	MFR9DJ	M09DJ
MS3409DJS	FF09DJS	—	—	M09DJS
MS3409DS	FF09DS	WFS3409DS	—	M09DS
MS3412D	FF12D	WFS3412D	MFR12D	M12D
MS3412DS	FF12DS	WFS3412DS	—	M12DS
MS3412L	—	—	—	M12L

MS3400

WALL MOUNT RECEPTACLE

Item 18e

CLASS D; K



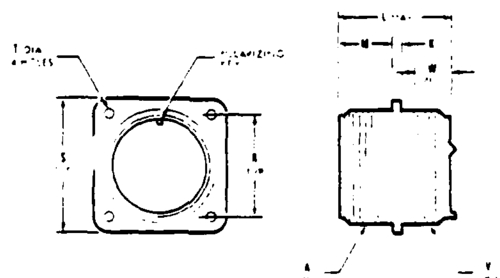
SHELL SIZE	A COUPLING THREAD CLASS 2A	K ±.015	L MAX. CONTACT SIZE 16 & 12	L MAX. CONTACT SIZE 8 4 & 0	M +.031 -.000	R T.P. ℄-℄	S ±.031	T +.010 -.005 CLASS D,L,J,W	T +.010 -.005 CLASS K	V ACCESSORY THREAD CLASS 2A
8S	1 2-28 UNEF	083	2.031	—	562	594	875	120	150	1 2-20 UNEF
10S	5 8-24					719	000			5 8-24
10SL	5 8-24					719	000			5 8-24
12S	3 4-20		2.031		562	812	094			3 4-20
12	3 4-20		2.125		750	812	094			3 4-20
14S	7 8-20		2.031		562	906	1 188			7 8-20
14	7 8-20		2.125		750	906	1 188			7 8-20
16S	1 -20		2 031	—	562	969	281			1 -20
16	1 -20	083	2 125	1 937	750	969	1 281		150	1 -20
18	1 1 8-18	125				1 062	375		177	1 1 16-18
20	1 1 4-18					1 156	1 500			1 3 16-18
22	1 3 8-18				750	1 250	1 625	120		1 5 16-18
24	1 1 2-18 UNEF				812	1 375	1 750	147		1 7 16-18 UNEF
28	1 3 4-18 UNS				812	1 562	2 000	147	177	1 3 4-18 UNS
32	2 -18 UNS				875	1 750	2 250	173	209	2 -18 UNS
36	2 1 4-16 UN					1 938	2 500			2 1 4-16 UN
40	2 1 2-16					2 188	2 750			2 1 2-16
44	2 3 4-16					2 375	3 000			2 3 4-16
48	3 -16 UN	125	2.125	1 937	875	2 625	3 250	173	209	3 -16 UN

MIL-C-5015
CRIMP, FRONT RELEASE

MS3412

BOX MOUNT RECEPTACLE WITH THREADED REAR SKIRT

CLASS D; L

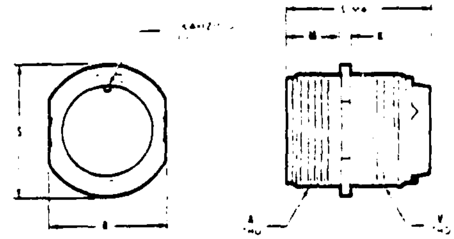


SHELL SIZE	A COUPLING THREAD CLASS 2A	K ±.015	L MAX. CONTACT SIZE 16 & 12	L MAX. CONTACT SIZE 8 4 & 0	M +.031 -.000	R T.P. ℄-℄	S ±.031	T +.010 -.005 CLASS D,L,J,W	T +.010 -.005 CLASS K	V ACCESSORY THREAD CLASS 2A
8S	1 2-28 UNEF	083	662	–	562	594	875	120	150	1 2-20 UNEF
10S	5 8-24					719	000			5 8-24
10SL	5 8-24					719	000			5 8-24
12S	3 4-20				562	812	094			3 4-20
12	3 4-20				750	812	094			3 4-20
14S	7 8-20				562	906	188			8-20
14	8-20				750	906	188			7 8-20
16S	-20				562	969	281			-20
16	[illegible]	083		[illegible]	750	969	281		150	-20
[illegible]	[illegible]	[illegible]				[illegible]	[illegible]		[illegible]	[illegible]
[illegible]	[illegible]					[illegible]	[illegible]			[illegible]
[illegible]	[illegible]				750	[illegible]	[illegible]	[illegible]		1 5 16-18
[illegible]	[illegible]				812	[illegible]	[illegible]	[illegible]		[illegible]
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	209	[illegible]
36	[illegible]					[illegible]	[illegible]			[illegible]
[illegible]	[illegible]					[illegible]	[illegible]			[illegible]
44	[illegible]					[illegible]	[illegible]			[illegible]
48	[illegible]	[illegible]	562	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]

MS3401

IN-LINE RECEPTACLE

Item 18f CLASS D



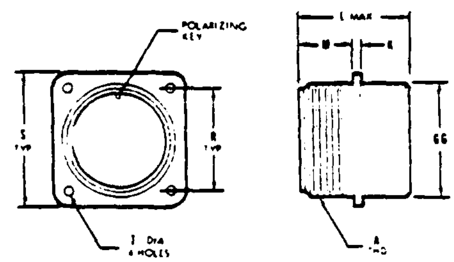
SHELL SIZE	A COUPLING THREAD CLASS 2A	K ± .015	L MAX. CONTACT SIZE 16 & 12	L MAX. CONTACT SIZE 8, 4 & 0	M +.03 -.000	R MAX.	R MIN.	S ± .031	V ACCESSORY THREAD CLASS 2A
8S	1 2-28 UNEF	083	2 031	—	562	504	496	729	1 2-20 UNEF
10S	5 8-24					629		854	5 8-24
10SL	5 8-24					629		854	5 8-24
12S	3 4-20		2 031		562	754	[illegible]	974	3 4-20
12	3 4-20		2 125		750	754	746	974	3 4-20
14S	7 8-20		2 031		562	879	871	1 099	7 8-20
14	7 8-20		2 125		750	879	871	1 099	7 8-20
16S	1 -20		2 031	—	562	1 005	996	1 224	1 -20
16	1 -20	083	2 125	2 500	750	1 005	996	1 224	1 -20
18	1 1 8-18	125				1 131	1 121	1 349	1 1 16-18
20	1 1 4-18					1 256	1 246	1 474	1 3 16-18
22	1 3 8-18				750	1 381	1 371	1 599	1 5 16-18
24	1 1 2-18 UNEF				812	1 506	1 496	1 715	1 7 16-18 UNEF
28	1 3 4-18 UNS				812	1 756	1 746	1 974	1 3 4-18 UNS
32	2 -18 UNS				875	2 007	1 996	2 224	2 -18 UNS
36	2 1 4-16 UN					2 257	2 246	2 474	2 1 4-16 UN
40	2 1 2-16					2 511	2 496	2 724	2 1 2-16
44	2 3 4-16					2 761	2 746	2 974	2 3 4-16
48	3 -16 UN	125	2 125	2 500	875	3 011	2 996	3 224	3 -16 UN

MIL-C-5015
CRIMP FRONT RELEASE

MS3402

BOX MOUNT RECEPTACLE

CLASS D



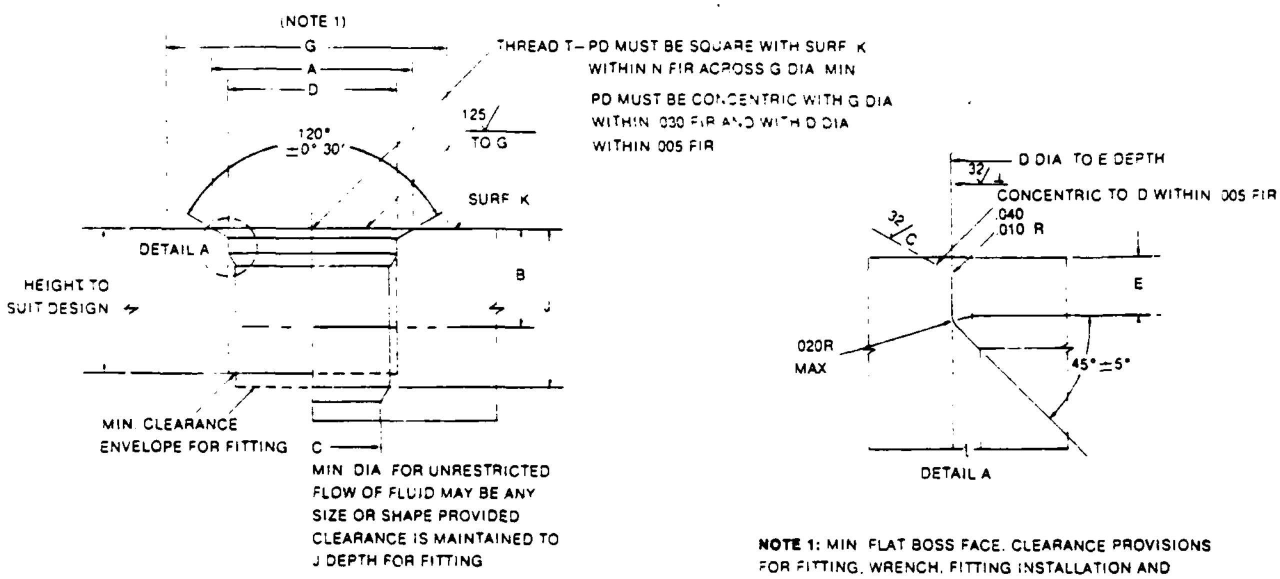
SHELL SIZE	A COUPLING THREAD CLASS 2A	K ± .015	L MAX. CONTACT SIZE 16 & 12	L MAX. CONTACT SIZE 8, 4 & 0	M +.03 -.000	R T.P. ℄ - ℄	S ± .03	T +.010 -.005 CLASS D, L, J, W	T CLASS K	GG DIA. +± .016
8S	1 2-28 UNEF	083	667	—	562	594	875	120	150	453
10S	5 8-24					719	000			625
10SL	5 8-24					719	1 000			625
12S	3 4-20				562	812	1 094			750
12	3 4-20				750	812	094			750
14S	7 8-20				562	906	[illegible]			875
14	7 8-20				750	906	[illegible]			875
16S	-20				562	969	[illegible]			953
16	-20	083		937	750	969	[illegible]		150	953
18	[illegible]	125				[illegible]	[illegible]		[illegible]	062
20	[illegible]					[illegible]	[illegible]			[illegible]
22	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
24	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
28	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
32	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
36	[illegible]				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
40	[illegible]					[illegible]				[illegible]
44	[illegible]						[illegible]			
48	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Item 19

tube fitting boss seals

PARKER O-RING HANDBOOK

MS33649 - POLL DWG



NOTE 1: MIN. FLAT BOSS FACE. CLEARANCE PROVISIONS FOR FITTING, WRENCH, FITTING INSTALLATION AND TOOL FILLET RADII MUST BE ADDED AS REQUIRED.
NOTE 2: TUBE FITTINGS PER MS33656
PLUG PER MS9954

TABLE A5-5 BOSS DIMENSIONS FOR MILITARY STRAIGHT THREAD TUBE FITTING O-RING GASKETS
Per MS33649 (Supersedes AND10049 and AND10050)
For MS9020, MS28778, and other O-ring packings shown in table B7. (? B-

GO TO TABLE B-7 Page B-49

PARKER O-RING SIZE NO.*	ACTUAL O-RING DIMENSIONS W	ACTUAL O-RING DIMENSIONS ID (1)	EQUIV-ALENT TUBE DASH NO.	TUBE OD NOM.	THREAD T PER MIL-S-8879	A DIA. +.015 −.000	B MIN. FULL THD. DEPTH	C DIA.	D DIA. +.005 −.000	E +.015 −.000	G DIA. MIN.	J MIN.	N
3-902	064 ± 003	239 ± .005	2	.125	.3125-24UNJF-3B	438	482	.062	328	.063	.602	.577	.003
3-903	064 ± 003	301 ± 005	3	.188	3750-24UNJF-3B	500	538	125	390		.665	.583	
3-904	072 ± .003	.351 ± 005	4	250	4375-20UNJF-3B	562	568	172	454	.075	.728	.656	
3-905	072 ± 003	414 ± 005	5	.312	5000-20UNJF-3B	625		234	517		790		
3-906	078 ± 003	.468 ± 005	6	.375	5625-18UNJF-3B	688	598	297	580	.083	852	.709	004
3-907	082 ± 003	530 ± .005	7	438	.6250-18UNJF-3B	750	614	360	643	.094	.915	.725	
3-908	087 ± 003	644 ± 005	8	.500	7500-16UNJF-3B	875	714	391	769		1 040	834	.005
3-909	097 ± 003	706 ± 005	9	.562	8125-16UNJ-3B	938	730	438	832	107	1 102	.850	
3-910	097 ± 003	755 ± 005	10	625	8750-14UNJF-3B	1 000	802	484	896		1 165	930	
3-911	116 ± 004	863 ± 005	11	688	1 0000-12UNJF-3B	1 156		547	1 023		1 352	1 064	
3-912	116 ± 004	924 ± .006	12	750	1 0625-12UNJ-3B	1 234		609	1 086		1 415		
3-914	116 ± 004	1 047 ± 006	14	875	1 1875-12UNJ-3B	1 362		734	1 211		1 540		
3-916	116 ± 004	1 171 ± .006	16	1 000	1 3125-12UNJ-3B	1 487	877	844	1 336		1 665		
3-918	116 ± 004	1 355 ± 006	18	1 125	1 5000-12UNJF-3B	1 675		953	1 524	125	1 790	1 116	008
3-920	116 ± 004	1 475 ± 010	20	1 250	1 6250-12UNJ-3B	1 800		1 078	1 648		1 978		
3-924	118 ± 004	1 720 ± 010	24	1 500	1 8750-12UNJ-3B	2 050		1 312	1 898		2 228	1 127	
3-928	118 ± 004	2 090 ± 010	28	1 750	2 2500-12UNJ-3B	2 425		1 547	2 273		2 602	1 243	010
3-932	116 ± 004	2 337 ± 010	32	2 000	2 5000-12UNJ-3B	2 675	[illegible]	1 781	2 524		2 852	1 368	

*PARKER DASH NUMBERS CORRESPOND WITH THOSE OF AS568

[illegible] B6 and B7

APPENDIX A

WESTINGHOUSE ELECTRIC CORPORATION
AEROSPACE ELECTRICAL DIVISION
LIMA OHIO
ENGINEERING DEVELOPMENT LABORATORY

Date March, 1975 **Report No.** LY 15075

PHM - ELECTRICAL SYSTEM
VERIFICATION & QUALIFICATION TEST REPORT
WESTINGHOUSE INTERNAL ADDENDUM
LY15075, PART II
AUGUST 1974

PHM GENERATOR
P/N 977J031-1
250 KVA, 8000 RPM

Contract No. ____________

Requested By ____________
Westinghouse Engineering

Under Supervision Of A E King
A. E. King, Mgr. Power Dynamics

Directed By ____________

Reported By 4.23.75
W. J. Shilling, Eng., Power Dynamics

Witnessed By ____________

Date	Rev.By	Pages	Remarks

The purpose of this Westinghouse Internal Addendum is to record available data on the subject generator which was not included in the original Q/T report. This information was not included because of its more detailed nature and was not considered pertinent as regards general publication.

CONTENTS

WEIGHT 11.21.77 77031-0# 364.5 Lbs

Weighed By R. CALLAHAN

APPENDIX

-02

375 lbs

EFFICIENCY AND TEMPERATURE TESTS

References

1. Test Data AA12160, 12163

2. Boeing Specification 312-80173, paragraph 4.3.4.1.2.7 (Efficiency) and Paragraph 4.3.4.2.2.1.3 (Temperature).

3. Test Letter G3-033, paragraph 2.

4. Test Report LY 15075, page 68

Description

(See Test Report LY 15075, page 68).

Generator Specification

The Boeing Specification paragraphs referenced above are here quoted as part of the description.

(4.3.4.1.2.7): "Generator efficiency shall be determined at half rated and at rated load and shall conform to the requirements of Section 3.1.1.1.2.9" (89% efficient at full load).

(4.3.4.2.2.1.3): "With candidate hot spot suitably instrumented for temperature, operate the generator at room temperature for two hours. Extrapolation of test data shall be used to determine hot spot temperatures at a 54°C ambient." (Insulation Life: 20,000 hours.)

Generator Test Set Up

(See Test Report LY 15075, page 68)

Because of the large input power required by the generator at full load (approximately 300 HP), a "feedback" test set-up was used. In this system two 250 KVA generators were used with one operating as a motor.

That is - the output of the generator on test supplied electrical power to the other generator being operated as a synchronous motor to drive the generator on test. In this arrangement, the laboratory needs to supply only make-up electrical power to a third small machine operating as a synchronous motor on the same gear head required above. This small machine supplies the "make-up" drive power to the generator under test. Another advantage of this system is that large load banks are not required and desired power factors for the tested generator are readily obtained by adjusting the circumferential position of the tested generator stator relative to drive motor stator. Efficiency was measured using a torque head which measured the torque input to the generator under test.

Temperature Measurements

To obtain the hot spot temperature of the main AC stator winding, consideration was given to the following:

1. One of the most effective cooling means is by air flowing directly on the stator winding end extensions. Thus the AC winding hot spot is not on the end extension but rather in the slots in the stator stack.

2. The cooling air temperature rises as it passes through the generator. Thus the winding hot spot will be in the stator slot between the mid point of the stator stack and the air-out end of the stack. The stack is 8.45 inches long.

With the above in mind, two thermocouples were brazed directly to the main AC stator winding, in two different slots, on the conductor closest to the air gap, and 2 inches from the air-out end of the stack. Two other thermocouples were similarly placed in still two other slots 3 inches from the air-out end of the stack. All four of the couples mentioned were brazed to conductors that had (phase) sleeving on their end extensions which would again cause higher temperatures because of poor effective end-extension cooling.

The rotating field temperature was determined by observing the change in field resistance relative to room temperature resistance. The hot resistance was determined by measuring the rotating field DC volts and amps (using slip rings). The average rotating field temperature was determined by this method.

Test Results

Vol. I

See Test Report LY15075/ page 69.

SHORT CIRCUIT TESTS

Reference

1. Test Data AA12171

2. Boeing Specification 312-80173, paragraph 3.1.1.1.3.2.11 and Fig. 3.1-5.

3. Westinghouse Test Letter G3-033, paragraph 3.0.

Description

To verify one point on the Generator Thermal Capability Curve of Figure 3.1-5 of Reference Spec, a three phase short circuit test of 1250 amps (3.9 per unit) was run for 16 seconds after first stabilizing generator at full load.

Test Results

Temperatures of Windings were:

Average field winding resistance hot = (field winding = .455 ohms at 25°C)	.585 ohms
Average field winding temperature =	99°C
Hot Spot of Stator AC winding =	271°C
Hot Spot Temperature adjusted for 54°C ambient instead of 27°C =	298°C

Based on Figure, page LY15075-75, 298°C would allow 880 hours insulation life or one application of short circuit will reduce insulation life less than .00051%.

Conclusions

The generator is thermally capable of 3.9 per unit current for 16 seconds.

WES~~NGHOUSE ELECTRIC CORPORATION, AEROSPACE ELECT~~ICAL DIV., LIMA, OHIO AA 12171

AP. ~US: 250 KVA PHM GENERATOR ; P/N 977J031-1 ; S/N 4

TEST LETTER: G3-033 ; PARA. NO: 3.0 CHARGE: A76-5J-LY20281

CUSTOMER: BOEING (PHM) TEST TITLE: SHORT CIRCUIT TESTS

CLOCK HOURS-START ____
STOP ____

AFA	AFV	SC LA	EFV	EFA	RPM	AIT °C	AMB °C	TIME	Re WDG °C
20	10.8	216	4.85	.65	8000	27	25	—	—
40	21.75	420	9.5	1.25	8000	27	25	—	—
60	32.6	631.2	14.6	1.92	8000	27	25	—	—
100	55.3	1041.8	26.0	3.48	8000	27	25	—	—
126	73.72	1250	36.2	4.7	8000	27	25	16 sec	94 start 271

STABILIZED GEN @ FULL LOAD CURRENT
AND APPLIED 1250 S.C I FOR 16 sec. 5" TH AIR OUTLET

RDSV ON APPLICATION OF 3φ SHORT CIRCUIT AT GEN. OUTPUT TERMINALS

PICT. #1 88 VOLTS (6 spikes)
PICT. #2 88 VOLTS (1 spike)
MAX DIODE VOLTAGE NOTED ON OSCILLOSCOPE ON APPLIC. OF 3 PHASE SHORT

PDSV @ 12 VOLTS @ NORMAL VOLTAGE 260 L-N

DISCONNECTED (3) 6800 Ω RES. AND USED ... TO ... TAKE ... REVERSE ... APPLICATION ... FROM RATED ...

Prev. Test Page: | Date: 5-15-74 | Engineer: W. J. SHILLING | Signed: MARKER-NULL

AED 1714 Eng.

ROTATING DIODE SPIKE VOLTAGES

References

1. Test Data Sheet AA12171, page 7.

2. Figure 1, page 9.

3. Westinghouse Test Letter G3-033, paragraph 3.1.

Description

The generator was operated at rated voltage (260V per phase), no load; and then a 3 phase short circuit was suddenly applied to the generator. The voltage across one diode was observed. by means of an oscilloscope and slip-ring test leads connected directly to one diode.

Test Results

Figure 1 shows the diode voltage observed immediately after the 3 phase short was applied. This shows a maximum peak inverse ("spike") voltage of 88 volts. Short circuit tests run to obtain machine constants (X'd, X"d, T'd, etc., AA12167) show initial line short circuit current is approximately 4.3 times the steady state value. The rotating field current and volts will then also tend to be 4.3 times steady state values. Or in other words, the rotating rectifier sees its severest loading (approximately 100 rotating field amps when a 3 phase short circuit fault is first applied The 88 volts is well under the 600 volt (PIV) rating of the diode and 300 volt working voltage (125°C) rating of the rating of the rotating suppressors (capacitors).

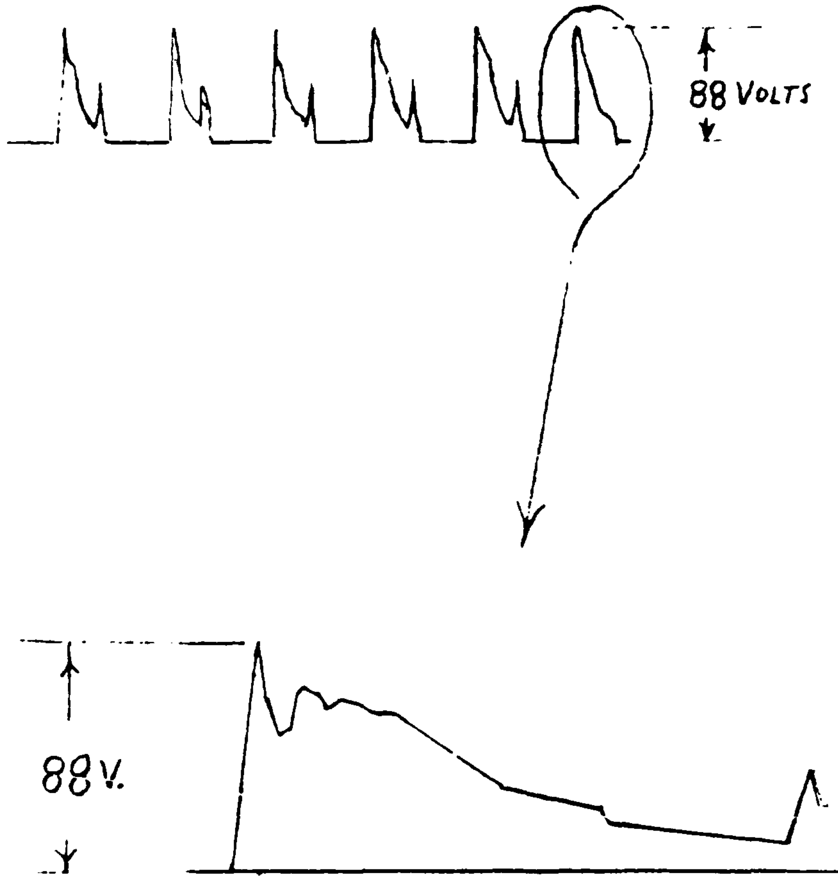
Conclusion

The rotating rectifier with suppressor has a voltage rating of better than 3 times the highest voltage seen in the application.

SKETCH SHEET
FORM 28577

WESTINGHOUSE ELECTRIC CORPORATION

SKETCH OF ROTATING DIODE SPIKE VOLTAGES-(APPLY 3Ø SHORT, 250 KVA GEN. 977J031-1, -2



TEST DATA AA12171

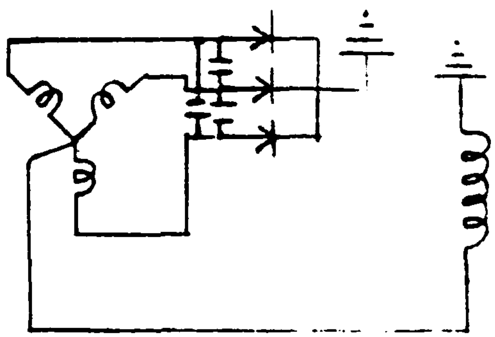


FIG 1

WJS 7.26.74

May 11, 1976

Subject: [illegible] Generator
Machine Constants
[illegible]
To Laurent 5/11/76

To L. Laurent

CC: H. E. Kerr
W. Myerson

Machine constants on the subject machine are as follows:

		Per Unit*	Ohms/phase
Sync React (Direct)	X_d	1.43	1.18
Sync React (Quad)	X_q	.53	.44
Trans React	X'_d	~~.10~~ .14	~~.10~~ .115
Subtrans. React	X''_d	~~.11~~ .12	~~.093~~ ~~.099~~ .099
Subtrans React (Quad)	X''_q	.086	.071
Neg. Seq. React	X_2	.10	.082
Zero Seq. "	X_0	.0106	~~.009~~ .009
Neg Seq. Res.	R_2 @ 25°C	.017	.014
Zero Seq Res	R_0 @ 25°C	.008	.007

Open Cct Time Const Main Field 25°C T'_{do} = .345 Seconds
Trans. time Const " Gen 25°C T'_d = .030 Seconds
Arm time Const " 25°C T_a = .006 Seconds

* Per Unit is based on 318 Amps/phase and 262 V/phase

W. J. Shilling

MACHINE CONSTANTS

References

1. Westinghouse Test Letter G3-033, paragraph 4.0.
2. Test Data Sheet AA12167
3. Picture #1, #2, #3, and #4 , pages 13 thru 16.
4. AIEE Test Code 503, paragraph 1.843 through 1.863, and 1.943.
5. Figure 6, page 17.

Description

Time constants, transient reactance (X'd), and subtransient (X"d) were determined by applying a sudden 3 phase short circuit at the generator terminals while maintaining constant dc excitation to the exciter field. The short circuit current transient is then observed and analyzed per the AIEE test code.

Test Results

Test results showed the following:

Transient Reactance, X'd	=	.154 pu (.126Ω)
Subtransient Reactance, X"d	=	.133 pu (.109Ω)
Transient Time Constant, T'd	=	.018 seconds
Subtransient Time Constant, T"d	=	.004 seconds
Short Circuit Time Constant, Ta	=	.00375 seconds

Discussion

Westinghouse computer program 331 calculates constants above as X'd = .124 p.u.; X"d = .113 p.u.; T'd = .03 seconds at 25°C and T_a = .006 at 25°C. Considering that there will be some reactance in the short circuit itself, it seems likely that the true machine reactances will be slightly less than the test values shown.

The time constants during test with a hot machine (approximately 66°C AC stator winding and 95°C rotating field) were approximately 2/3 the values of the computer calculations for a machine with all windings at 25°C.

WESTINGHOUSE ELECTRIC CORPORATION, AEROSPACE ELECTRICAL DIV., LIMA, OHIO AA 12167

APPARATUS: 250 KVA PHM GENERATOR ; P/N 977J031-1 ; S/N PU4

TEST LETTER: G3-033 ; PARA. NO: 4 G CHARGE: A7G-SJ-LY20281

CUSTOMER: BOEING (PHM)

CLOCK HOURS-START ______
STOP ______

TEST TITLE: DIRECT AXIS, SHORT CIRCUIT TRANSIENT & SUBTRANSIENT REACTANCES & TIME CONSTANTS PER T.S. 553114 PARA. 1.13.1

AFA	AEV	VI-N	AIT	RPM
23.4	12.76	260	45°C	8000

BEFORE APPLICATION OF 3φ S.C.

STEADY STATE VOLTAGE = .4V
AFTER APPLICATION OF 3φ S.C.

MAX A-C STATOR WINDING TEMPERATURE DURING FAULT 66°C

Field = 12.8 / 23.4 = .5475

.547 / .431 − 1.269 x 259 = 328.7
29°C 234
95°C

PICT. # 1 CAL. 480 AMPS

PICT. # 2 φ1 APPLICATION OF 3φ S.C.
PICT. # 3 φ1 STEADY STATE

PICT. # 4 φ2 APPLICATION OF 3φ S.C.
PICT. # 5 φ2 STEADY STATE

PICT. # 6 φ3 APPLICATION OF 3φ S.C.
PICT. # 7 φ3 STEADY STATE

PICT # 8 SEP. EXCITATION ON EXCITER APPLY 3φ S.C. RDSV

PICT # 9 SEP. EXCITATION ON EXCITER AFTER REMOVAL OF 3φ S.C. RDSV

Prev. Test Page: ______ Date: 5-5-77 Engineer: W. J. SHILLING Signed: MARKER-NULL

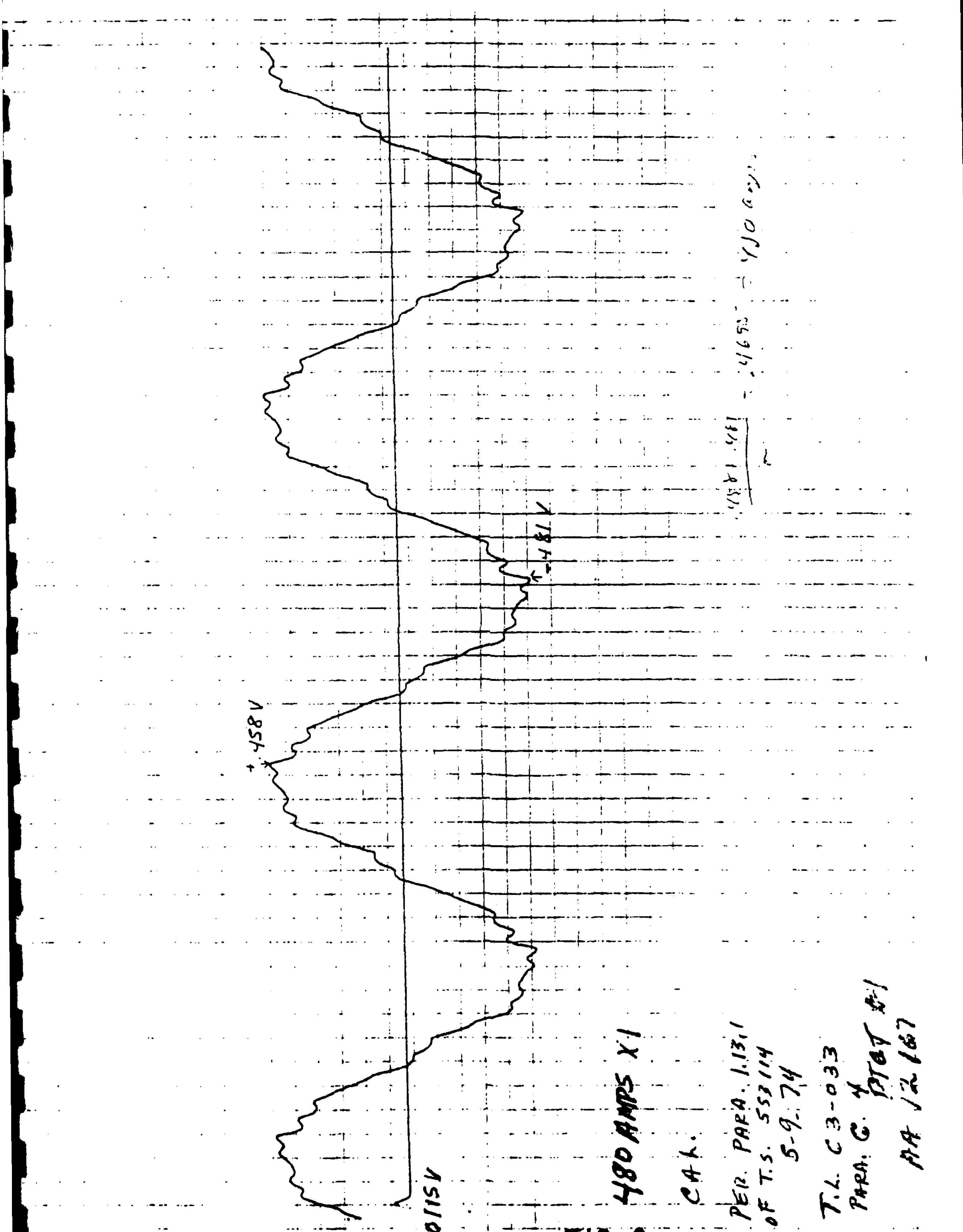

+.458 V
-.481 V
.0115 V
480 AMPS X1
CAL.
PER. PARA. 1.13.1
OF T.S. 553114
5-9-74
T.L. C3-033
PARA. C. 4
PTET #1
AA 12167

FIG 2

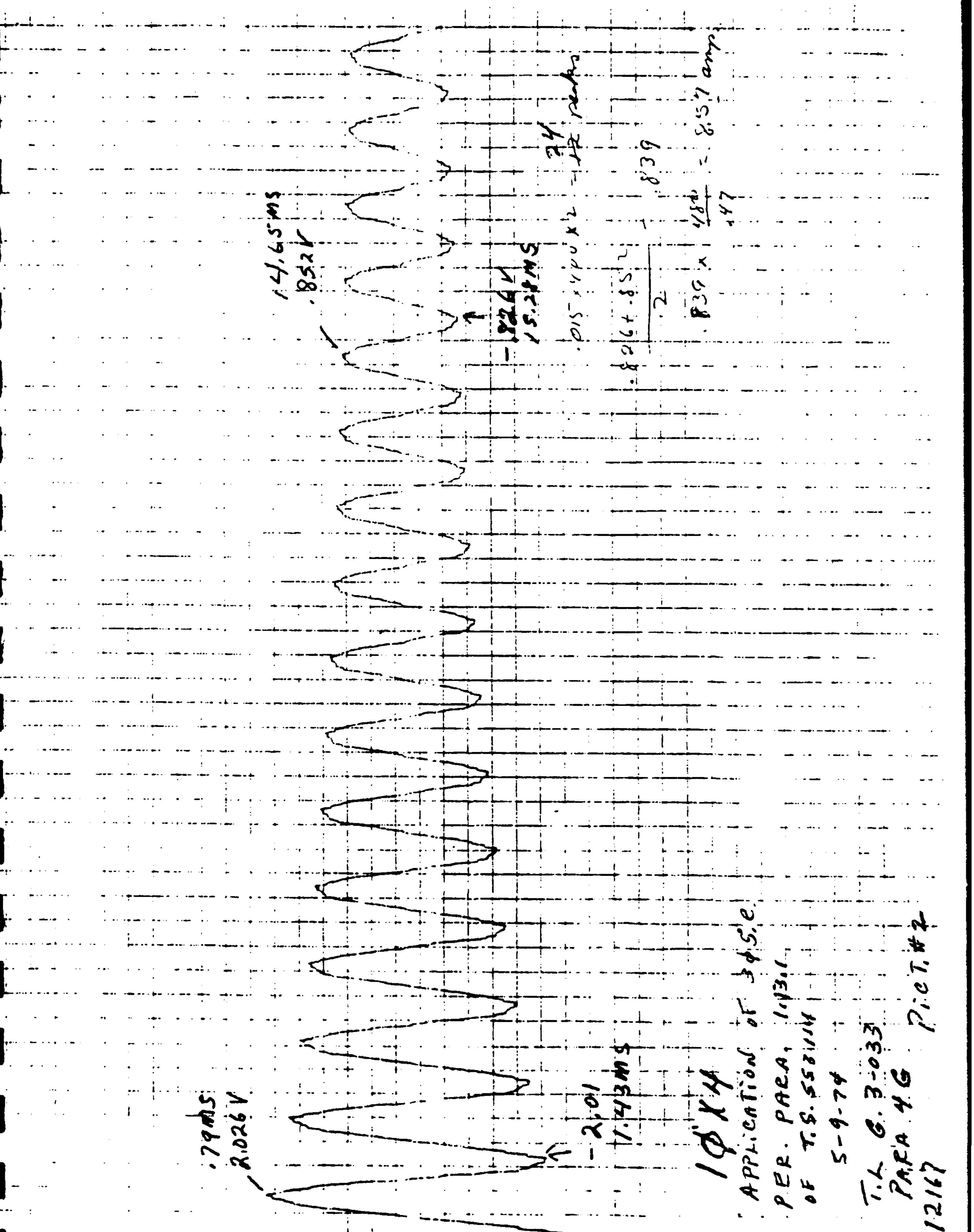

.79MS
2.026V
-2.01
1.43MS
14.65MS
.852V
-.826V
15.28MS
1Ø XH
APPLICATION OF 3Ø S.E.
PER. PARA. 1.13.1
5-9-74
T.L. G.3-033
PARA 4.G
PICT.#2
AA12167
8.57 amp

FIG 3

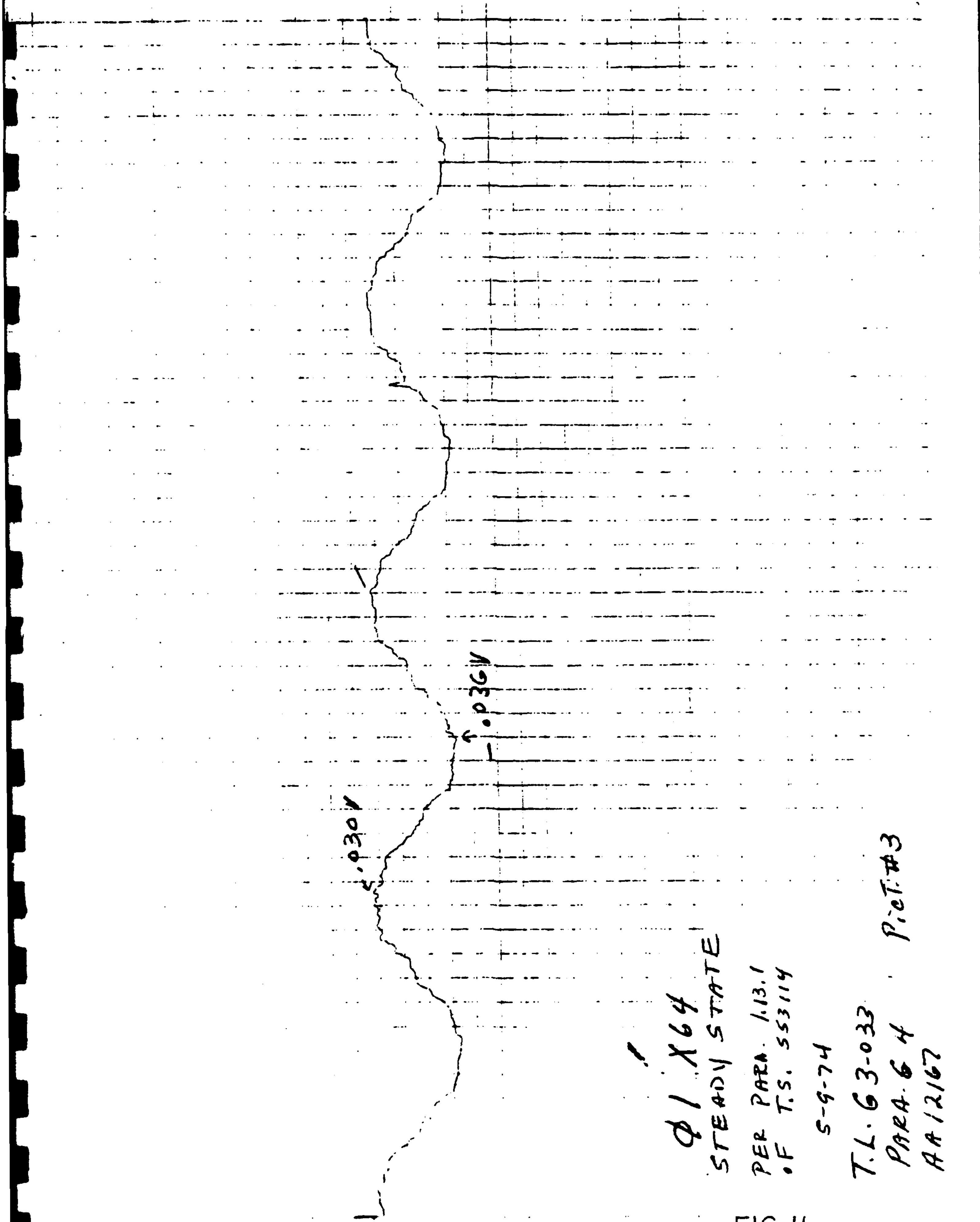
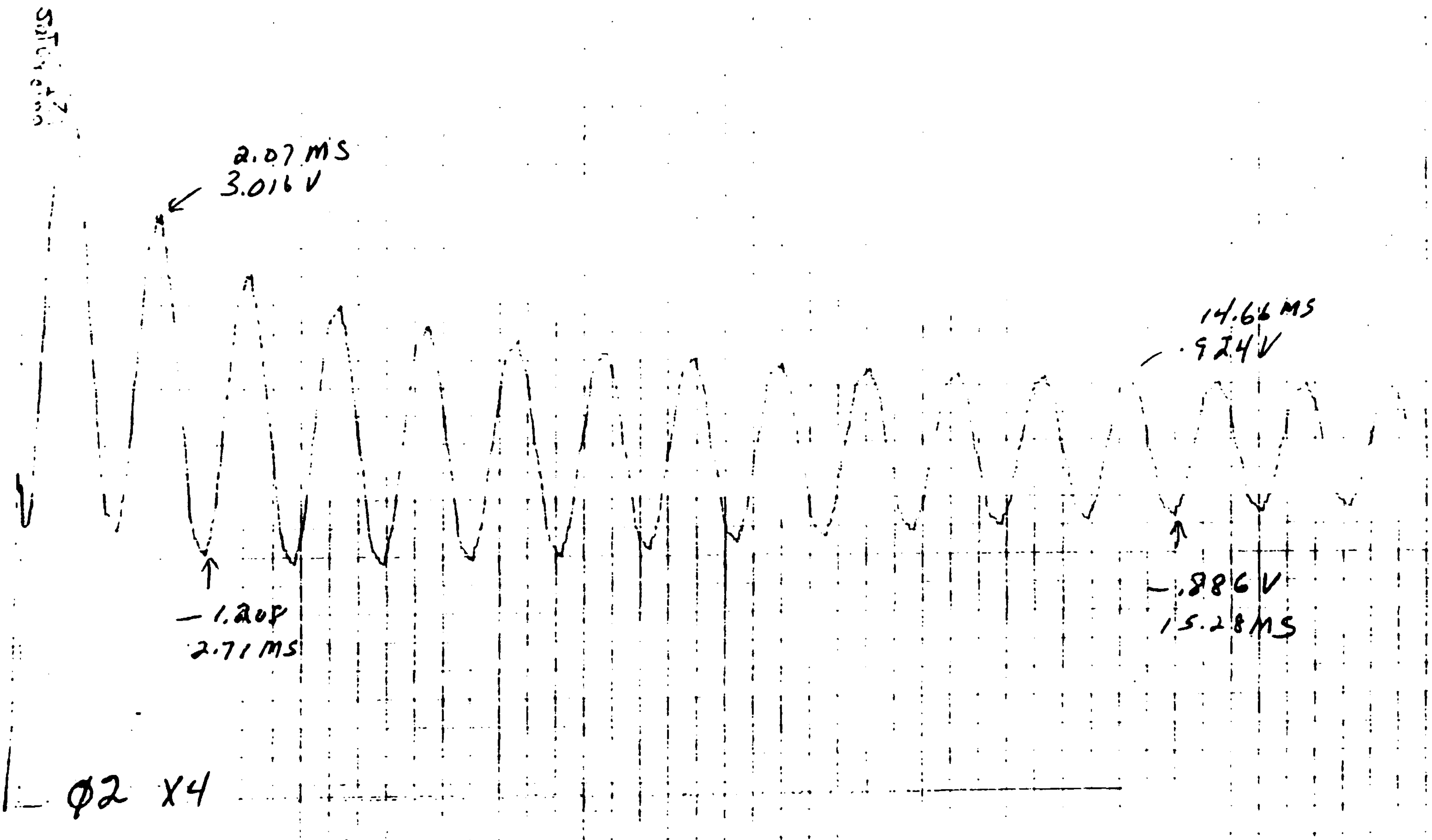

.030V
.036V
Φ1 X64
STEADY STATE
PER PARA. 1.13.1
OF T.S. 553114
5-9-74
T.L. 63-033
PARA. 6.4
AA12167
Pict #3

FIG 4



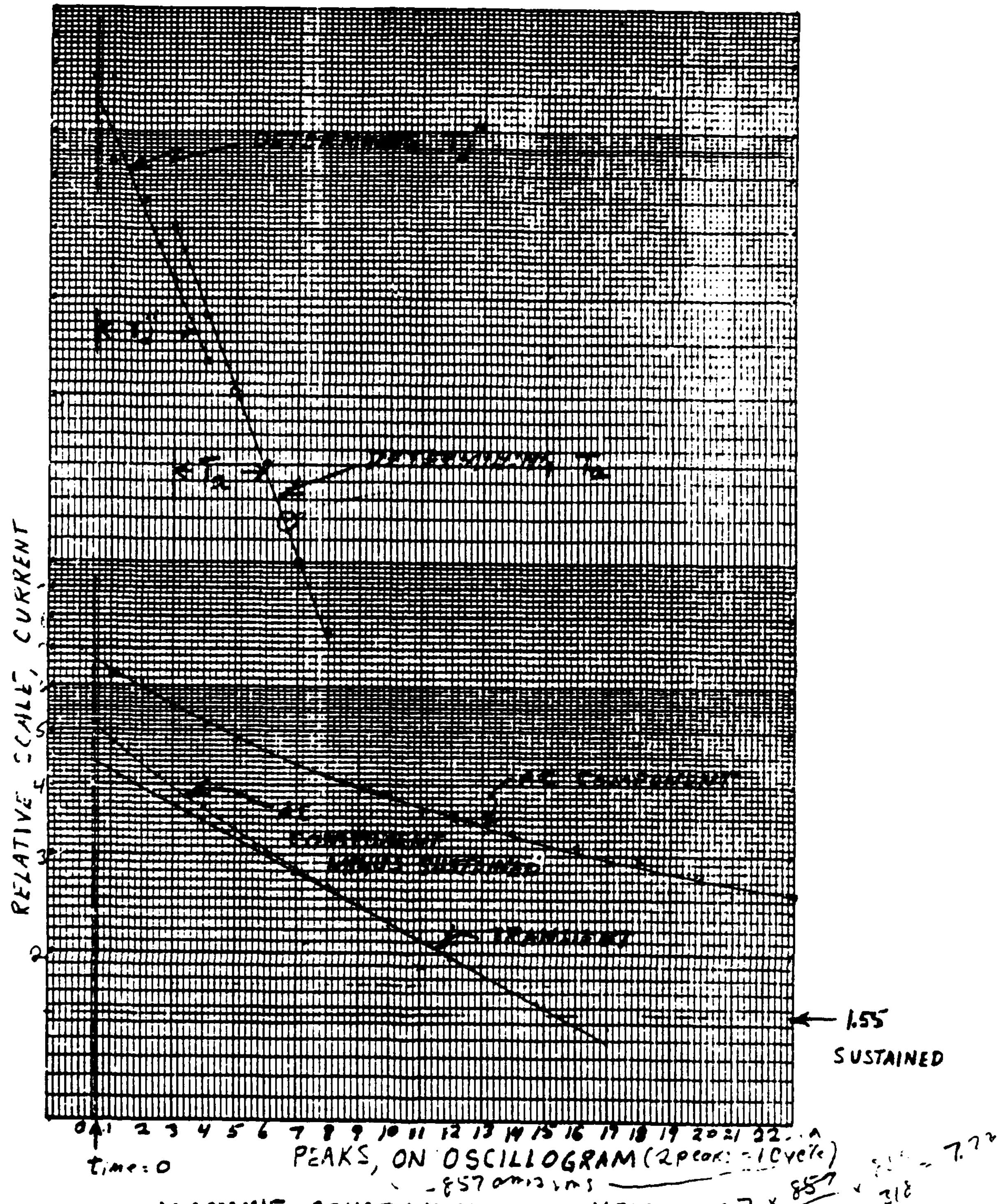
APPLICATION of 3Φ S.C.

PER PARA. 1.13.1
OF T.S. 553114
5-9-74

T.L. 63-037
PARA 6 4
AA12167

PICT.# 4

FIG 5



MACHINE CONSTANTS ANALYSIS
(Ref Fig 27, 35 AIEE CODE 503)

$6.7 \times \frac{.857}{2.5} \times \frac{...}{.318} = 7.22$

$X''_d = \frac{1}{7.22} = .138$

$T'_d = \frac{14.4}{2} \times \frac{1}{400} = .018$ sec

FIG 6

SATURATION AND CORE LOSS

References

1. Test Data: AA12164, 12166

2. Curves: Figures 7 & 8, pages 19 & 20.

3. Westinghouse Test Letter G3-033, paragraph 7.0.

Description

No load and constant current saturation curves at .8 P.F. lag were run at 8000 rpm. Slip rings were used to measure rotating field current.

Core losses were determined by measuring torque required by the generator while obtaining the no load saturation curve. The torque measured did include losses of the exciter. An estimate of exciter losses were made and deducted from total input torque. Friction and windage losses (at 8000 rpm with no excitation) were also subtracted from input torque. The remaining torque was converted to watts loss and represented core losses of the main machine.

Test Results

Test results are shown as Figures 7 & 8.

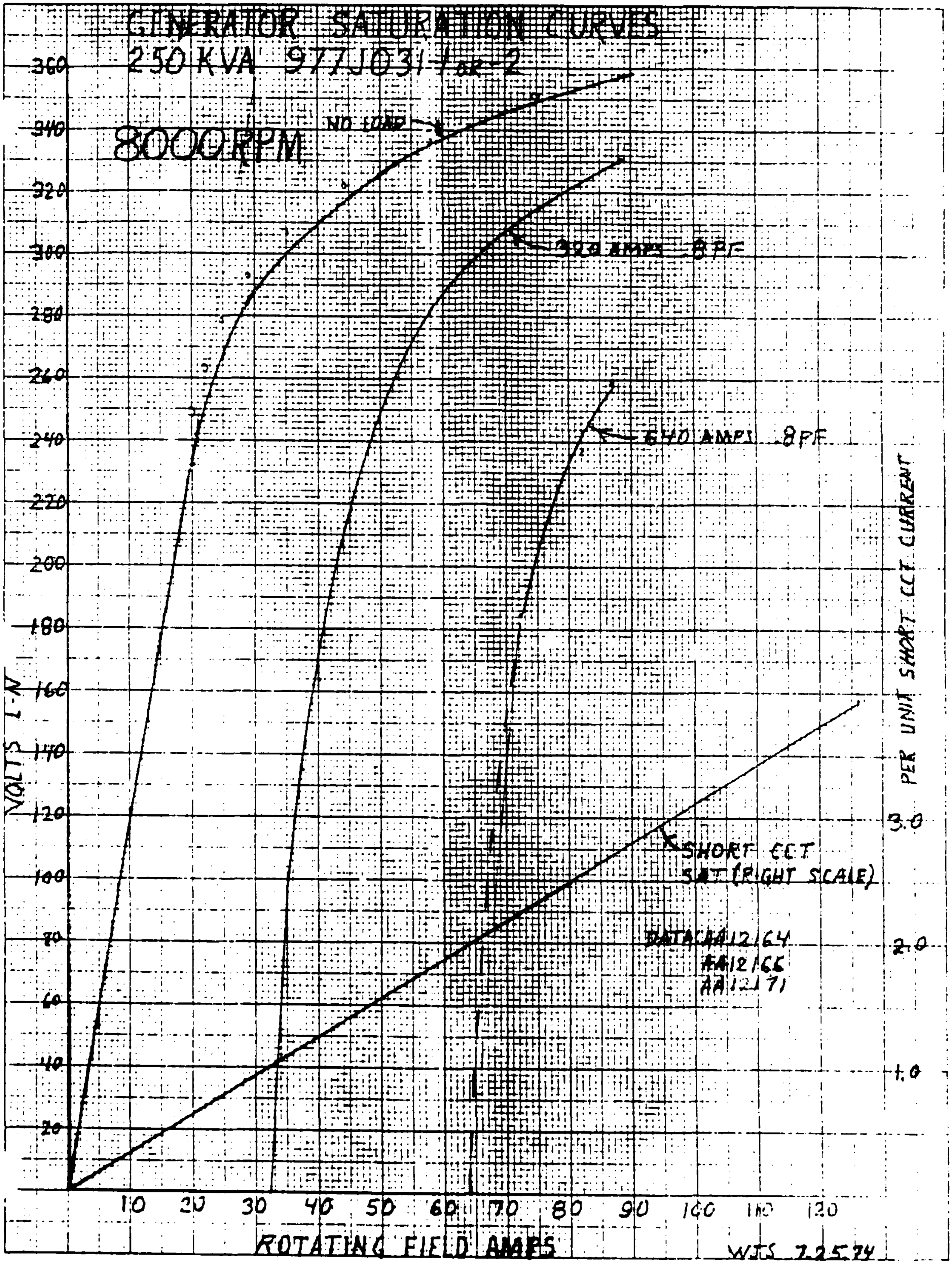
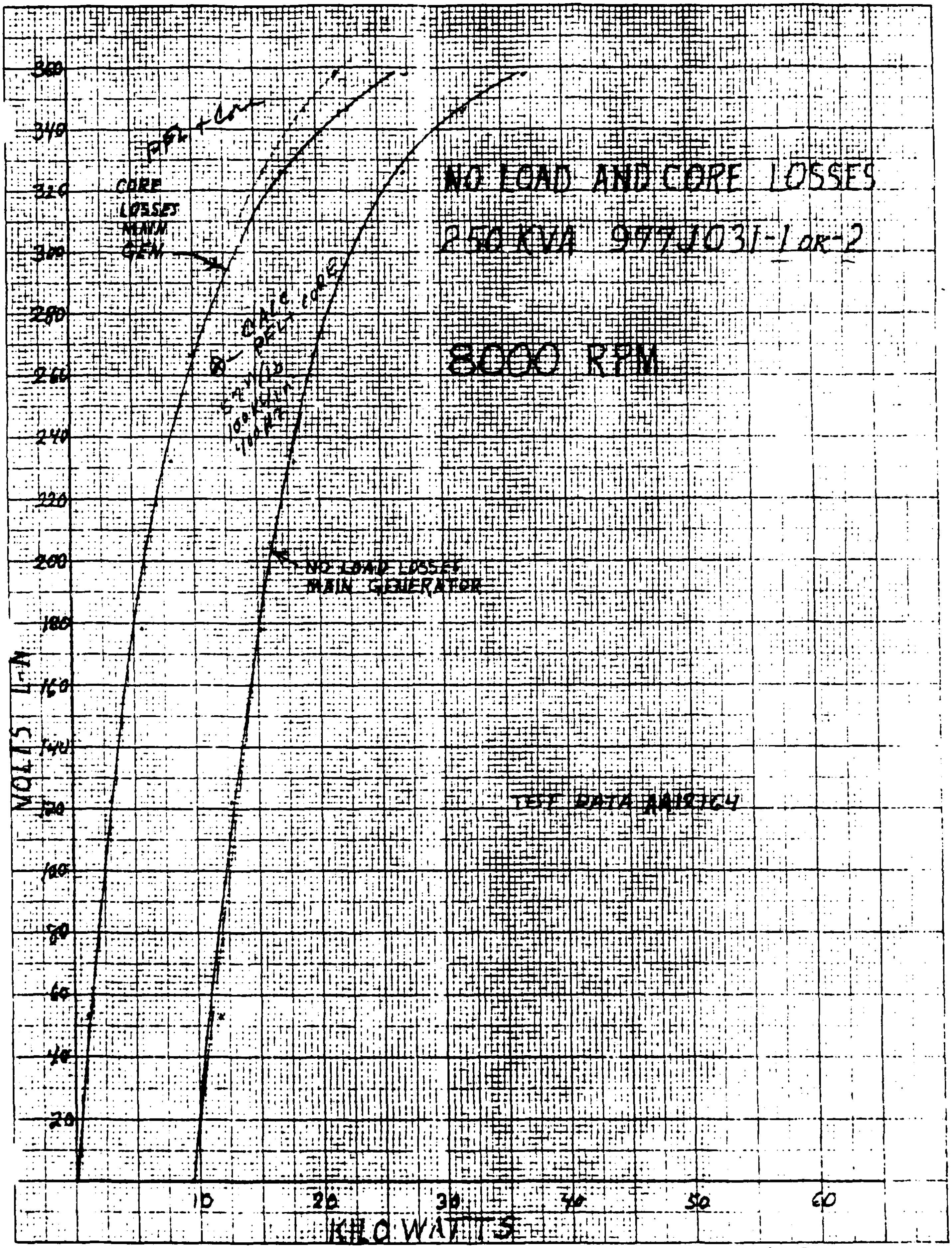

GENERATOR SATURATION CURVES
250 KVA 977J031 Gr-2
8000RPM
NO LOAD
320 AMPS .8PF
640 AMPS .8PF
SHORT CCT
SAT (RIGHT SCALE)
DATA AA12164
AA12166
AA12171
VOLTS L-N
PER UNIT SHORT CCT CURRENT
ROTATING FIELD AMPS
WJS 7.25.74

FIG 7



NO LOAD AND CORE LOSSES
250 KVA 977J031-1 or -2
8000 RPM
CORE LOSSES MAIN GEN
NO LOAD LOSSES MAIN GENERATOR
TEST DATA
VOLTS L-N
KILOWATTS
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
10
20
30
40
50
60

FIG 8

WESTINGHOUSE ELECTRIC CORPORATION, AEROSPACE ELECTRICAL DIV., LIMA, OHIO AA 12164

APP US: 250KVA PHM GENERATO ; P/N 977J031-1 ; S/N P

TEST LETTER: 63-033 ; PARA. NO: 7(a) CHARGE: A76-5I-LY20281

CUSTOMER: BOEING (PHM)

CLOCK HOURS-START ______

STOP ______

TEST TITLE: NO LOAD SATURATION

L-N VOLTS	AFA	AFV	TORK IN.LB.	WATTS IN	RPM	AIT °F			Field Watts	Core + Field + Exc Loss	Exc Losses	Exc Loss − 270	Core Loss + Field	Core Loss
.5	0	0	100	9473	8000	88					270	0		
53.5	5	2.2	112.5	10657			—		11	1148	270	0	1148	1137
122	10	5.15	132.5	12551					51	3078	280	10	3068	3017
178.5	15	7.46	160	15156					112	5683	295	25	5658	5546
232	20	10.56	185	17525					211	8052	320	50	8002	7791
267	25	13.2	207.5	19650					[illegible]	10083	370	100	9983	9653
289.3	30	16.2	285	26498					460		410	140		
326	50	27.4	340	32208					[illegible]	17525	700	430	17095	15775
346	70	35.7	340	36944					2709	22135	1100	830	21405	19194
358	90	50.6							4554	27471	1500	1230	26241	21687

EXCITER USED FOR EXCITATION

TORQ INCLUDES EXCITER

Prev. Test Page: | Date: 5-8-74 | Engineer: W. J. SHILLING | Signed: MARKER-NULL

AED 1714 Eng.

WESTINGHOUSE ELECTRIC CORPORATION, AEROSPACE ELECTRICAL DIV., LIMA, OHIO AA 1216F

AP. TUS: 250 KVA PHM GENERATOR ; P/N 977J033-1 ; S/N

TEST LETTER: 63-033 ; PARA. NO: 7 c & d CHARGE: A7G-6J-LY20281

CUSTOMER: BOEING PHM

TEST TITLE: LOAD SATURATION TESTS 100% & 200% LOAD .8PF

CLOCK HOURS-START ____ STOP ____

PARA.			c	c	c	c	c	c	c			d	d	d	
VI-N			94.5	135	163.5	218.5	260	300	330			185	237	258.6	
A1 X	240		1.315	1.315	1.315	1.315	1.338	—	—			2.66	2.66	2.66	CST
A2 X	240		1.34	1.34	1.34	1.34	1.342	1.34	1.34	322 AMPS		—	—	—	
A3 X	240		1.33	1.33	1.33	1.33	1.342	—	—			—	—	—	
W1 X	960		27	37.5	43.8	58.5	70.2	—	—			108	122	144	
W2 X	960		27	37.5	44.2	58.8	70.5	81	88.5			—	—	—	
W3 X	960		27.5	38	44.2	58.8	70.5	—	—			—	—	—	
KVARS X	1200		32.2	40.2	53.5	72.8	88	—	—			—	—	—	
AFA			35.3	37.5	40	45.2	52.5	66	88.2			72.4	82	86.7	
AFV			20.8	26.7	23.6	27.1	35.8	39	58.4			44.9	52.1	63	
EFA			1.1	1.16	1.27	1.45	1.73	2.2	3.0			2.45	2.91	3.1	
EFV			8.8	9.2	10.15	11.6	14.3	17.4	24			19.7	23.4	26	
RPM			8000	8000	8000	8000	8100	8000	8000			8000	8000	8000	
LOAD	%		100	100	100	100	100	100	100			200	200	200	

Prev. Test Page: Date: 5-8-74 Engineer: W. J. SHILLING Signed: MARKER-NULL

AED 1714 Eng.

P.M. GENERATOR LOAD CHARACTERISTICS

References

1. Westinghouse Test Letter G3-033, paragraph 9.0.
2. Test Data AA12158, AA12159
3. Curve, page 24.

Description

See Test Letter (Reference 1. above).

Test Results

DC Characteristics, see Curve page 24.

AC Characteristics, see test data (Reference 2. above).

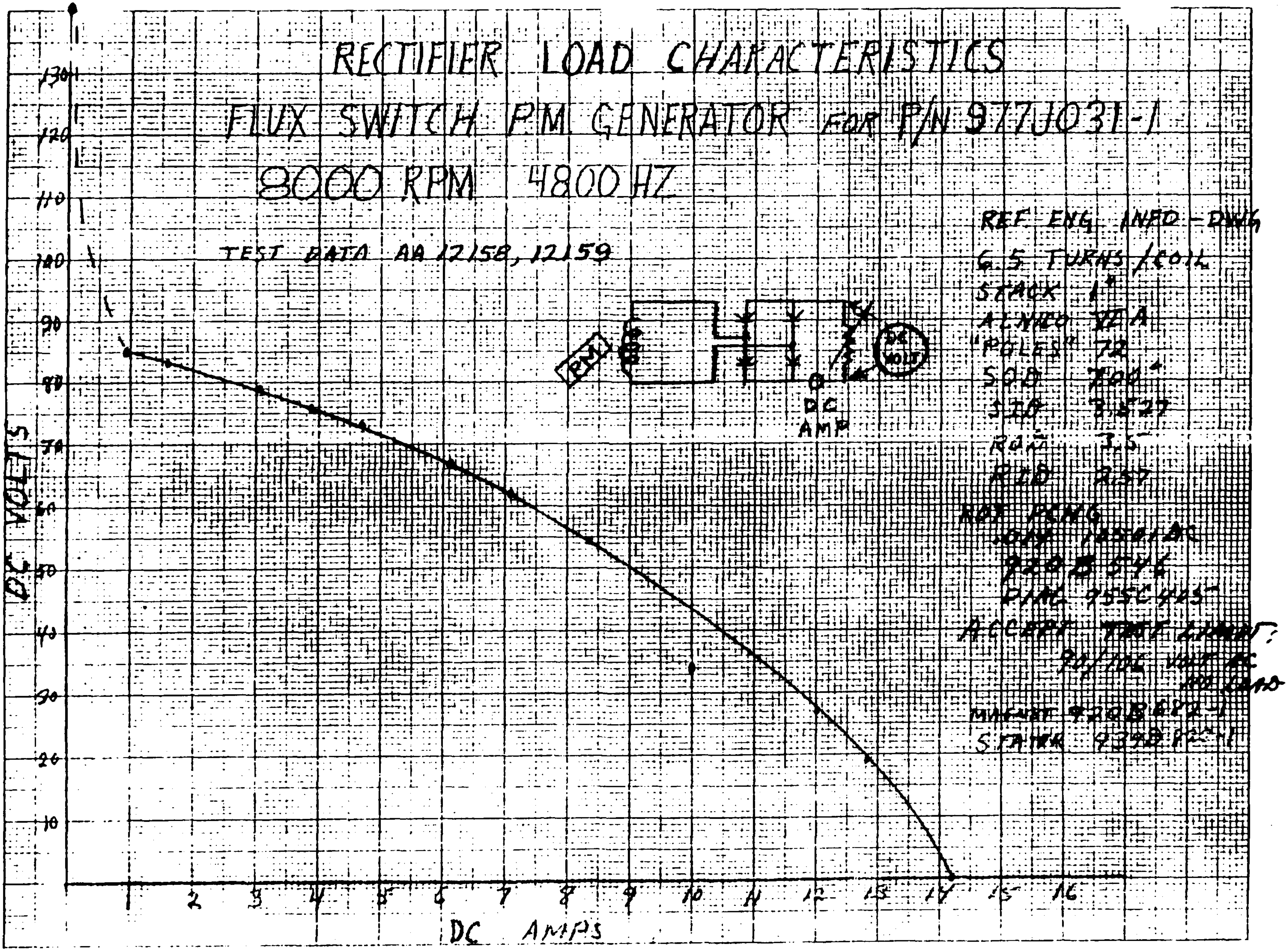

RECTIFIER LOAD CHARACTERISTICS
FLUX SWITCH PM GENERATOR FOR P/N 977J031-1
8000 RPM 4800 HZ
TEST DATA AA 12158, 12159
REF ENG INFO - DWG
6.5 TURNS / COIL
STACK 1"
ALNICO VIA
"POLES" 72
DC AMP
DC VOLTS
DC AMPS

FIG 9

WESTINGHOUSE ELECTRIC CORPORATION, AEROSPACE ELECTRICAL DIV., LIMA, OHIO AA **12158**

APPARATUS: 250KVA PHM GENERATOR ; P/N 977J031-1 ; S/N 0U.

TEST LETTER: G3-033 ; PARA. NO: 9 (b) CHARGE: A7Q-5T-LY20281

CUSTOMER: BOEING (PHM)

CLOCK HOURS-START ______

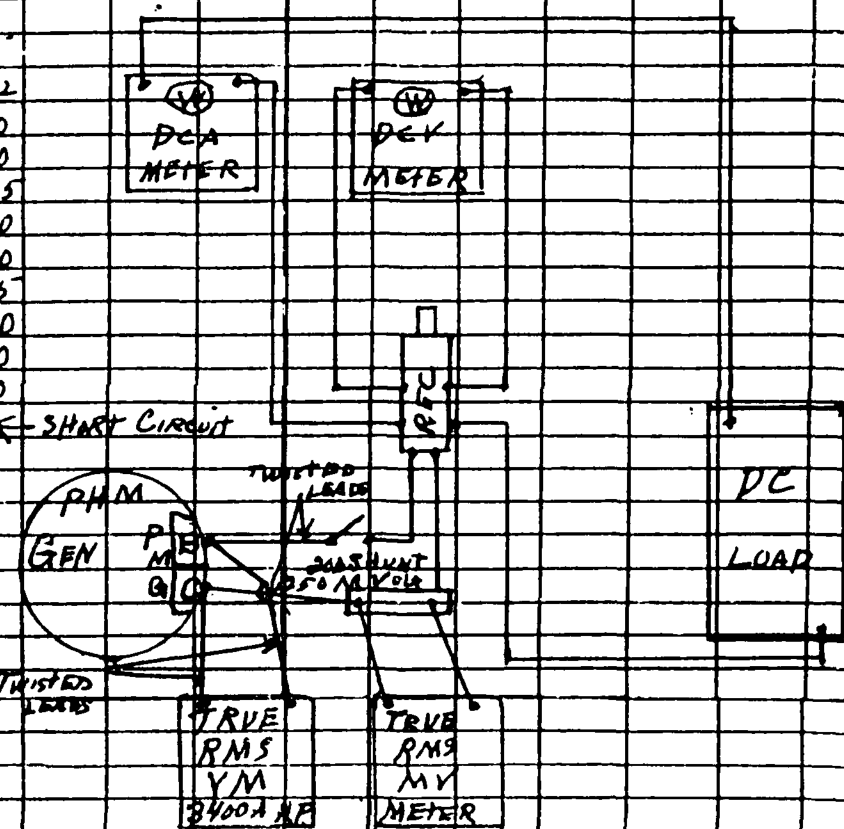
STOP ______

TEST TITLE: VERIFICATION TEST ON GENERATOR USED A ROTATING RECTIFIER FROM STANDARD GEN.

M VOLTS ACROSS SHUNT	AC AMPS	PM Ø VOLTS	DC AMPS	DC VOLTS
[illegible]	.064	98	0	141
.018	1.44	100	.93	85
.027	2.17	100	1.59	83.2
.047	3.77	96.5	3.05	79.0
.058	4.65	94	3.87	76.0
.071	5.70	91	4.7	73.5
.0915	7.34	84	6.1	67.0
.105	8.45	78	7.08	62.0
.122	9.78	70	8.35	54.5
.149	11.96	57	9.95	34.0
.155	12.44	36	12.0	27.0
.18	14.45	26.5	12.8	19.0
[illegible]	16.45	5.5	14.2	.16 ← SHORT CIRCUIT

TRUE RMS M VOLT METER S/N 628-03458
3400A RMS HEWETT PACKARD
TRUE RMS VOLT METER S/N 714-07768
3400A RMS HEWETT PACKARD
WESTINGHOUSE DC AMP METER
S/N 2653473
WESTINGHOUSE DC VOLT METER
S/N 2637063
20 AMP SHUNT 250 M VOLT S/N 3
CALB 10 AMP = .1246

$\frac{10A}{.1246} = \frac{X}{.215}$



Prev. Test Page: AA12156 | Date: 3-16-74 | Engineer: W. HYVARINEN | Signed: COOVER + DEVIER

AED 1714 Eng.

WES[illegible]NGHOUSE ELECTRIC CORPORATION, AEROSPACE ELEC[illegible]CAL DIV., LIMA, OHIO AA 12159

AP[illegible]US: 250KVA PHM GENERATOR ; P/N 977J031-1 ; S/N 0U

TEST LETTER: G3-033 ; PARA. NO: 9 (a) CHARGE: A7G-5J-LY20281

CUSTOMER: BOEING (PHM)

CLOCK HOURS-START ______

STOP ______

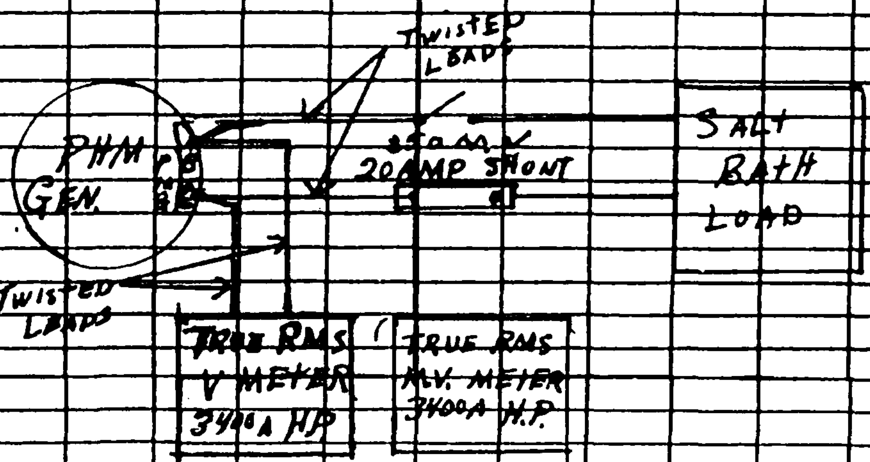
TEST TITLE: VERIFICATION TEST ON GENERATOR

M. VOLTS ACROSS SHUNT	AC AMPS	PMG VOLTS
0	0	98.3
.27	2.17	96.7
.06	4.82	92.5
.09	7.22	86.9
.12	9.63	78.0
.15	12.04	65.5
.18	14.45	47.0
.215	17.26	2.18 ← SHORT CIRCUIT

RMS MVOLT METER S/N 528-03458
3400A RMS HEWETT PACKARD
20 AMP SHUNT 250 M.VOLTS S/N 3

CALB. 10AMP = .1246

PMG VOLT METER S/N 714-07708
3400A RMS HEWETT PACKARD
E PUT METER " " MODEL 224



Prev. Test Page: AA 12158 | Date: 3-16-74 | Engineer: W. HYVARINEN | Signed: COOVER & DEVIER

AED 1714 Eng.

APPENDIX A

TEST LETTER G3-033

SM 11-63 LPLCO

SPECIFICATIONS FOR LABORATORY TEST NO. G3-033

☐ Dept. 81. (Engr. to send all four copies to lab.) Lab. adds cost and schedule and returns 2 copies to:

☐ ________Engr. Dept.—Eng. Dept. clerk distributes:

☐ 1 copy to Section File ☐ 1 copy to Engr. Mgr.

FILE—Del. Fol. Section after above is crossed out.

APPARATUS: 250 KVA PHM GENERATOR

OBJECT: VERIFICATION TESTS ON GENERATOR

REFERENCE: Customer Spec: Boeing 312-80178 Revision C

SE 40720

Scheduled SE/PE 40819 Priority ______

Trouble Docket or Development Project No. ______

Sample LY 20287 Charge A7G-5()-LY20281

Test LY ______ Eng. Test ______

Hours ______ $ ______ Start ______ Cpt. ______

Frame/Type ______ Rotation ______ (End opposite shaft)

P/N 977J031-1 G. O. ______

Customer Boeing (PHM)

Style 77031-01 Section Power Dynamics

OUTLINE ______ Line Wiring Diag. ______ Diag. WAF ______ AC DC ______ Wd.

RATING 250 KW KVA 260/ph. V 320 A 8000 rated rpm. 10500 max. rpm. 3 Ph. 400 Cy.

Res. ___°C Arm ______ Main Shunt ______ Aux. Series ______ Comp. ______ I.P. ______ Total Coil ______ Check and record all res. (After running in brushes.)

Excitation ___V ______A. Brush Setting ______

Winding On Neutral ______ CW. bars CCW. ______ Comm. bars. Brake tests at fld. temp. ______°C. Ground test 60 cy., 1 sec. ______ V.

Brushes No. ___ Grade ______ Size ______ lg. ______ w. ______ tk. Dwg. ______ Ounces pressure ______

Ventilation: Self Forced Open Encl. ______ CFM. ______ inches water Dia. tube ______ Special Enclosure ______

Capacitor: ______ mfds. S No. ______ Thermoguard Spencer No. ______ Switch Op. Speed ______

Comm. test is/is not to be approved prior to curve test. Govt. witness test: USAF ______ USN ______ None ______

Test Specs. 857246 (Acceptance) Other test letters, on same unit or set-up ______

Record Data on Forms ______ Plot Curves ______ Check Weight ______

DISPOSITION AFTER TEST: ______

INSTRUCTIONS and PROCEDURE: (Engineer to requisition all associated apparatus listed below. Laboratory to provide all test equipment required to perform tests.)

SEE ATTACHED

Signed W J Shilling Engineer—Date 7.26.73 Test No. G3-033

Approved A E [illegible] Section Manager L ______ Sub. ______

Sheet 1, 10 Sheets

TABLE OF CONTENTS

A. COORDINATION WITH QUALIFICATION TESTS

This test letter is written to assure that critical verification tests will be run on the generator to assure acceptance of the generator design by design engineering.

It is the intent to coordinate requirements of this test letter with the qualification tests.

B. TEST SYMBOLS, THERMOCOUPLES, AND SYMBOLS

1. Basic Symbols

For Basic symbols see T.S. 857246

2. Slip Rings and Thermocouples

Most verification tests will require Slip Rings and Thermocouples.

Place thermocouples as follows:

Main AC Winding - Slot 2" from drive end	#1
Main AC Winding - Slot 2" from drive end	#2
Main AC Winding - Slot 3" from drive end	#3
Main AC Winding - Slot 3" from drive end	#4
Main AC Winding - Top Drive End	#5
Main AC Winding - Top Drive End	#6
Frame (Top over Middle of Stack)	#7
Ambient, AT	#8
Air In Temperature, AIT (Three)	#9, #10, #11
Air Out Temperature, AOT (Three)	#12, #13, #14

3. Special Metering

3.1 Use Slip Rings to determine Alternator Field Amps AFA

3.2 Alternator Field Volts AFV

Rotating Field Temperature

The rotating field average temperature may be determined by:

$$R_{Hot} = \frac{\text{AFV - Brush Drop}}{\text{AFA}}$$

R_{25} = Field Resistance, 25^{o}C

RFT = Rotating Field Avg. Temperature ^{o}C =

$$\left(\frac{R_{Hot}}{R_{25}} \times 259\right) - (234)$$

3.3 Rotating Diode Spike Volts RDSV

(Oscilloscope required for AVF)

3.4 Air Flow CFM

C. TEST CONDITIONS

Unless otherwise specified the following test condition shall be held.

1. Ambient 20C to 50C (68F to 112F)
2. Balanced Current Loading $\pm$ 1%
3. Generator Term. Volts, TV_{LN} = 260 (450 V_{LL})

4. LA = 320

5. P.F. = .80 lag

6. Frequency = 400 Hz

D. TEMPERATURE LIMITS

The following are temperature limits unless otherwise indicated by the engineer. (These temperatures are considered safe for short time operation. For life consideration engineer will analyze actual temperature versus time versus location situation.)

	Cont. Loads	Short Time (5 minutes or less)
AC Windings	280°C	400°C
Rotating Field	280°C	400°C
Exciter Field	240°C	300°C

E. RATING

Generator rating is as follows.

	P.F.	380/420 Hz	Time	Regulation
Full Load Current	.8	320	Continuous	
Nominal KVA, F. L.		250	Continuous	
Full Load Voltage (L-L)		$450V_{LL}$		± 1%
Air In		60°C Max		
200% Overload Amps	.8	640*	50 Seconds	± 3%
200% Overload KVA Nom.	.8	500*	50 Seconds	
Min. Short Cct. Current		930 Amps	16 Seconds	
Short Cct. Current Limit		1250 Amps	16 Seconds	
125% Overload	.8	400 Amps	10 Minutes	
150% Overload	.8	480 Amps	2 Minutes	

* 400 Hz minimum

F. FAILURE REPORTING

Should any major failure occur, notify engineer at once. Record in Test Data Sheets the nature of failure. After the generator has been repaired, acceptance test generator per test spec. Record successful completion of Acceptance Test in Test Data Sheets.

G. TESTS

1. Acceptance Test and Resistances

Before running verification tests use a generator that has passed acceptance test spec. Also measure and record resistances of all accessible windings of generators.

2. Efficiency and Temperature Tests (Regulator Recommended)

Reference: Customer Specification 312-80173, paragraphs 4.3.4.1.2.7, 4.3.4.2.2.1.3, 4.3.4.1.2.6

2.1 Full Load

Run Generator at 250 KVA, .8 P.F. lag, 260/450 volts, 320 LA, 400 Hz, room temperature ambient.

2.1.1 Read and Record at 3 minutes: All thermocouples, TV_{LL} (all 3 phases), LA, HZ, LW (watts), EFV, EFA, AIT, AOT, CFM, TORK (for efficiency), AFV, AFA, RFT, (Rotating Field Temperature), RDSV, AT, TIME (Minutes).

2.1.2 Repeat 2.1.1 at 10 minutes.

2.1.3 Repeat 2.1.1 except run two hours. LIMITS: 89% efficiency minimum.

2.2 Overload - 125%

Repeat test 2.1 except run at full load one hour then apply on additional 25% load (paragraph E above) and for only 10 minutes. Record full load and overload readings.

2.3 Overload - 150%

Repeat test 2.2 except 150% overload rating (paragraph E above) and 2 minutes. (It is not necessary to hold full load another hour prior to overload if stabilized temperatures have been attained at full load.)

2.4 Overload - 200%

Repeat test 2.2 except at 200% rating (paragraph E above) and for only 50 seconds. (Only the maximum reading thermocouples need be read instead of all TC's.)

2.5 Efficiency at Half Load

Also determine efficiency at half load.

3. Short Circuit Test

Paragraph 3.1 is a system test which will require a regulator, control panel, transformers, etc. to give "current limiting" operation.

3.1 Three Phase Short

Run at full load until temperatures appear stabilized, then apply a three phase short at the generator terminals for 16 seconds and release.

Record at 16 seconds: Maximum reading thermocouple, TV_{LL} (voltage across short), LA, HZ, EFV, EFA, AIT, AFV, AFA, RFT, RDSV (on application, steady state, and removal), TIME.

To get worse RDSV it will be necessary to repeat short application and removal but in this case it is not necessary to stabilize at full load nor is it necessary to hold the short 16 seconds.

3.2 L-L Short

Repeat paragraph 3.1 except separately excite to give 1250 amps L-L short. Record all L-L and L-N terminal volts (six readings). Also disregard RDSV volts measurement.

4. Machine Constants (X'_d, X''_d, T'_d, T''_d, T'_a)

Run short circuit oscillogram per T. S. 553114 paragraph 1.13.1 (approximately three times).

Only one phase trace is desired per oscillogram in order to properly analyze the trace. Make sure that all of first 10 or so peaks are seen.

Record: Oscillogram, RPM, HZ, AIT, AFV, AFA, RFT, RDSV, EFA, Maximum AC Stator Winding Thermocouple, LA (Sustained).

Note that RFT is required to determine effect of temperature on time constants.

5. Transient

Apply and remove 200 KVA, .4 P.F. load. Record on oscillogram: GTVLL, LA, EFA, EFV.

Also record at 200 KVA, Meter Readings: GTVLL, LA, HZ, LW (Watts), EFV, EFA, AIT, AFV, AFA, RFT, AT.

Limit: Maximum voltage deviation = 81 volts , L-L

6. Waveform

Record all L-L and L-N voltages (measured as % of fundamental) for all harmonics, including even, through 21st and any noticeable harmonic above 21st. Also record peak to peak and rms voltages. Record GTV, PF, LA, FREQ, EFA, AIT, HZ, and one polaroid of no load volts L-L.

a. Run test at no load.

b. Repeat test at half load and full load 1.0 PF.

c. Repeat test at half load and full load .8 PF lag.

7. SAT CURVES AND CORE LOSS

a. No Load and Core Loss

Run a no load sat curve to approximately 70 AFA. Above 50 AFA take readings quickly. Run at 400 Hz.

Read and Record: TV_{LN}, LA (zero for no load), HZ, RPM, LW (watts - zero for no load), AFA, AFV, TORK, AIT.

b. Friction and Windage

Repeat (a) at EFA = 0.

c. Repeat (a) at LA = 320, .8 PF. TORK reading no required.

d. Repeat (a) at LA = 640 amps, .8 PF. Take all readings quickly. TORK reading not required.

8. Weight, C. G., and Rotor Moment

a. Weigh Generator

b. Determine Center of Gravity

c. Determine rotor moment of inertia.

9. P. M. Generator Load Characteristics

a. AC Characteristic

Load P. M. into a resistive load and determine AC volts (PMACV) versus AC amps (PMACA) at 8000 rpm from no load to short circuit. Above 4 amps take readings quickly.

b. Repeat test A except rectify output of generator and use resistance DC load. Determine DC volts versus amps characteristic (PMDCV vs. PMDCA).