(2)

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HIGH TEMPERATURE VSCF GENERATOR SYSTEM

Westinghouse Electric Corp
P.O. Box 989
Lima, OH 45802

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

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High temperature VSCF generator

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The high temperature VSCF generator program was designed to develop a generating system capable of withstanding constantly high oil-in temperatures of 200°C in an ambient environment of 200°C. This is a requirement due to anticipated new fighter aircraft designs that will not be capable of cooling the oil to 100°C as in today's designs due to size restrictions of the heat exchanger and/or extended operation of the aircraft at supersonic speeds. The generator uses composite material to withstand the constant use of 200°C inlet oil.

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1.0 Program Overview

1.1 Introduction

The High Temperature Variable Speed Constant Frequency (VSCF) Program is a program designed to develop a generating system that can withstand high oil-in temperatures of 200°C. This is required because of anticipated new fighter aircraft designs that will not be capable of cooling the oil to 100°C as in today's designs. The forecasted increase in power levels required for future aircraft will produce ambient temperatures for components/sub-systems and a lower heat sink temperature available for cooling. The program was originally established to be performed in a series of seven phases beginning with a conceptual design and analysis. The second phase required a high temperature component and subsystem design. This phase included the detailed design and drawings for the generator. Phase III was the actual fabrication of the high temperature generator. Phase IV was to include generator testing. Phase V was to include design of a high temperature converter and breadboard generator control unit. Phase VI was the fabrication of these devices. Phase VII required the testing of the complete system. The original contract for the program called for delivery of the high temperature generator, high temperature converter, breadboard generator control unit, line contactor, current transformer package, and all interconnecting cables and connectors. Due to budgetary constraints, the program was canceled at the end of Phase III, Generator Fabrication. The only hardware to be delivered is the high temperature generator. The purpose of this final report is to tell of the findings discovered throughout the program.

1.2 Contractual Requirements

The High Temperature VSCF Program officially began on September 16, 1985 with the receipt of the official contract. The program was to be an exploratory development effort to design, develop, and test a high temperature VSCF generator system used in conjunction with 400 Hz aircraft power systems. The primary program objective was to demonstrate a high temperature, high efficiency, high reliability VSCF generator system for high performance, supersonic persistence aircraft. The generator was required to be of a brass board design intended for laboratory use only.

The program was to be performed in seven distinct phases:

- Phase I - Conceptual Design and Analysis
- Phase II - High Temperature Component and Subsystem Design
- Phase III - High Temperature Component and Subsystem Fabrication
- Phase IV - High Temperature Component Test and Subsystem Evaluation
- Phase V - High Temperature VSCF Generator Design
- Phase VI - High Temperature VSCF Generator Fabrication
- Phase VII - Generator Test and Reporting

The contract requires the fabrication and delivery of one high temperature VSCF generator system.

The high temperature VSCF generator system is rated 60 kVA, 115/200 Volt, 400 Hertz. The system's intended use was for laboratory evaluation tests. The system was required to be in general accordance with MIL-E-23001B(AS).

The original contract was modified on May 13, 1988 canceling the program at the end of Phase III, Generator Fabrication, due to budget constraints at WPAFB. The generator will be the only piece of hardware to be delivered under the contract.

1.3 Objective

The program has nine main objectives as listed in the contract. They are as follows:

1) Determine approaches to the high temperature VSCF problem.

2) Determine critical, high temperature component and subsystem technology barriers.

3) Conduct trade studies to determine the best approach to the high temperature VSCF problems.

4) Develop high temperature technology needed for the best system approach.

5) Test and evaluate high temperature component and subsystem technology.

6) Design high temperature VSCF generator.

7) Fabricate high temperature VSCF system.

8) Test and evaluate high temperature VSCF generator.

9) Reporting.

Although the program was canceled prematurely, a significant number of these objectives were met. They will be discussed more thoroughly later in this report.

Other objectives the contractor had included were manufacturability and economical performance.

1.4 Summary

The High Temperature VSCF Program has met the objectives and contract requirements for the first three phases. Several approaches to the high temperature VSCF problem have been identified. High temperature technology barriers were identified and solutions found. Design and fabrication of the generator have been completed. The following sections provide in greater detail, a description of the High Temperature VSCF Program.

1.5 Scope of Effort

The objective of this program was to design and demonstrate the capability of a variable speed constant frequency (VSCF) power generating system with the rotating generator operating in a 200°C ambient with 200°C cooling oil. The converter for the system was required to operate in a 200°C ambient with 110°C cooling oil. The remaining components such as the generator control unit would be existing hardware or breadboard units operating in the laboratory ambient.

The program was performed within the following specific phases:

- Phase I - Conceptual designs and analysis which resulted in a specific approach and recommendations for a variable speed, constant frequency power generating system with two separate fluid cooling loops.
- Phase II - Design of the high temperature components and subsystems for the 60 kVA VSCF system with 200°C cooling loop for the generator and 110°C cooling loop for the converter.
- Phase III - Fabrication of the components for the high temperature (rotating) generator and preparation of a test procedure for evaluation of these components.

2.0 Generator Design

2.1 Conceptual Designs and Analysis

2.1.1 Preferred Speed

Designs were investigated with a speed range (maximum to minimum) of 1.7:1. These point designs were capable of 90 kVA, unity power factor at minimum speed for five seconds. Input frequency of the exciter generator was limited to 1300 Hz or less at the maximum speed. A summary of the dimensions, weights, and losses of the electromagnetic components for several point designs are given in Tables 1 and 2.

Typical mechanical losses are given in Tables 3, 4, 5 and 6 over the speed range of interest and for a 26,000 rpm generator. Mechanical losses for other point designs are included in Table 2.

TABLE 1
GENERATOR DESIGN SUMMARY

	DESIGN #1 12942-22000 RPM	DESIGN #2 15294-26000 RPM	DESIGN #3 17647-30000 RPM
	12 POLE	**12 POLE**	**12 POLE**
MAIN GENERATOR			
Stator O.D.	6.250 IN	6.250 IN	6.250 IN
Rotor O.D.	5.194 IN	5.194 IN	5.194 IN
Stack Length	3.27 IN	2.770 IN	2.400 IN
TOT. EM WT.	18.351 LB	15.745 LB	13.818 LB
EXCITER GENERATOR	**6 POLE**	**6 POLE**	**4 POLE**
Stator O.D.	5.376 IN	5.376 IN	4.900 IN
Rotor O.D.	3.635 IN	3.635 IN	3.000 IN
Stack Length	0.710 IN	0.600 IN	0.78 IN
TOT. EM WT.	4.203 LB	3.759 LB	4.209 LB
PMG			
Stator O.D.	3.634 IN	3.634 IN	3.634 IN
Rotor O.D.	3.000 IN	3.000 IN	3.000 IN
Stack Length	0.485 IN	0.410 IN	0.360 IN
TOT. EM WT.	1.151 LB	0.974 LB	0.855 LB
TOTAL			
GEN. E.M. WT.	23.705 LB	20.478 LB	18.882 LB

TABLE 2

Generator Loss Design Summary

WPAFB HIGH TEMPERATURE VSCF STUDY PROGRAM-GENERATOR DESIGN SUMMARY
(GENERATOR LOSSES,WATTS)

	DESIGN #1 22000RPM		DESIGN #2 26000RPM		DESIGN #3 30000RPM	
SYSTEM LOAD KVA	60		60		60	
SYSTEM P.F.	UNITY	0.75	UNITY	0.75	UNITY	0.75
GEN. KVA	65.	49.2	65.	49.2	65.	49.2
GEN.VOLTS,L-N	117.6	125.	117.6	125.	117.6	125.
GEN.AMPS/PHASE	184.4	131.2	184.4	131.2	184.4	131.2
GEN.ROT.FLD.AMPS.	15.6	13.2	15.9	13.5	15.7	13.3
MAIN GENERATOR						
STATOR WNDG.	1642.	831.	1552.	786.	1496.	758.
STATOR CORE	977.	1056.	1030.	1112.	1154.	1247.
ROTOR WNDG.	1052.	754.	939.	672.	657.	613.
POLE FACE	33.	37.	38.	42.	40.	44.
TOTAL WATTS	3704.	2678.	3558.	2611.	3547.	2662.
EXCITER GEN.						
TOT. E.M. LOSS	250.	179.	247.	177.	199.	142.
PMG						
TOT. E.M. LOSS	200.	200.	250.	250.	300.	300.
TOTAL E.M. LOSS	4154.	3057.	4055.	3038.	4046.	3104.
STRAY	208.	153.	203.	152.	202.	155.
ROTATING DIODES	31.	26.	32.	27.	31.	27.
FRICT. & WINDAGE	1275.	1275.	1880.	1880.	2282.	2282.
OIL SPRAY	1208.	1208.	2109.	2109.	3889.	3889.
PUMP POWER/LOSS	166.	166.	186.	186.	198.	198.
TOTAL GEN.LOSS	7042.	5885.	8465.	7392.	10648.	9655.

TABLE 3

GENERATOR MECHANICAL LOSSES PROGRAM

TITLE:
HIGH TEMP GENERATOR PER LAYOUT ED 405691

BEARING AND SEAL LOSSES

INPUT:

RPMAX = 26000 (Maximum RPM [rev/min])
RPMIN = 15294 (Minimum RPM [rev/min])
WDEB = .5118 (Width of drive end bearing [in])
DEBOD = 2.1654 (Drive end bearing outer diameter [in])
DEBID = 1.1811 (Drive end bearing inner diameter [in])
VISO = 4.61E-5 (Viscosity of oil [lb-sec/ft^2])
WAEB = .5906 (Width of anti-drive end bearing [in])
AEBOD = 2.0472 (Anti-drive end bearing outer diameter [in])
AEBID = .9843 (Anti-drive end bearing inner diameter [in])
DOSF = 1.593 (Diameter of seal face [in])
SLF = 6 (Seal face load [lbs])
CDFD = .001 (Damper radial clearance around D.E. bearing [in])
CADD = .001 (Damper radial clearance around A.D.E. bearing [in])

OUTPUT:

RPM	Drive end Bearing [Watts]	Anti-drive end bearing [Watts]	Shaft seal [Watts]	D.E. damper film [Watts]	A.D.E. damper film [Watts]	Total [Watts]
15294.0	14.9	14.1	25.9	10.8	16.8	82.5
16364.6	16.6	15.7	27.8	12.4	19.2	91.7
17435.2	18.4	17.4	29.6	14.1	21.8	101.3
18505.8	20.3	19.2	31.4	15.9	24.5	111.3
19576.4	22.2	21.1	33.2	17.7	27.4	121.7
20647.0	24.2	23.0	35.0	19.7	30.5	132.5
21717.6	26.3	24.9	36.8	21.8	33.8	143.7
22788.2	28.5	27.0	38.7	24.0	37.2	155.3
23858.8	30.7	29.1	40.5	26.4	40.8	167.3
24929.4	33.0	31.2	42.3	28.8	44.5	179.8
26000.0	35.3	33.4	44.1	31.3	48.4	192.6

TABLE 4

Generator Windage Losses

TITLE:

HIGH TEMP GENERATOR PER LAYOUT ED 405691

WINDAGE LOSSES

INPUT:

DEN = .044 (Density of gas [lb/ft^3])
ROD = 5.194 (Rotor diameter [in])
VISG = 1.795E-5 (Viscosity of gas [lb/ft-sec])
MGAP = .025 (Main radial air gap [in])
MSL = 2.77 (Main stack length [in])
BRGAP = .075 (Air gap between band rings & stator windings [in])
LBRO = 2.14 (Length of band ring, outer surface, total both ends [in])
LBRI = 1.08 (Length of band ring/inner surface/total both ends [in])
EAGAP = .016 (Exciter radial air gap [in])
EOD = 3.635 (Exciter armature outer diameter [in])
LES = .6 (Length of exciter stack [in])
EBGAP = .08 (Exciter banding ring gap [in])
LEBR = 1.1 (Length of exciter banding ring, total both sides [in])
PMGAP = .016 (PM air gap [in])
PMOD = 3 (PM rotor outer diameter [in])
PMSL = .41 (PM stack length [in])
MRW = 2.597 (Maximum radius of wedge [in])
POLES = 12 (Number of poles)

OUTPUT:

Speed [rpm]	Rotor Ends [Watts]	Main air gap [Watts]	Main banding rings [Watts]	Exciter stack [Watts]	Exciter banding rings [Watts]	PM [Watts]	Pole drag [Watts]	Balance weights & screws [Watts]	Total [Watts]
15294.0	25.1	101.2	87.1	76.2	30.7	2.2	0.0	11.0	283.4
16364.6	30.4	121.6	105.0	31.4	37.0	2.6	0.0	13.4	341.5
17435.2	36.3	144.6	125.1	37.3	44.0	3.1	0.0	16.3	406.7
18505.8	43.0	170.1	147.4	43.8	51.9	3.7	0.0	19.4	479.3
19576.4	50.4	198.3	172.2	51.0	60.6	4.3	0.0	23.0	559.8
20647.0	58.6	229.4	199.5	58.9	70.1	4.9	0.0	27.0	648.5
21717.6	67.7	263.4	229.4	67.5	80.6	5.7	0.0	31.4	745.7
22788.2	77.6	300.5	262.0	76.9	92.1	6.4	0.0	36.3	851.8
23858.8	88.3	340.7	297.5	87.1	104.5	7.3	0.0	41.7	967.1
24929.4	100.0	384.2	336.0	98.1	118.0	8.2	0.0	47.5	1092.0
26000.0	112.7	431.1	377.4	109.9	132.5	9.2	0.0	53.9	1226.8

TABLE 5

Generator Churning Losses

TITLE:
    HIGH TEMP GENERATOR PER LAYOUT EM 405691

CHURNING LOSSES

INPUT:
    IDW   = 2.85 (Internal diameter of exciter winding [in])
    GAP   = .04 (Gap between stack and banding rings, both sides [in])
    ERFLAG = NO (Are electrical rings wedges exposed? [YES/NO])
    ! Ignore if NO
    IDER   = 3.84 (Inner diameter of electrical ring [in])
    ODER   = 4.34 (Outer diameter of electrical ring [in])
    GADF   = .05 (Gap between end turns and electrical ring, both sides [in])
    ! Continue
    FMAXS = .264 (Rotor oil flow at RPMAX [lb/sec])
    FMINS = .155 (Rotor oil flow at RPMIN [lb/sec])
    PFMAXS = 4.105 (Oil pumped at a speed of RPMAX [gpm])
    PFMINS = 2.414 (Oil pumped at a speed of RPMIN [gpm])
    PMAXS = 54 (Pump discharge pressure at a speed of RPMAX [psig])
    PMINS = 27.5 (Pump discharge pressure at a speed of RPMIN [psig])
    EFFP   = 34 (Pump efficiency [%])

OUTPUT:

Speed [rpm]	K.E. imparted to gas from exciter [Watts]	K.E. imparted to gas from main rotor [Watts]	Oil [Watts]	Total [Watts]	Pump [Watts]
15294.0	21.6	0.0	784.2	805.8	84.9
16364.6	26.5	0.0	960.9	987.5	99.7
17435.2	32.1	0.0	1162.5	1194.5	115.5
18505.8	38.3	0.0	1390.3	1428.7	132.5
19576.4	45.4	0.0	1646.2	1691.6	150.7
20647.0	53.2	0.0	1931.7	1985.0	170.0
21717.6	62.0	0.0	2248.4	2310.4	190.4
22788.2	71.6	0.0	2598.0	2669.6	212.0
23858.8	82.2	0.0	2982.0	3064.2	234.7
24929.4	93.7	0.0	3402.2	3495.9	258.6
26000.0	106.3	0.0	3860.1	3966.4	283.6

TABLE 6

Total Generator Mechanical Losses

TITLE:

HIGH TEMP GENERATOR PER LAYOUT ED 405691

TOTAL GENERATOR MECHANICAL LOSSES

Speed [rpm]	Bearing & seal [Watts]	Windage [Watts]	Churning [Watts]	Pump [Watts]	Speed increaser [Watts]	Total [Watts]
15294.0	82.5	283.4	805.8	84.9	0.0	1256.7
16364.6	91.7	341.5	987.5	99.7	0.0	1520.3
17435.2	101.3	406.7	1194.5	115.5	0.0	1817.9
18505.8	111.3	479.3	1428.7	132.5	0.0	2151.8
19576.4	121.7	559.8	1691.6	150.7	0.0	2523.7
20647.0	132.5	648.5	1985.0	170.0	0.0	2935.9
21717.6	143.7	745.7	2310.4	190.4	0.0	3390.2
22788.2	155.3	851.8	2669.6	212.0	0.0	3888.7
23858.8	167.3	967.1	3064.2	234.7	0.0	4433.4
24929.4	179.8	1092.0	3495.9	258.6	0.0	5026.3
26000.0	192.6	1226.8	3966.4	283.6	0.0	5669.4

The relative weights of the point designs are shown in Table 7. These weights include a penalty for the waste heat exchange of 2.857 lbs./kW of loss within the generator and an allowance for the structural weight for each design. The relative weights are graphically illustrated in Figure 1. This analysis revealed the maximum generator speed should be between 22,000 and 26,000 rpm and that a weight between 35-½ to 39 lbs. can be achieved.

2.1.2 VSCF Configurations

A trade-off study was made to determine the preferred packaging configuration for a VSCF generator system with a two loop cooling configuration. Primary assumptions for this study were:

- Weight to heat load trade-off for the low temperature cooling loop is one pound per 35 watts;
- Weight to heat load trade-off for the high temperature cooling loop is one pound per 350 watts;
- AC filter capacitor, when available, for the high temperature environment will weigh two to four times the present capacitors; these capacitors are being developed to reduce size and weight on all production programs.
- Monsanto OS-124 oil properties were used for heat transfer and fluid flow calculation.

Eleven different packaging configurations were investigated as described in Tables 8 and 9. Configuration I as illustrated in Figure 2 resulted in the lightest overall packaging configuration. The coolant heat load for the high temperature loop and the low temperature loop is given by Tables 10 and 11, respectively, for the preferred packaging configuration. Table 12 gives a projected weight breakdown for the entire high temperature VSCF generator system.

2.1.3 Oil Management System

The oil management system preferred for the VSCF is shown in Figure 3. A functional description of each of the components is given in Table 13.

2.1.4 Technical Barriers

Certain problems must be resolved before the design of a lightweight generator with a 200°C cooling loop can be accomplished. Aluminum alloy (AMS 4150) presently used for wedges in the rotor with a 120°C cooling loop does not have adequate strength at the higher temperature. These wedges are subject to a stress intensity of 20,000 psi. A metal matrix composite of aluminum reinforced with silicon carbide is an alternative material for these wedges. However, development of a technically feasible fabrication technique for a Al/SiC wedge is required.

An aluminum matrix with silicon carbide offers higher strength, higher elastic modulus, and lower coefficient of expansion when compared with alloys of aluminum. Therefore, uses of a Al/SiC composite for the rotor shaft and the stator cooling jacket is an alternative for the aluminum alloys presently used with 120°C coolant. Both of these components contact magnetic steel punchings and the relative coefficient of expansion is an important design consideration for higher temperature operation.

Use of a lower expansion and stronger composite material such as cast AZ91 mg/20V percent SiC or cast 357 Al/20V percent SiC for frames in place of the lightweight alloys presently used are alternatives. However, development of a feasible fabrication technique is required.

Presently generator use diodes in the rotating rectifier which can operate with oil cooling temperatures up to 150°C. Development of rotating rectifier assembly which uses new high temperature diodes is required. Insulating varnish is used to prevent motion of the conductors in the main stator, permanent magnet generator stator and both the stator and rotor of the exciter generator. Selection of a compatible high temperature cooling oil and varnish is required.

TABLE 7
RELATIVE WEIGHTS

Min RPM	11,764	12,941	15,294	17,647
Max RPM	20,000	22,000	26,000	30,000
Alt., Losses, Watts	6,400	6,876	8,279	10,450
Gen E.M. Wt., Lbs	25.0	23.7	20.5	18.9
Structural, Lbs.	16.0	15.3	15.0	15.1
Penalty for Heat Loss, 350 Watts/lb.	18.3	20.1	24.2	30.4
Total	59.3	59.1	59.7	64.4
Relative Wt	1.003	1.000	1.010	1.090

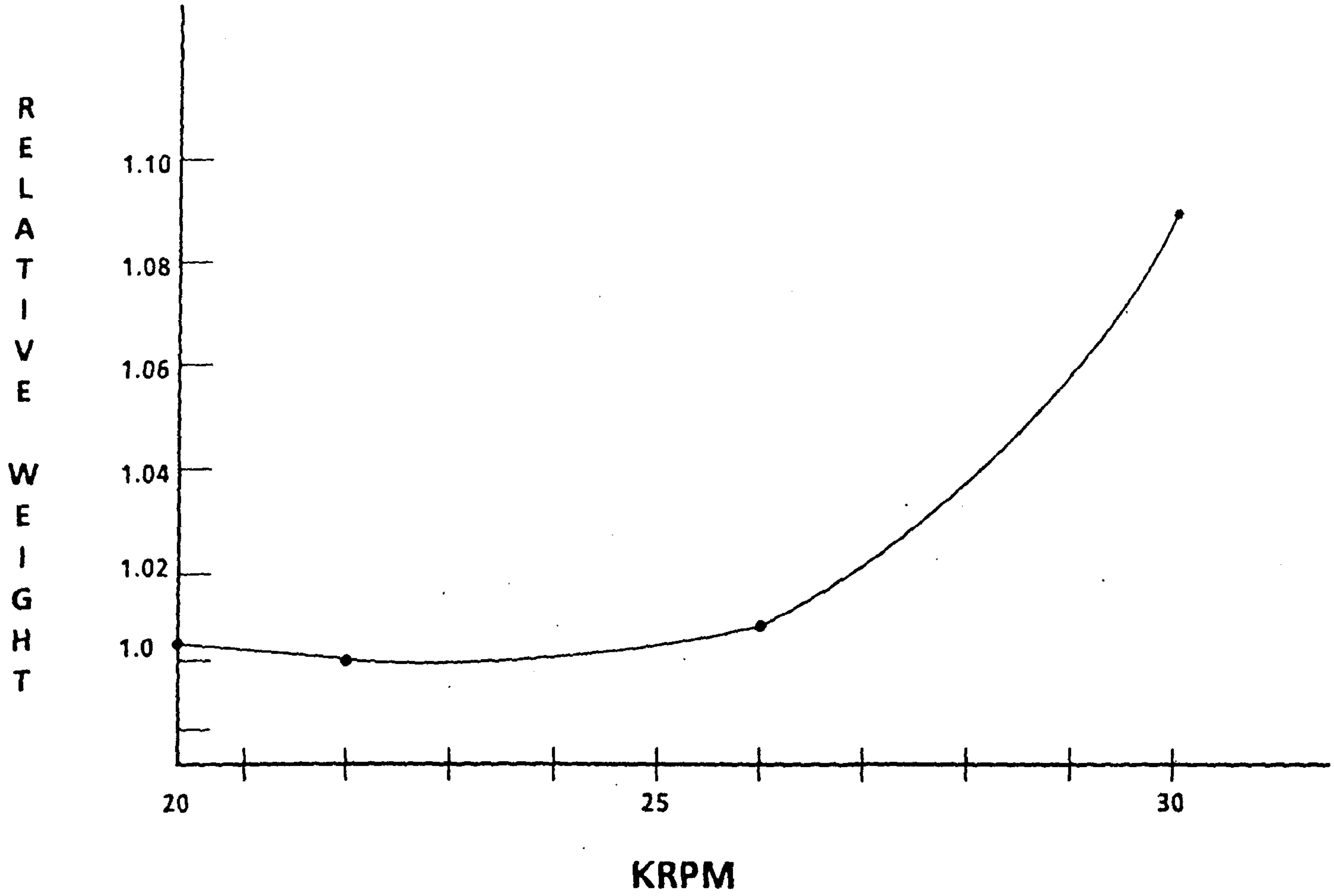
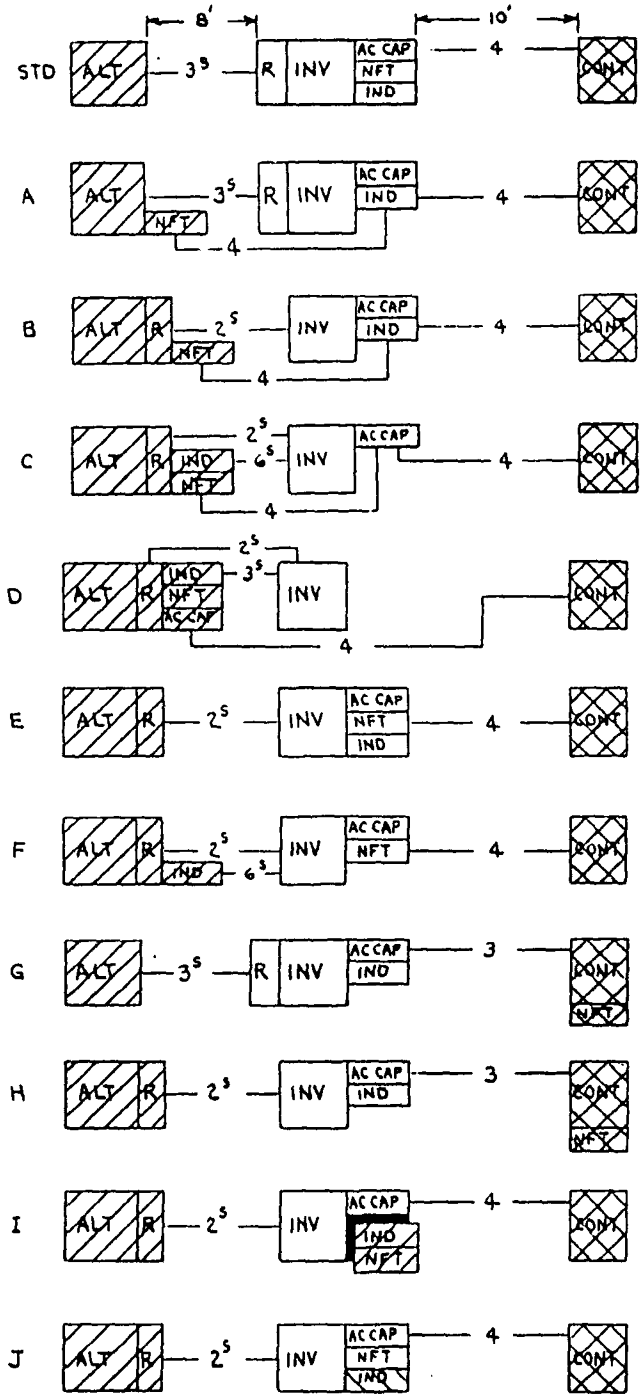


FIGURE 1
RELATIVE WEIGHT VERSUS SPEED

TABLE 8

HIGH TEMPERATURE VSCF GENERATOR SYSTEM
ALTERNATE POWER CIRCUIT CONFIGURATIONS



LOW LOSS DESIGN

THERMAL BARRIER

LOW TEMP COOLANT (110°C)

HIGH TEMP COOLANT (200°C)

NATURAL CONVECTION (200°C)

- 3^S - THREE SHIELDED CABLES

- 4 - FOUR CABLES (NO SHIELD)

Table 9

HIGH TEMPERATURE VSCF GENERATOR SYSTEM

COMPARISON OF PACKAGING VARIATIONS

	RECTIFIER WEIGHT CHANGES	INDUCTOR WEIGHT CHANGES	NFT WEIGHT CHANGE	AC CAPACITOR WEIGHT CHANGE	CABLING CHANGES BETWEEN LRU'S			TERMINAL BD WEIGHT CHANGES	OIL LINE WEIGHT CHANGES	OIL RESERVOIR WEIGHT SAVINGS	INVERTER LOSS DECREASE	EQUIVALENT WEIGHT @ 35 W/1b	GENERATOR LOSS INCREASE	EQUIVALENT WEIGHT @ 33.0 W/1b	TOTAL HARDWARE WEIGHT CHANGE	TOTAL EQUIVALENT WEIGHT CHANGES	TOTAL WEIGHT CHANGE
CONFIGURATION	LBS	LBS	LBS	LBS	NO	SIZE	LBS	LBS	LBS	LBS	WATTS	LBS	WATTS	LBS	LBS	LBS	LBS
A	---	---	3.0	---	4	8	2.1	1.0	---	(1.0)	208	(5.9)	208	0.6	5.1	(5.3)	(.2)
B	1.5	---	3.0	---	4 2dc/3ac	8 0/1	2.1 (1.2)	1.0	---	(1.0)	808	(23.1)	1106	3.2	5.4	(19.9)	(14.5)
C	1.5	1.2	3.0	---	4 2dc/3ac 8 6	8 0/1 1	2.1 (1.2) 15.7	2.5	---	(2.0)	1388	(39.7)	1658	4.8	22.8	(34.9)	(12.1)
D	1.5	1.2	3.0	10	2dc/3ac 8 3 4	0/1 1 1	(1.2) 8.2 9.6	1.5	---	(2.0)	1358	(38.8)	1718	4.9	31.8	(33.9)	(2.1)
E	1.5	---	---	---	2dc/3ac	0/1	(1.2)	---	---	---	600	(17.1)	900	2.6	.3	(14.5)	(14.2)
F	1.5	1.2	---	---	2dc/3ac 8 6	0/1 1	(1.2) 15.7	1.5	---	(1.0)	1180	(33.7)	1480	4.2	17.7	(29.5)	(11.8)
G	---	---	8.3	---	1	1	(3)	---	---	---	208	(5.9)	---	---	5.3	(5.9)	(0.6)
H	1.5	---	8.3	---	1 2dc/3ac	1 0/1	(3) (1.2)	---	---	---	808	(23)	900	2.6	5.6	(20.4)	(14.8)
I	1.5	1.2	3.0	---	2dc/3ac	0/1	(1.2)	1.0	3.8	(2.0)	1227	(35.1)	1547	4.4	7.3	(30.7)	(23.4)
J	1.5	5.5	---	---	2dc/3ac	0/1	(1.2)	---	---	---	800	(22.8)	900	2.6	5.8	(20.2)	(14.4)

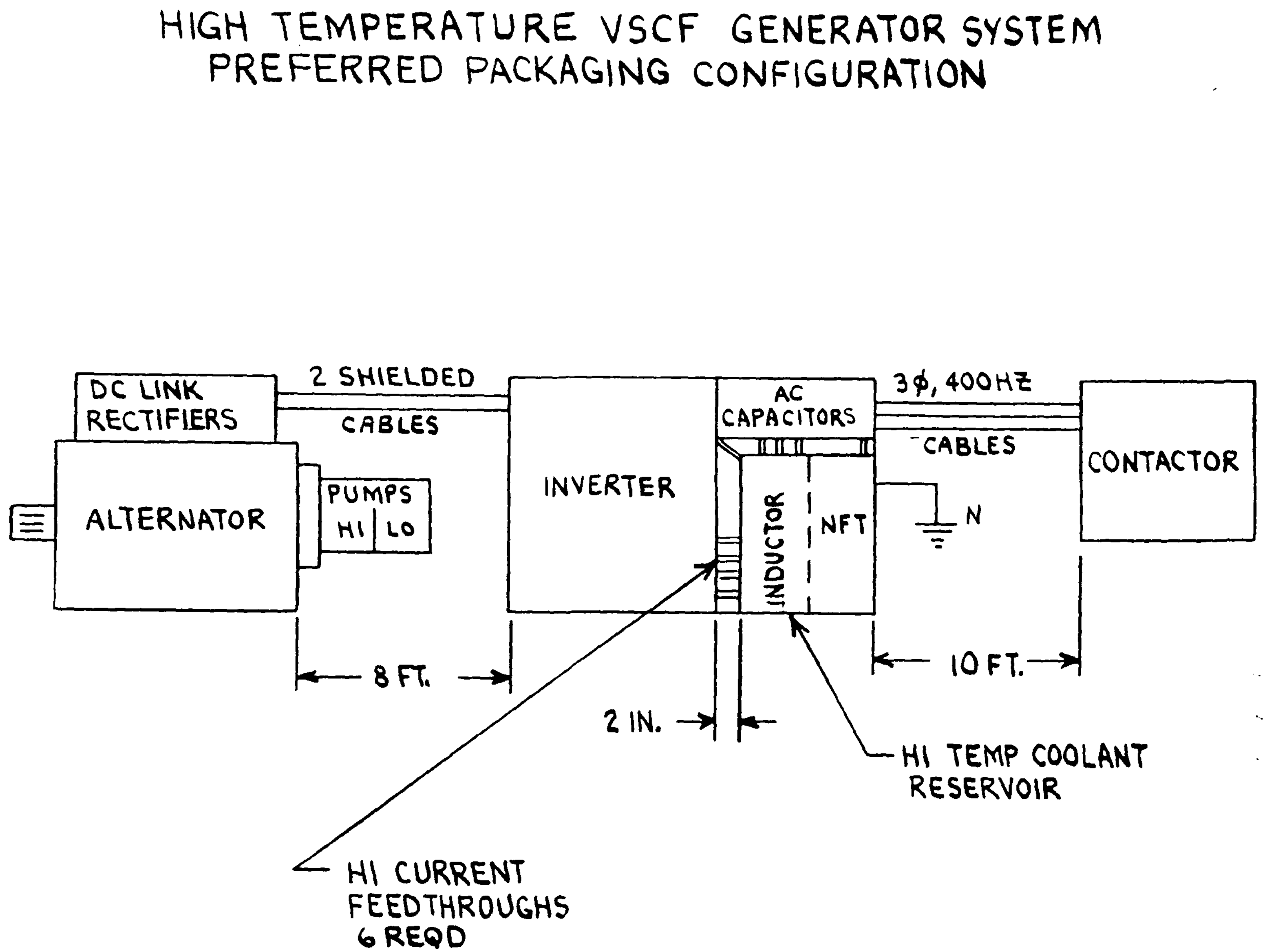


Figure 2

Preferred Packaging Configuration

TABLE 10

HIGH TEMPERATURE COOLANT HEAT LOAD FOR PREFERRED SYSTEM CONFIGURATION @ 60 KVA, 1.0 PF

	Watts	
Neutral Forming Transformer @ 1/3 Unbalance		208
Output Inductor		580
DC Link Rectifiers		900
Heat Transfer from Reservoir to Inverter		(141)
Alternator		
Stator Winding	1552	
Stator Core	1030	
Rotor Winding	939	
Pole Face	38	
Exciter Generator	247	
P/M Generator	250	
Stray	203	
Rotating Diodes	32	
Friction and Windage	1880	
Oil Spray	2109	
Total Alternator		8280
Pump Power, Hi Temp Loop		186
Total		10013

TABLE 11

LOW TEMPERATURE COOLANT HEAT LOAD FOR PREFERRED SYSTEM CONFIGURATION @ 60 KVA, 1.0 PF

	Watts	
Inverter		
Power Transistor	1200	
Commutating Diodes	144	
Base Bias Diodes	108	
Base Bias Capacitors	6	
Base Collector Diodes	18	
Collector Base Zener	6	
CCFT	144	
Sub-total		1626
Output Filter Capacitors		30
Input Filter Capacitors		15
Wiring Within the Inverter		100
Control Power		40
Heat Transfer from Reservoir via Feed Throughs		66
Heat Transfer from Reservoir via Intercasting Ribs		75
Heat Transfer from Ambient		200
I^2R of Feed Throughs to Reservoir		20
Pump Power, Low Temp Loop		200
Total		2372

TABLE 12

HIGH TEMPERATURE VSCF GENERATOR SYSTEM

WEIGHT PROJECTIONS

Generator Package		
E/M Components	23.7 Lbs	
Structures	14.4	
Rotating Rectifier	0.9	
Output Rectifier	4.4	
Pumps and Relief Valves	2.4	
		45.8 Lbs
Oil Lines and Components		
High Temp Loop	4.1	
Low Temp Loop	4.4	
Control Valves	2.2	
Filters	2.0	
		12.7
Inverter		
Bridge w/o DC Link Rect	18.7	
AC Capacitors	5.0	
AC Inductor	6.7	
Neutral Form Transformer	8.5	
Structures	9.8	
Wiring and Terminals	3.0	
		51.7
DC Power Lines	2.6	2.6
Oil Mass		
Low Temp Side	10.0	
High Temp Side	2.5	
		12.5
TOTAL FOR SYSTEM		125.3 Lbs

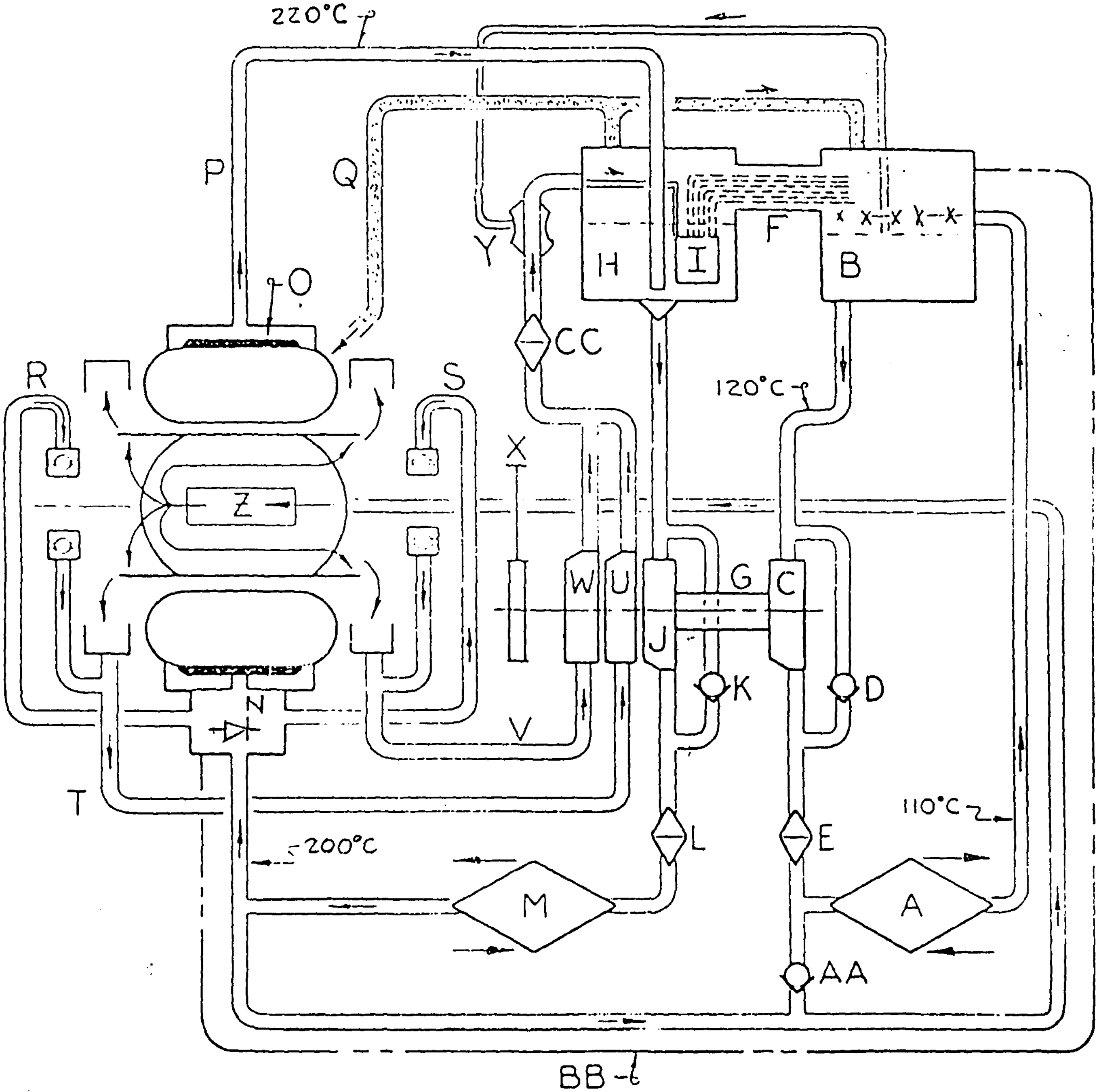


FIGURE 3

SYSTEM OIL CIRCUIT

TABLE 13

OIL MANAGEMENT SYSTEM COMPONENTS

A. Heat Exchanger for Low Temperature Loop
B. Inverter
C. Pump for Low Temperature Loop
D. Relief Valve for Cold Start-ups
E. Filter in Low Temperature Loop
F. Six Conductors, Oil Tight, Shielded Feed Through With Thermal Isolation
G. Shaft Seals and Thermal Isolation for Pumps
H. Expansion Compartment for High Temperature Loop
I. Output Inductor
J. Oil Supply Pump in High Temperature Loop
K. Relief Valve for Cold Start-ups
L. Oil Filter in High Temperature Loop
M. High Temperature Loop Heat Exchanger
N. Alternator Output Rectifier
O. Cooling Jacket Around AC Stator
P. Oil Return to Sump (Expansion Compartment)
Q. Gas Return from Expansion Compartment
R. Oil Supply for Drive End Bearing, Squeeze Film Damper, and Shaft Seal
S. Oil Supply for Anti-Drive End Bearing and Squeeze Film Damper
T. Scavenge Passage for Drive End of Alternator
U. Scavenge Pump for Drive End of Alternator
V. Scavenge Passage for Anti-Drive End of Alternator
W. Scavenge Pump for Anti-Drive End of Alternator
X. Speed Reduction Gears for Pumps
Y. Aspirator for Removal of Excess Liquid from Inverter
Z. Rotating Rectifier

AA. One-Way Flow Relief Valve Which Supplies Make-up for Leakage Through the Shaft Seal on the Pump
BB. Shielded DC Power Line from Generator to the Inverter
CC. Filter in Scavenge Pump Return

The experiments performed for selection of the cooling oil and varnish are presented in Section 3. Section 4 contains a discussion of the development of a high temperature rotating rectifier assembly for installation in the center of a shaft. Composites with a lightweight metal matrix are discussed in the following section.

2.2 High Temperature Component and Subsystem Design

A detailed design of an alternator for a 60 kVA, 0.75 lagging to unity power factory, capable of 200 percent overload for 5 seconds, was made for a VSCF system. The speed range selected for the alternator is 15,294 minimum to 26,000 rpm. A summary of data of interest for the electromagnetic components is given in Table 14. A cross-sectional view of the alternator and listing of the parts are given in Figure 4 and Table 15, respectively.

This design included an aluminum matrix composite for the shaft, rotor wedges, and stator cooling jacket sleeve.

Emphasis was placed upon the use of alloy 2124 and alloy 2014 reinforced with 20 - 25 percent by volume of particulate silicon carbide (SiC). Both powder metallurgy and cast composite systems were investigated. Figures 5 through 7 give a comparison of the tensile properties of composites with the properties of an unreinforced alloy. It can be noted from these curves that significant improvement of tensile strengths are provided by these composite systems at temperatures between 150 and 250°C. Tensile elongations of composites are considerably lower than the unreinforced alloy. However, fracture toughness data from a limited number of tests of these Al/SiC composites has demonstrated reasonable fracture toughness values (20 ksi $\sqrt{in}$) particularly at elevated temperatures where the parts operate.

An aluminum matrix reinforced with silicon carbide particulate offers a lower coefficient of expansion (CTE) when compared with the CTE of the unreinforced alloy. Figure 8 shows the reduction as a function of the volume percent of SiC. The relative expansion between the magnetic steel and its support structured material is an important design consideration.

TABLE 14
GENERATOR DESIGN SUMMARY

	15294-26000 RPM
MAIN GENERATOR	**12 POLE**
Stator O.D.	6.300 IN
Rotor O.D.	5.194 IN
Stack Length	2.820 IN
TOT. EM WT.	16.453 LB
EXCITER GENERATOR	**6 POLE**
Stator O.D.	5.587 IN
Rotor O.D.	3.635 IN
Stack Length	0.600 IN
TOT. EM WT.	4.064 LB
PMG	
Stator O.D.	3.634 IN
Rotor O.D.	3.000 IN
Stack Length	0.410 IN
Rotor Wt.	0.606 LB
TOT. EM WT.	0.974 LB
TOTAL	
GEN. E.M. WT.	21.491 LB

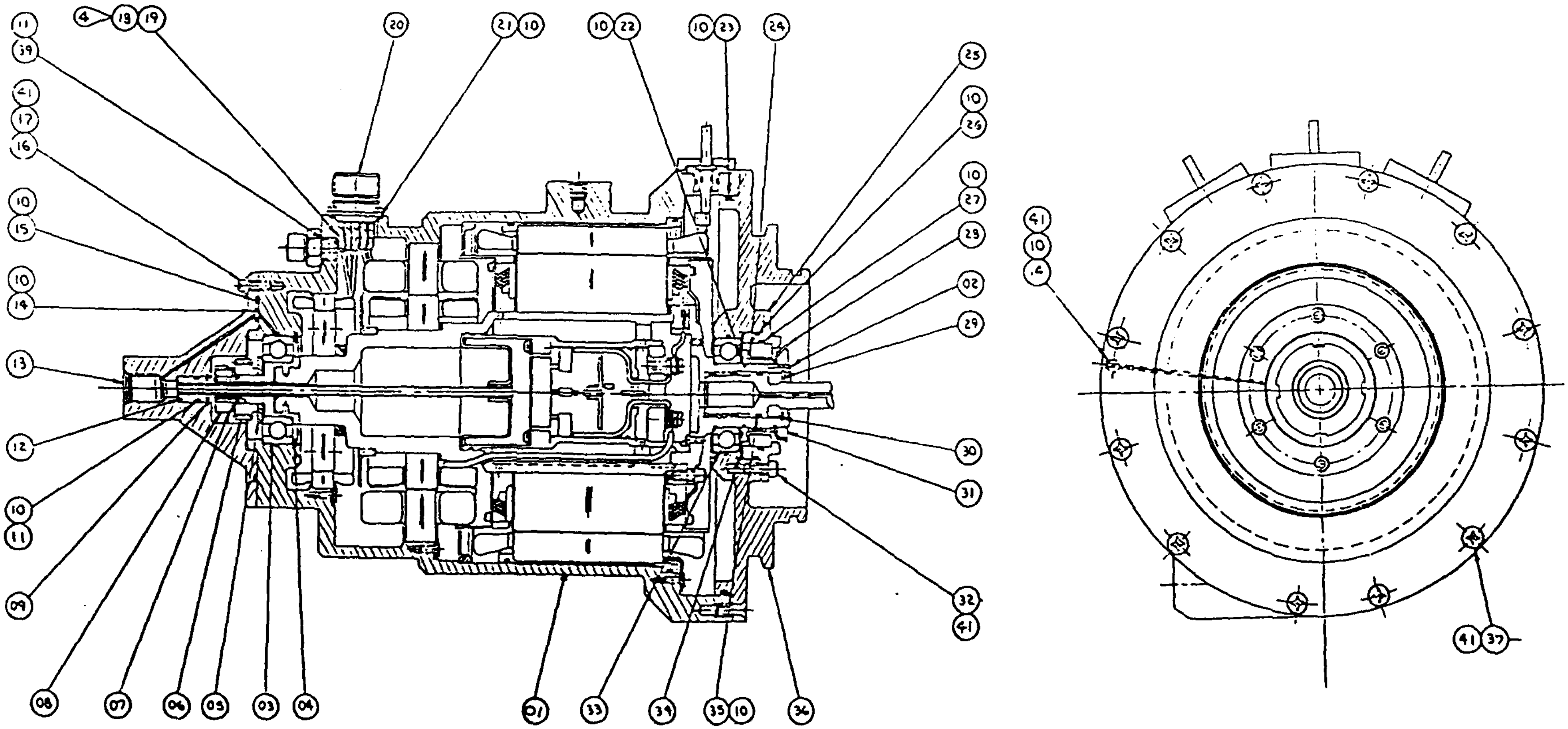


Figure 4

Generator General Assembly

TABLE 15
GENERATOR GENERAL ASSEMBLY PARTS DESCRIPTION

ITEM	NOTE	PART NAME	DEF	GOVT OR VENDOR PART NUMBER / (SIZE) REFERENCE INFORMATION	CODE IDENT NO.	MATL SIZE CODE PART NO. OR REF DWG	~~GROUP NOTE~~	PN -1
43		MARKING				83860HC		AR
42		SOLDERING		(1)		82031RB		AR
41		OIL		MIL-L-23699		53701XP01B		AR
40		SCREW, FIL HD				28B8800-52		4
39	V	PACKING				931A025-16		1
38		VALVE		D532A-4D-5				1
37		SCREW, FLT HD		MS24693-C272	96906	962C475-35		12
36		ENDBELL				ED406452-1		1
35	V	PACKING				910C886-15		1
34		SPRING				945B945-1		1
33	V	BEARING				968C645-1		1
32		SCREW, FIL HD				15C7989-31		6
31		NUT				15C8030-15		1
30		SLEEVE				953B975-1		1
29		RING		MS16627-1093	96906	967C007-2		1
28		WASHER, KEY				14C4796-15		1
27	V	PACKING				931A025-45		1
26	V	PACKING				931A025-46		1
25		HOUSING				ED406456-1		1
24	V	SEAL, FACE				967C018-1		1
23	V	PACKING				910C886-13		1
22	V	PACKING				953B270-1		1
21	V	PACKING				931A025-7		1
20		CONNECTOR				900A603-1		1
19		SLEEVING				935A312-1		5
18		TAPE, LACING		(6)		.03-.05 41372AA46X		AR
17		WASHER, FLAT		NAS620-6	80205	935A208-6		6
16		SCREW, FIL HD				28B8801-7		6
15	V	PACKING				955C165-16		1
14	V	PACKING				931A025-15		2
13		COVER				ED406454-1		1
12		TUBE ASSY				ED406466-1		1
11	V	PACKING				931A025-16		1
10		LUBRICANT		(5)		53701TM02R		AR
09		RING				18B1766-26		1
08		NUT				958C564-14		1
07		WASHER, KEY				953B974-1		1
06		PINION				968C737-1		1
05		WASHER				953B995-1		1
04		RING		MS16631-4206	96906	936A082-1		1
03		BEARING				972C777-1		1
02		ARMATURE				ED406050-1		1
01		STATOR, GEN				ED406469-1		1

DWG NO. 977J457 SH

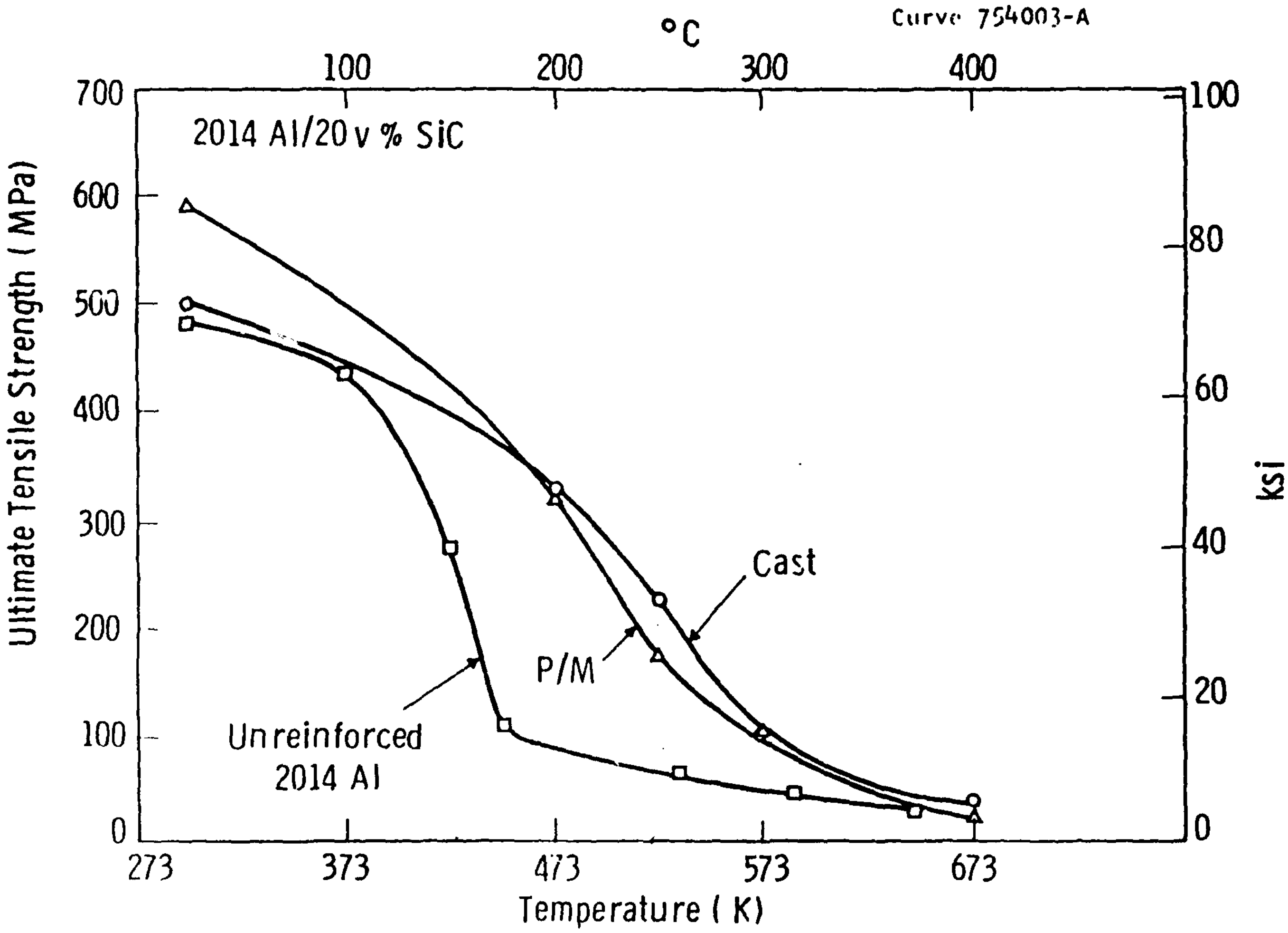


FIGURE 5
ULTIMATE TENSILE STRENGTHS OF THE POWDER METALLURGY BASED AND CAST 2014 AL/20 V PERCENT SiC COMPOSITES AND THE UNREINFORCED 2014 A1 (TAKEN FROM REF. 3) AS A FUNCTION OF TEMPERATURE

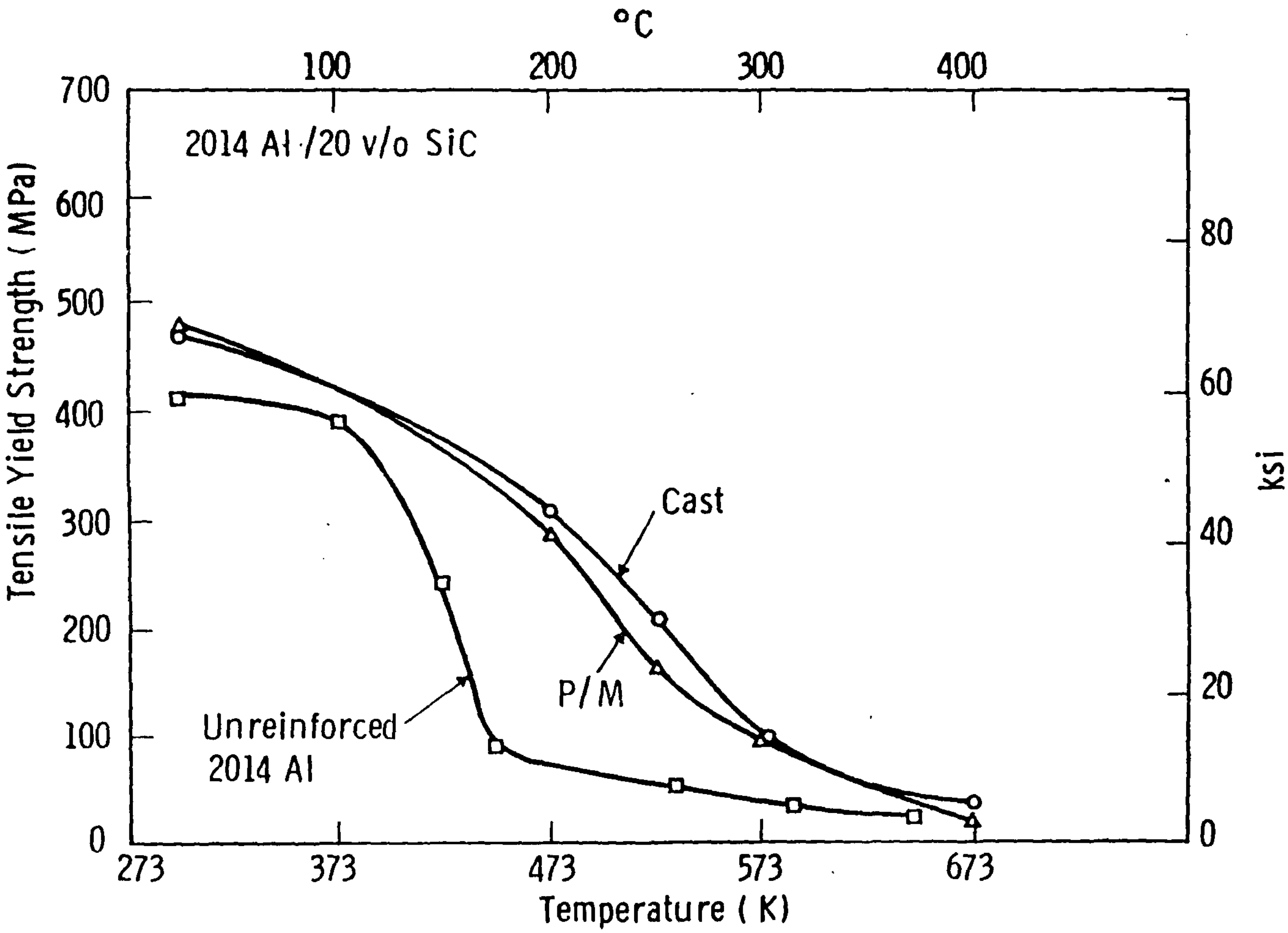


FIGURE 6
TENSILE YIELD STRENGTHS OF THE POWDER METALLURGY
BASED AND CAST 2014 A1/20 V PERCENT SiC COMPOSITES,
AND THE UNREINFORCED 2014 A1 (TAKEN FROM REF. 3) AS A FUNCTION OF TEMPERATURE

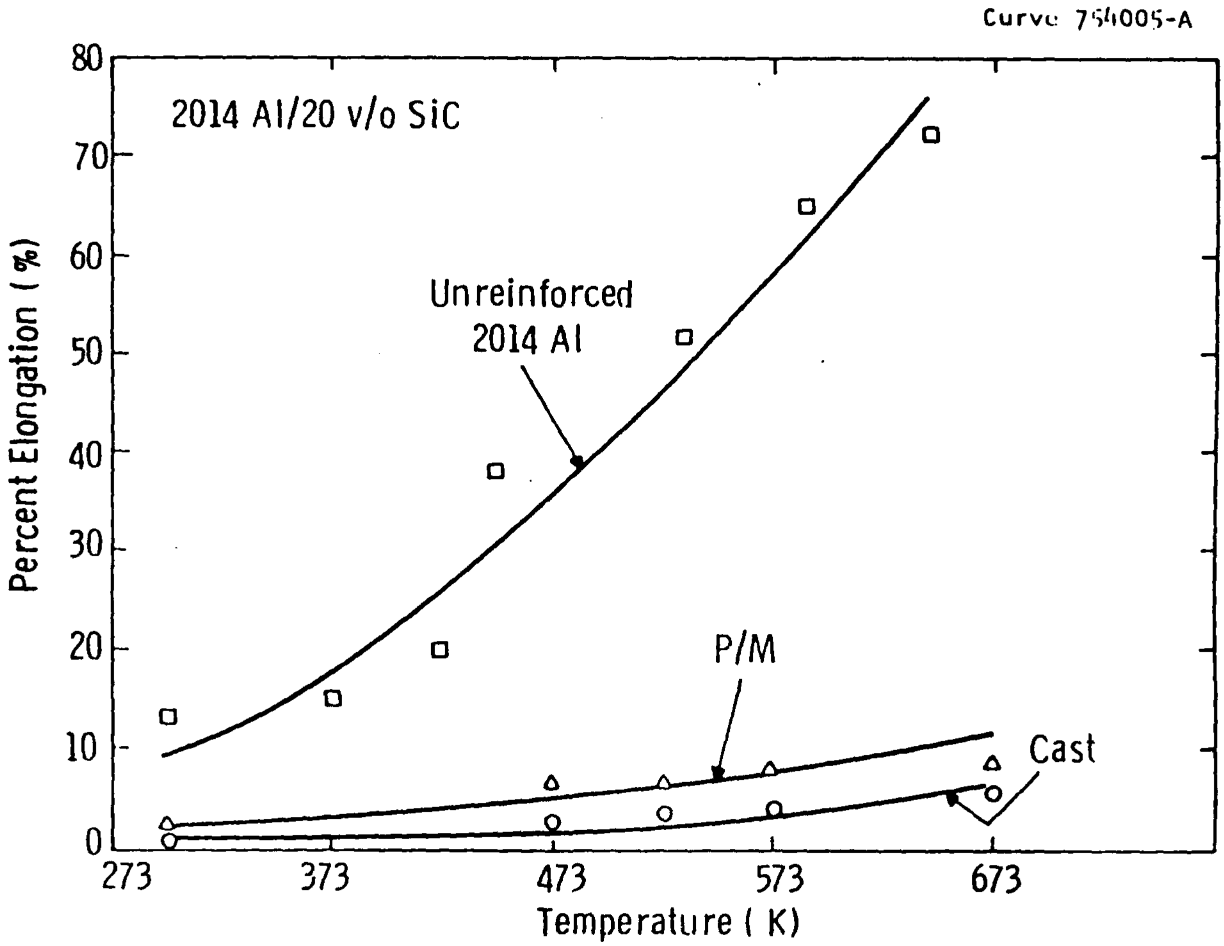
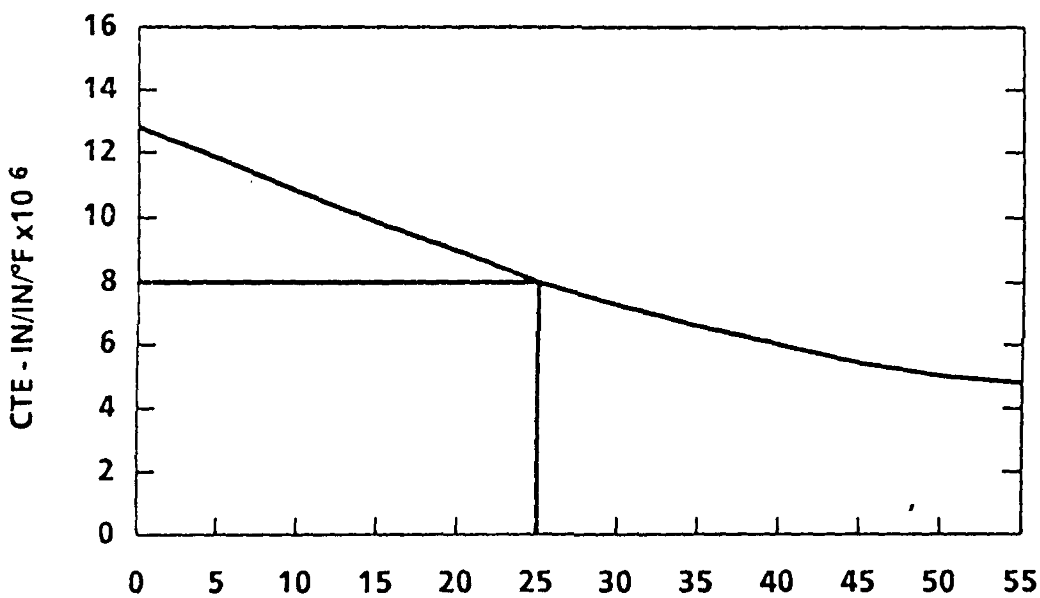


FIGURE 7
TENSILE ELONGATIONS OF THE POWDER METALLURGY BASED AND CAST 2014 Al/20 v PERCENT SiC COMPOSITES, AND THE 2014 Al (TAKEN FROM REF. 3) AS A FUNCTION OF TEMPERATURE

Magnetic steel with a CTE of 5.2 x 10^{-6} in/in/°F is successfully supported with aluminum structures with a CTE of 12.7 x 10^{-6} in/in/°F when the coolant inlet oil temperature is limited to 120°C.

An increase of coolant temperature to 200°C from 120°C means the relative expansion of the magnetic steel components and their support will increase unless a support material with a CTE of approximately 9.0 x 10^{-6} in/in/°F is used. An aluminum matrix reinforced with 25 percent by volume of SiC particulate offers this desired property.



SiC_p PERCENT BY VOLUME
FIGURE 8

REDUCTION IN CTE DUE TO INCREASE IN PARTICULATE REINFORCEMENT CONTENT

2.3 Main Generator

The main section is a 12 pole synchronous AC generator with a wound salient pole rotating field. Rotor laminations are made from high permeability, high strength iron-cobalt electrical sheet steel. The poles of the rotating field lamination are punched integral with the hub for high strength mechanical construction. The rotating field is wound using round wire with heavy build ML (DuPont TRADEMARK) enamel. Direct impingement of the oil spray on the rotor wire provides highly effective heat transfer.

2.3.1 Exciter Design

The output frequency of the exciter was limited to 1300 Hz because of rectifier loss considerations at the high operating temperatures which are imposed by the cooling oil. This design constraint limits the maximum number of poles the exciter can have. Six pole exciters were selected for the 12942-22000 RPM and 15294-26000 RPM speed ranges. A 4 pole exciter was selected for the 17647-30000 rpm speed range.

Because of rectifier design considerations, it was preferred that the rectifiers operate at lower currents and higher voltages than would normally be selected for devices operating at lower temperatures. This dictated a relatively high resistance generator field winding which was achieved by winding 39 turns of .040 inch diameter wire around each of the rotor poles. The exciter was designed to match the desired voltage and current parameters of the rectifiers and main rotating field.

2.3.2 Permanent Magnet Generator

The PMG is a three phase generator with a rotor that utilizes samarium-cobalt magnets. These magnets are capable of operating at temperatures up to 250°C. Output of the PMG provides power for generator excitation, control functions and protective functions.

2.3.3 Electrical Insulation

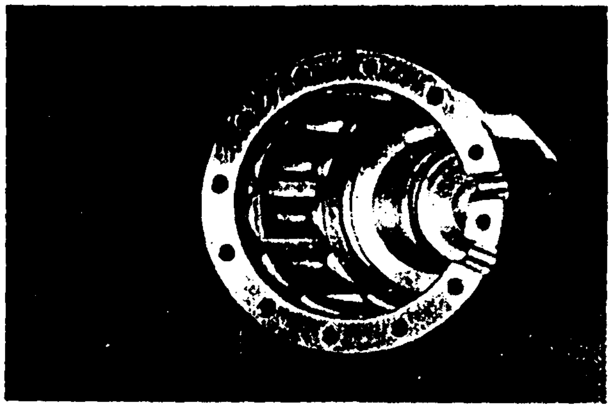
Electrical isolation from all windings to ground is provided with high temperature Kapton polyimide film insulation. Heavy build ML polyimide enamel wire insulation is used in all windings of the generator. A design criteria was established that limited the insulation hot spot temperature to 280°C based on compatibility with the properties of the high temperature oil. Winding current densities were selected on this basis.

The parts shown in Figure 9 were made from 2124 aluminum/25V percent SiC_p for the alternator shown in Figure 4. The cooling jacket (sleeve) on the main wound stator is shown in Figure 10 before the wound stator was installed in the casing. Figure 11 shows a subassembly of the rotor with the composite shaft. Figure 12 shows the wedge within the 12 pole rotor and Figure 13 is a picture of the complete alternator.

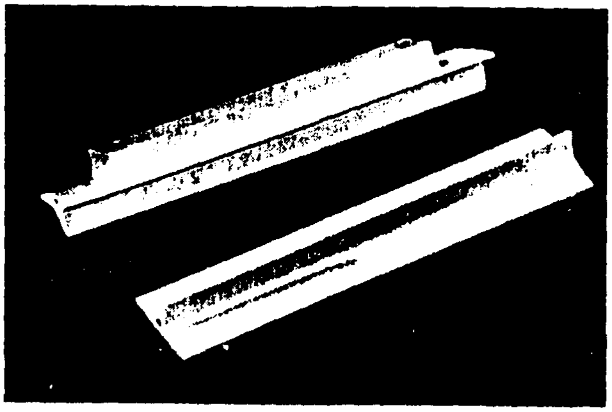
2.4 Test Procedure

The alternator was designed to accommodate a universal slip ring assembly. These slip rings are mounted on the anti-drive side of the gearbox which provides the drive pad for the alternator. A cross section of the slip ring installation is shown in Figure 14. These slip rings allow testing to be performed in two phases. The first phase consists of extraction of the three phase power from the new six pole exciter generator through three slip rings. External rectification of the excitation power is provided and the DC power would be delivered to the rotating field winding through two additional slip rings. Both a conventional rectifier assembly and the high temperature rectifier assembly can be used to convert the excitation power to DC. The second phase of tests would be conducted with the high temperature rectifier assembly installed internally. Rotating, full-load tests would be conducted at speeds up to 26,000 RPM. The test procedure for the Phase IV verification tests is presented in the Appendix.

W-ESD 2124 Al/25 v % SiC COMPOSITES



Shaft



Wedges

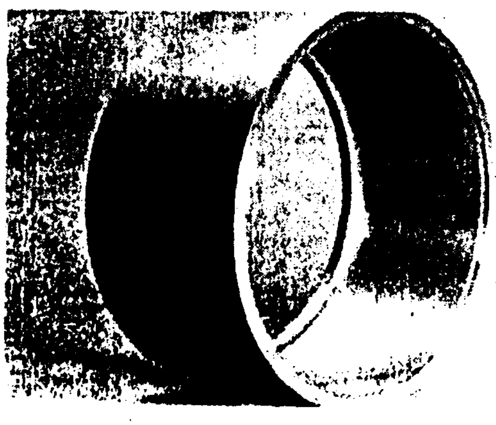


FIGURE 9
THE PICTURES OF THE SHAFT, WEDGES AND SLEEVE, PRODUCED FROM THE 2124 P/M BASED Al/25 v PERCENT SiC COMPOSITE MATERIAL

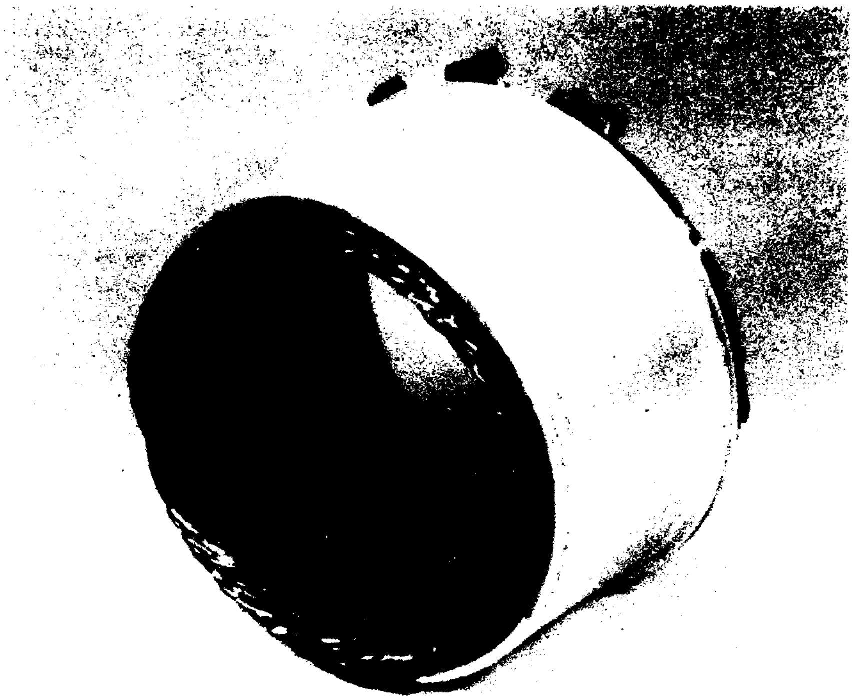


FIGURE 10
MAIN AC STATOR

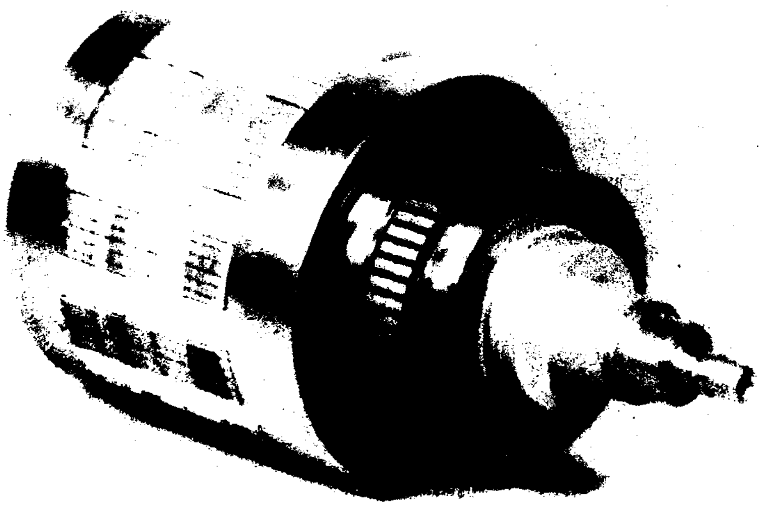


FIGURE 11
ROTOR ARMATURE

FIGURE 12
MAIN AC ROTOR

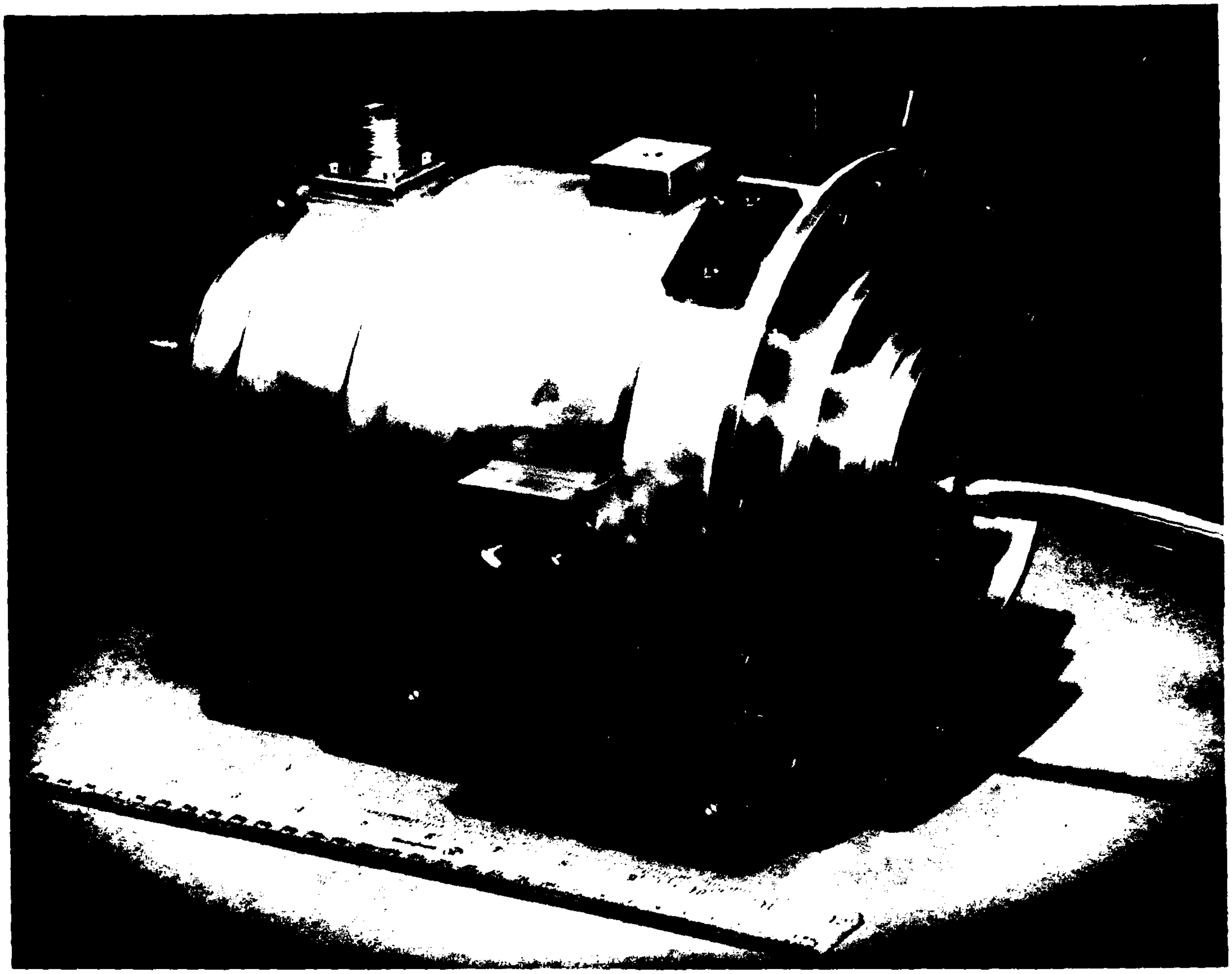


FIGURE 13
ASSEMBLED GENERATOR

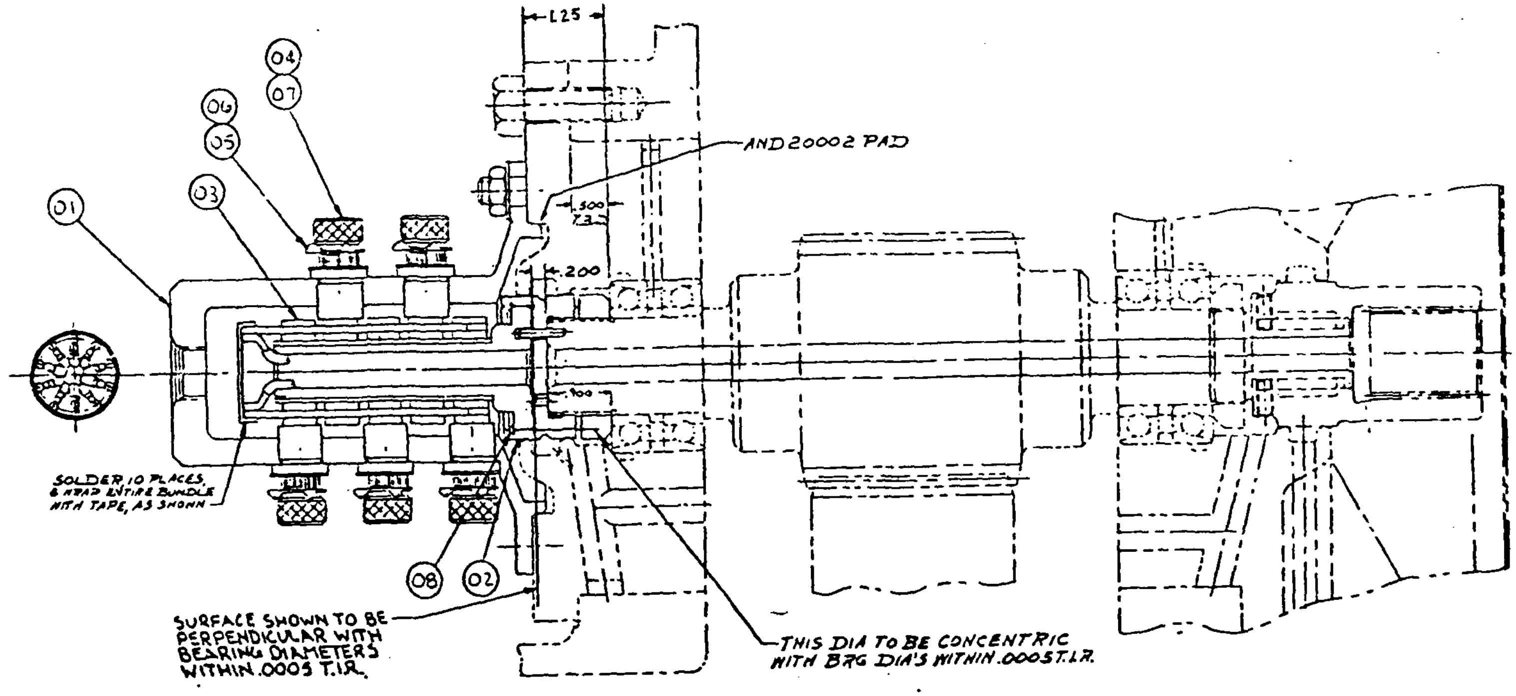


Figure 14

Slip Ring Assembly

3.0 Oil Tests

3.1 Abstract

This section describes the tests that were done to select the oil to be used during the high temperature generator tests.

Four inch long by 0.25 inch diameter helical coils of #18 gauge copper wire coated with Pyre ML enamel were subsequently treated with four candidate varnishes. Then, groups of ten coils were immersed in each of three aircraft generator coolants at 250°C under N_2. Coil samples were withdrawn after 500 and 1000 hours and tested for helical bond strength to determine the resistance of the insulation to the aircraft fluids.

This program was done at the Westinghouse R&D Center in Pittsburgh, Pennsylvania by Dr. J. Meier. The following discussion is excerpted from his report on oil testing of compatibility with the various varnishes.

3.2 Experimental Procedures

<u>Coil Preparation</u> Helical coils were prepared from double build PYRE ML copper wire of #18 gauge by coiling the wire around a 1/4 inch diameter mandrel to a length of 4 inches as shown in Figure 15. The coils were then baked for five hours at 200°C prior to coating with the respective resins. The coating procedure used follows: Approximately 20 coils were dipped sequentially into each of the four resins and withdrawn at a rate of 4 in/min. The excess resin was allowed to drip off the coils at room temperature and a curing cycle for the coated coils consisted of 1 hour at 100°C, 1 hour at 150°C and 1 hour at 200°C. After the first curing cycle the coils were cooled, dipped again in the reverse direction, drained at room temperature, and cured for 1 hour at 100°C, 1 hour at 150°C and 16 hours at 230°C. Coated coils (five with each resin) were retained as the controls and subsequently tested for bond strength. Coated coils are shown in Figure 15. The coating thickness was approximately 3 mil.

<u>Coil Aging in Hot Fluids</u> With the exception of the coated but unaged control specimens, the remainder of the coil samples (10 for each resin system) were placed in the 250°C fluids under N_2 atmosphere using test fixtures shown in Figure 16. The N_2 flow rate was controlled by a flowmeter to 0.5 standard cubic feet per minute. After 500 and 1000 hours exposure to the hot fluids, five samples were withdrawn, labeled and retained for bond strength testing. Coils were aged as described in American Society for Testing and Materials Document ASTM D3145-75, Thermal Endurance of Electrical Insulating Varnishes by the Helical Coil Method.

<u>Coil Testing</u> When all the samples had been aged under N_2 in the 250°C fluids for the required 1000 hour aging period, they were removed from the fluids and tested at 250°C in a Dillon Tester with a crosshead speed of 2 in/min. Using a standard two inch distance between coil supports, the force (lbs to break) was recorded for each coil. An average of five coils was computed for each sampling period and the average values recorded in Table 16. The test procedure described in ASTM D 2519-75, Standard Test

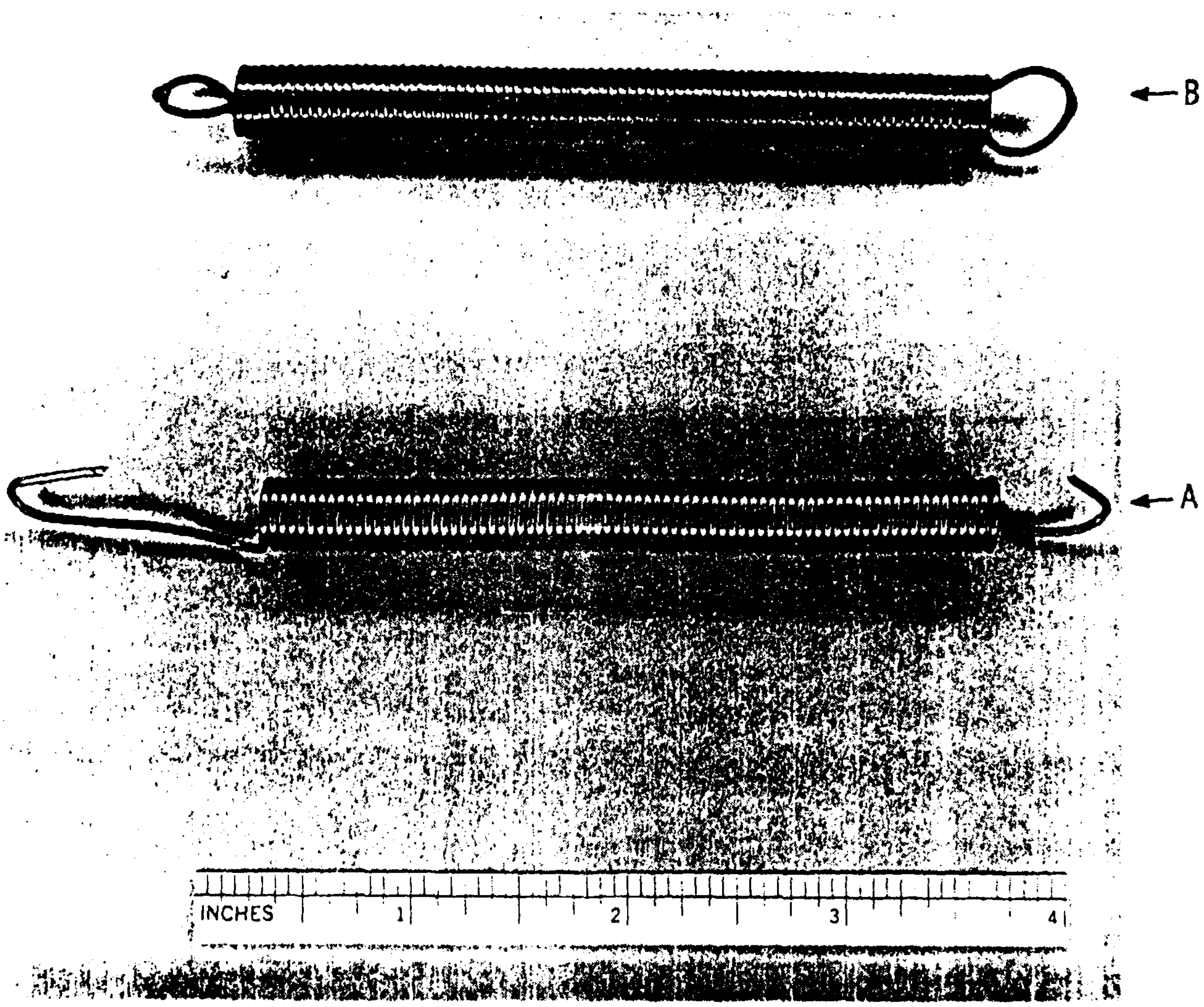


FIGURE 15
Helical coils (A) Uncoated (B) Coated and Baked

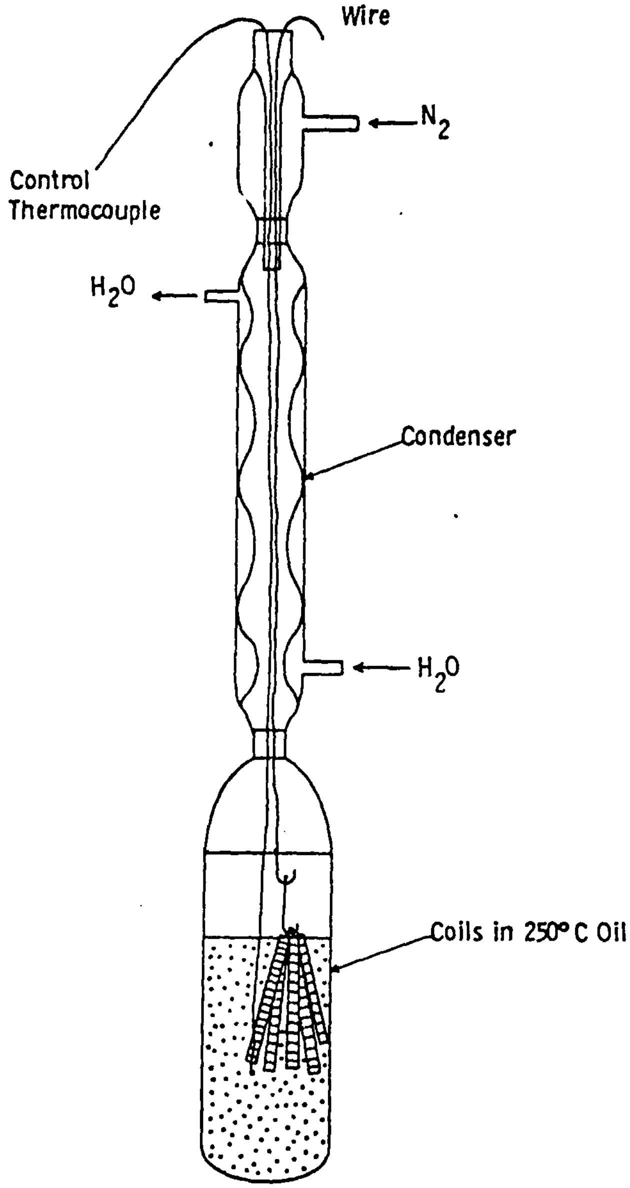


FIGURE 16
Schematic of Fluid Aging Chambers

Method for Bond Strength of Electrical Insulating Varnishes by the Helical Coil Test, was followed.

CONCLUSIONS

Based on coil bond strength values (Table 16):

- Exxon 2380 causes degradation of coil samples treated with insulation systems PDG-981, Thermid IP-600 and Thermid FA-700.
- MLO-87-53 attacks PDG-981 while the Thermid systems are largely unaffected.
- MLO-86-428 attacks Thermid FA-700 while PDG-981 and Thermid IP-600 are largely unaffected.

From acid number testing (Table 17):

- PDG-981, Thermid IP-600 and Thermid FA-700 exhibit large increases in acid number when aged in Exxon 2380.
- When aged in MLO-87-53, little change in acid number is observed (from 0.4 to 2.2 maximum).
- When aged in MLO-86-428, there is a very large increase in acid number for the Doryl resin system while the others exhibit much less increase in acid number.

Based on viscosity data (Table 18):

- The two Thermid insulation systems exhibit a fairly large increase when aged in Exxon 2380 while Doryl and PDG-981 are not as affected.
- The MLO-87-53 system exhibits only a marginal increase in acid number for coils coated with Thermid and PDG-981 and FA-700 but larger changes for Doryl and Thermid IP-600.

TABLE 16
HELICAL COIL BOND STRENGTH VALUES AT 250°C

	DORYL B-109			PDG-981			THERMID IP-600			THERMID FA-700		
	0	500 HRS	1000 HRS	0	500 HRS	1000 HRS	0	500 HRS	1000 HRS	0	500 HRS	1000 HRS
Exxon 2380[b]	3.3	13.6	10.5	18.1	0	0	18.8	16.5	11.0	20.1	4.0	5.3
MLO-87-53	3.3	14.8	13.9	18.1	11.8	1.0	18.8	21.0	20.4	20.1	14.9	16.6
MLO-86-428	3.3	16.6	14.1	18.1	25.8	29.0	18.8	18.5	19.0	20.1	13.2	10.8

a. Each value shown is the average of five separate coil values.
b. The Mil Spec equivalent of Exxon 2380 is RMR 4750.

TABLE 17
ACID NUMBER[a] AFTER 1000 HOURS AGING AT 250°C

	UNAGED CONTROL	V DORYL B-109-9	PDG 981	THERMID IP-600	THERMID FA-700
Exxon 2380	0.37[b]	5.27	18.3	26.6	23.9
MLO-87-53	0.08[b]	47.68	8.43	4.8	2.6
MLO-86-428	0.39[b]	2.13	1.68	2.24	1.8

a) Mg KOH/gm of oil
b) Baseline data supplied by USAF

TABLE 18
VISCOSITY[a] AFTER 1000 HOURS AGING AT 250°C

	UNAGED CONTROL	V DORYL B-109-9	PDG 981	THERMID IP-600	THERMID FA-700
Exxon 2380	48	61.1	53.25	95.0	80.6
MLO-87-53	70.4	93.2	84.26	100.1	80.3
MLO-86-428	34.2	36.6	31.80	36.4	20.9

a) Centipoise; all values measured at room temperature

Although the incomplete cure of the Westinghouse Doryl prior to aging results in low bond strength (Table 16), the fact that the coil strength increases from the control value of approximately 3 lbs. to approximately 14 lbs. after 500 hours aging in the three fluids demonstrates good fluid resistance and enhanced cure. This represents the real life situation in a generator where the Doryl varnish will continue to full cure at normal operating temperatures. The reduction in bond strength from 500 to 1000 hour aging averages approximately 15 percent for the three test fluids.

The relative levels of sludge in the aged fluids (Table 19) (a combination of degraded resin and oxidized or otherwise degraded oil) substantiate the identification of the best oil/resin systems.

RESULTS AND DISCUSSION

<u>Bond Strength</u> Result of the helical coils treated with four resin systems (Westinghouse Doryl 8-109-9-AB-4336, P. D. George 981, Thermid IP-600 and Thermid FA-700) and aged in the three test fluids (Exxon 2380, MLO-87-53 and MLO-86-428) for up to 1000 hours under N_2 at 250°C are given in Table 16. From Table 16, it can be seen the control value for the Doryl treated coils is quite low. However, the bond strength increases significantly after heating for 500 hours in all three fluids. This indicates that the cure cycle for the Doryl resin was not adequate and suggests that cure continued in the fluids. Doryl varnish will advance to complete cure at normal operating temperatures in a generator. Also, the data shows that the fluids attack the Doryl to various degrees. That is, the bond strength values between 500 and 1000 hours exposure show about a 30 percent reduction for Exxon 2380 fluid, approximately 7 percent reduction for MLO-87-53 and approximately 15 percent reduction for MLO-86-428.

In the case of PDG-981, the control values are quite high at approximately 18 lbs. to break indicating that the resin cure was adequate. However, RMR-4705 and MLO-87-53 degrade the resin badly. After 500 hours in the case of RMR-4705 (RMR 4705 is the Mil equivalent of Exxon 2380) and 1000 hours for MLO-87-53, the coils act more like springs. That is, the resin is swollen and extremely weak and can be wiped off the coils with finger pressure. In the case of MLO-86-428, the coil breaking strength shows approximately a 40 percent increase above the control suggesting additional resin cure is taking place during the 250°C exposure.

In addition, it should be noted that both MLO-87-53 and MLO-86-428 attacked copper as evidenced by surface erosion and also attacked the Fe/constantin thermocouple wire used to monitor fluid temperature.

In the cases of Thermid IP-600 and Thermid FA-700, the control values again show values of approximately 19 to 20 lbs. indicating well-cured oil specimens. However, the aggressive nature of Exxon 2380 toward these two resin systems is shown by the significant loss in bond strength (approximately 40 percent for the IP-600 and approximately 75 percent for the FA-700 system) after 1000 hours exposure.

Thermid IP-600 show little or no change in bond strength after 1000 hour exposure to either the MLO-87-53 or MLO-86-428. However, Thermid FA-700 shows a decrease in bond strength of approximately 25 percent after 1000 hour exposure to MLO-87-53 and exposure to MLO-86-428 results in a 50 percent decrease in bond strength after 1000 hour exposure. The use of P. D. George 981 for the generator insulation was reaffirmed by these tests.

Acid Number and Viscosity All three coolants were sampled prior to coil aging and both the acid number and viscosity were measured at room temperature. In addition, the fluids were sampled after 1000 hour aging at 250°C under N_2 and the acid number and viscosity measured at room temperature. Acid numbers were determined as described in ASTM D 974-139, Standard Test Method for Acid and Base Number by Color-Indicator Titration, by titrating oil samples (diluted with toluene) with 0.1 N methanolic KOH. The acid number is defined as mg of KOH/gm of oil. Viscosity was measured with a size 200 Cannon-Fenske Viscomer (20-80 centistoke range).

The acid number and viscosity data are shown in Tables 16 and 17, respectively. From Table 16, it can be seen that Exxon 2380 shows little change in acid number in the presence of Westinghouse Doryl while the other three resin systems exhibit increased acid number.

In the case of where the Westinghouse Doryl treated coils are aged in MLO-87-53, a large increase in acid number is observed while the other fluids are not affected to any significant degree. In the case of MLO-86-428, the acid number remains essentially invariant for all systems.

Viscosity data in Table 16 show that the Exxon 2380 fluid increases in viscosity from a control value of 48.0 to 61.0 in Westinghouse Doryl, 95.0 in Thermid IP-600 and to approximately 81 in Thermid FA-700. Fluid MLO-87-53 shows a viscosity increase from a control of 70 to approximately 93 for Westinghouse Doryl, 84 in PDG 981, 100 in Thermid IP-600 and 80 for Thermid FA-700. MLO-86-428 appears to be the most stable of the fluids tested as its viscosity does not change significantly from the control value.

It should be mentioned that the viscosity values were measured on filtered oil. That is, in some cases a sludge formed on the bottom of the glass flask. This sludge is largely due to oil degradation except in some cases where the oil insulation was seriously degraded (i.e. see Table 16 for coil strength values that are close to 0 as this indicated degradation of the coil insulation).

An estimate of the relative level of sludge in the oil is given in Table 19. This sludge is a combina'ion of degraded coil insulation and degradation products from the hot oil. No attempt was made to identify the specific origin of the sludge. However, it is safe to conclude that in cases where the coil bond strength was zero, or a very low value, the amount of sludge observed resulted from degraded coil insulation.

TABLE 19
SLUDGE CONTENT IN COOLING FLUIDS AFTER 1000 HRS AT 250°C
Under N_2

	W DORYL B-109-9	PDG 981	THERMID IP-600	THERMID FA-700
Exxon 2380	None	Large Amt	Small Amt	Small Amt
MLO-87-53	Small Amt	Small Amt	Small Amt	Small Amt
MLO-86-428	None	None	None	None

4.0 HIGH TEMPERATURE ROTATING RECTIFIER

4.1 Design

The three-phase full-wave rectifier uses six diode chips which have been selected for low reverse current leakage at 200°C and above. The limiting temperature operation of these diodes is reached when the reverse current leakage (at the normal reverse blocking voltage) is high enough to result in an increase in temperature which further increases the leakage, until a catastrophic run away condition is reached. This condition may not be reached until after several hours of operation.

Since it is necessary to limit the temperature rise of the junctions, the normal exciter winding operation was changed from 25 volts and 50 amperes to 50 volts and 25 amperes. This reduced the diode losses by at least 50 percent. Although the reverse blocking voltage was increased, it is well below the avalanche voltage. The voltage rating of the diodes for rotating rectifiers is determined more by the switching voltage at the highest current and highest frequency (fastest speed) rather than for the reverse blocking voltage. Since the current was reduced 50 percent, the switching voltage was also reduced even though the steady state DC voltage was doubled.

A glass passivated die of the same size (0.25 inch square) as normally used for 50 ampere designs was chosen. The chip is conservatively sized for 25 amperes which results in a less critical solder joint during mounting the die.

The diode chips chosen for constructing the rotating rectifier were selected for a reverse leakage current of less than 500 microamperes at 200 volts and 200°C. The leakage began to rise rapidly (exponentally) as the temperature reached 250°C. If the reverse leakage was more than five milliamperes at 250°C and 200 volts, the chip was also rejected. The avalanche voltage was greater than 600 volts on all chips.

4.2 Packaging

The mounting substrate for the diode chips is 0.062 inch thick 99.5 percent beryllium oxide. It is used for maximum heat dissipation and electrical insulation and is shown in Figure 17 (ED406068). Both sides of this circular disc are metallized and nickel plated for attachment of the heat sinks and base plate. The 0.032 thick Kovar base plate shown in Figure 18 (EDSK406061) and the two 0.020 thick molybdenum heat sinks in Figure 19 (ED406065) are brazed to the beryllia substrate to make a base subassembly as shown in Figure 20 (ED406076). Some problems of cracking of the beryllia were encountered during the cool-down from the brazing temperature. This was caused by brazing large areas of metal to each side of the beryllia. Although low expansion metals were used, they did not match the expansion rate of the beryllia. Brazing metal to one side of a ceramic is normally successful since the ceramic will bend enough to accommodate the mismatch in thermal expansion rates. When metal is brazed to both sides, it is impossible for the ceramic to bow to relieve the stress on both sides. This frequently results in small cracks developing. Cracks are not desirable (but not necessarily a cause of failure) and two changes were made to reduce the stress. The brazing material was changed to obtain a lower eutectic temperature (625°C from 780°C) and small slits were put in the Molybdenum heat sinks to reduce the strength of the metal. The reduction in the eutectic temperature of the braze material greatly reduced the stress caused by Kovar on one side and Molybdenum on the other side. The result was a satisfactory part.

The diode chips are attached to the molybdenum heat sinks with gold-germanium eutectic (345°C) for a high strength bond at high temperature. The Molybdenum heat sinks on the top of the diode chips are attached with 92.5 percent Pb, 5 percent Sn, 2.5 percent Ag solder (eutectic at 270°C). This is relatively weak solder with high compliance properties. This is necessary since if a strong solder is used on both sides of the chip (e.g., 88 percent Au, 12 percent Ge), pieces of silicon will be cleaved from the chip.

When a normal diode is used in a rotating rectifier at high speed and high temperature, it tends to fail by the die and heat sink sliding off location and shorting to the case. Since the die is held in this assembly with gold-germanium solder, this is not expected to happen. The weakest joint is on top of the die where the 92.5 percent Pb, 5 percent Sn, 2.5 percent Ag solder is used. To strengthen this joint, compression springs shown in Figure 21 (ED406099) are added. These are made from chrome vanadium steel wire and should not be adversely affected by temperatures of 250°C. They are designed to be a snug fit around the locating studs and inside the blind holes in the alumina ceramic cap. Their radial motion is thus limited and they, in turn, limit the radial motion of the heat sinks on the tops of the diode chips and contribute to the chips and heat sinks staying on location.

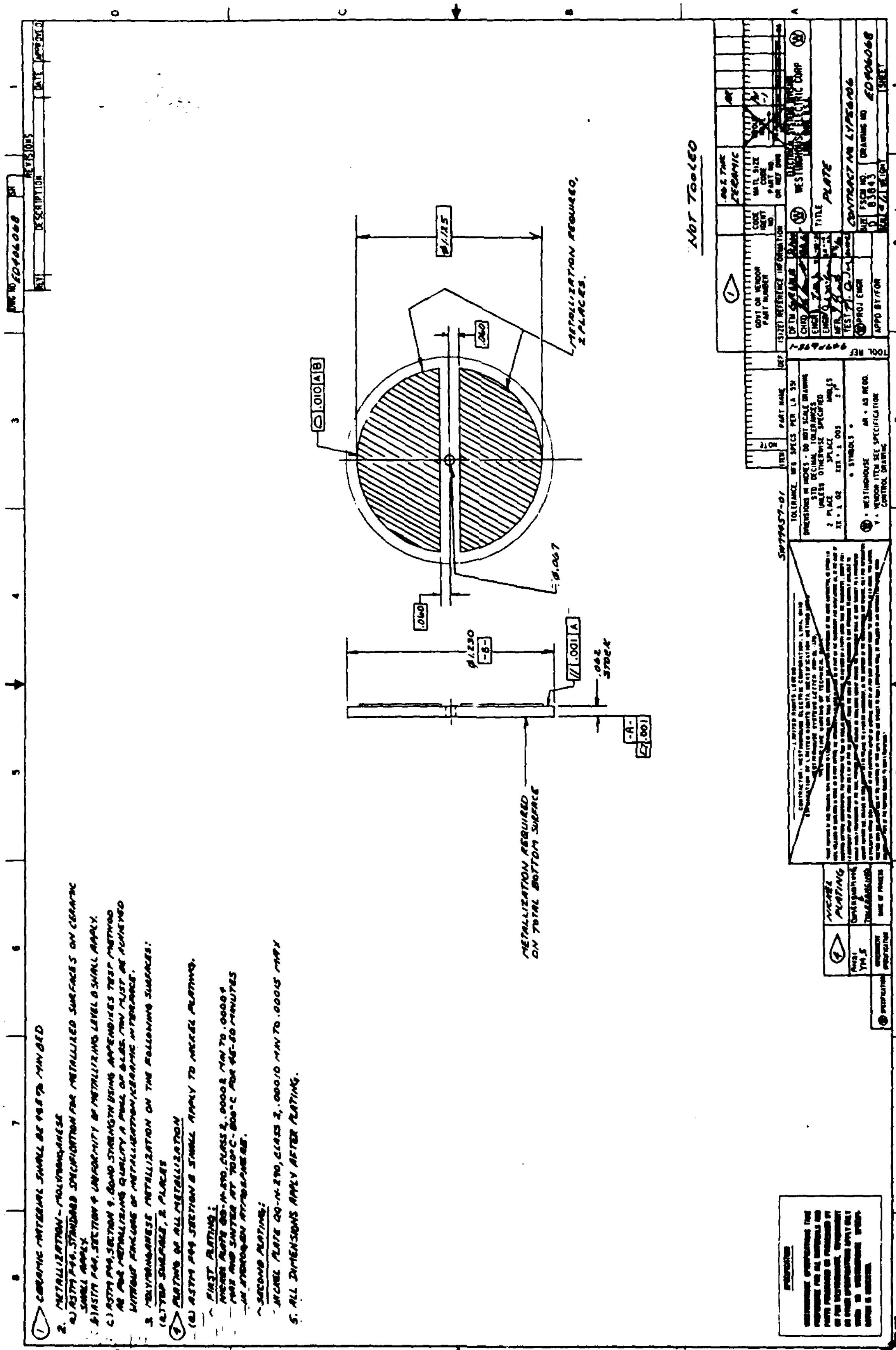


FIGURE 17
PLATE (ED406068)

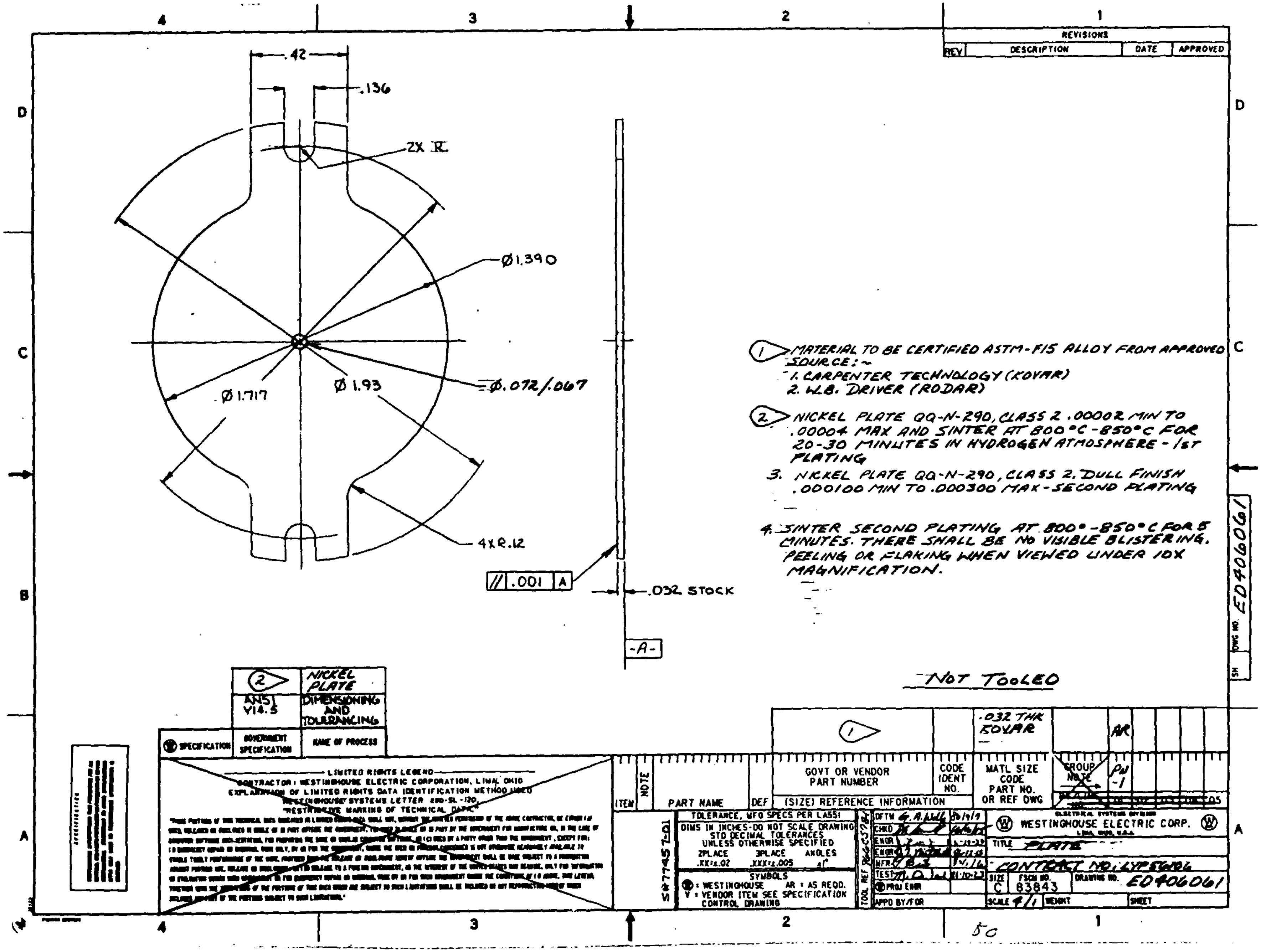


FIGURE 18
PLATE (ED406061)

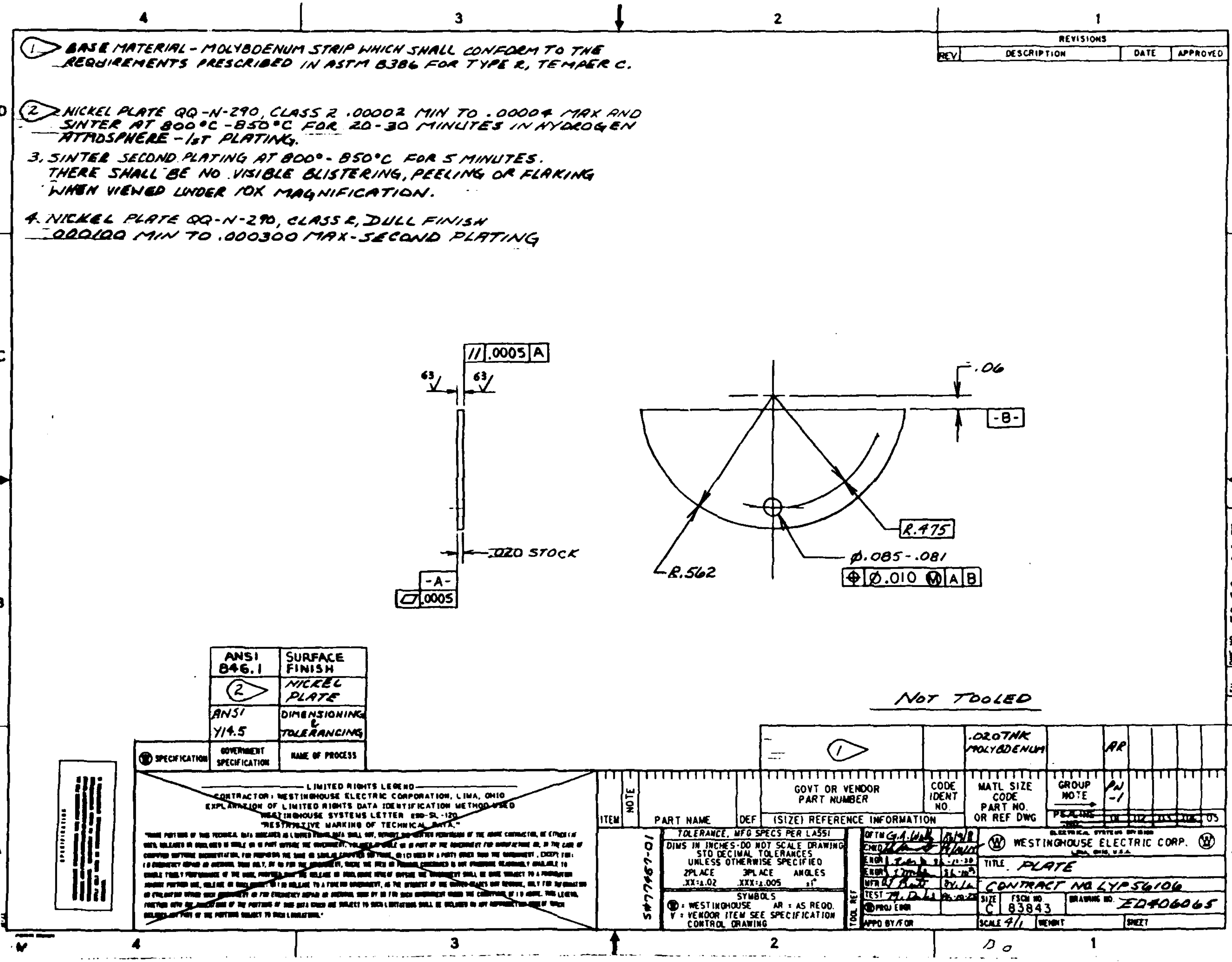


FIGURE 19
PLATE (ED406065)

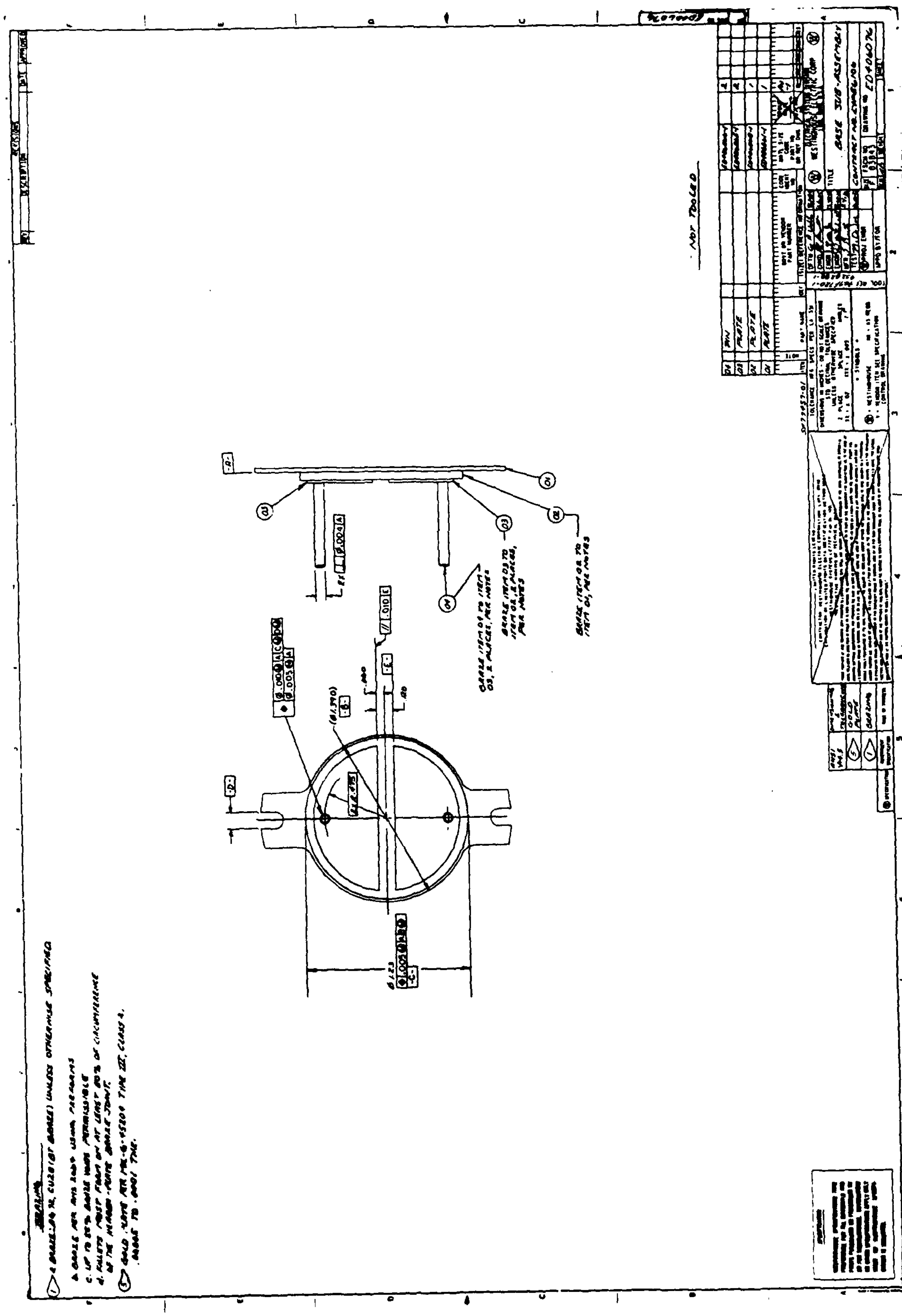


FIGURE 20
BASE SUBASSEMBLY (ED406076)

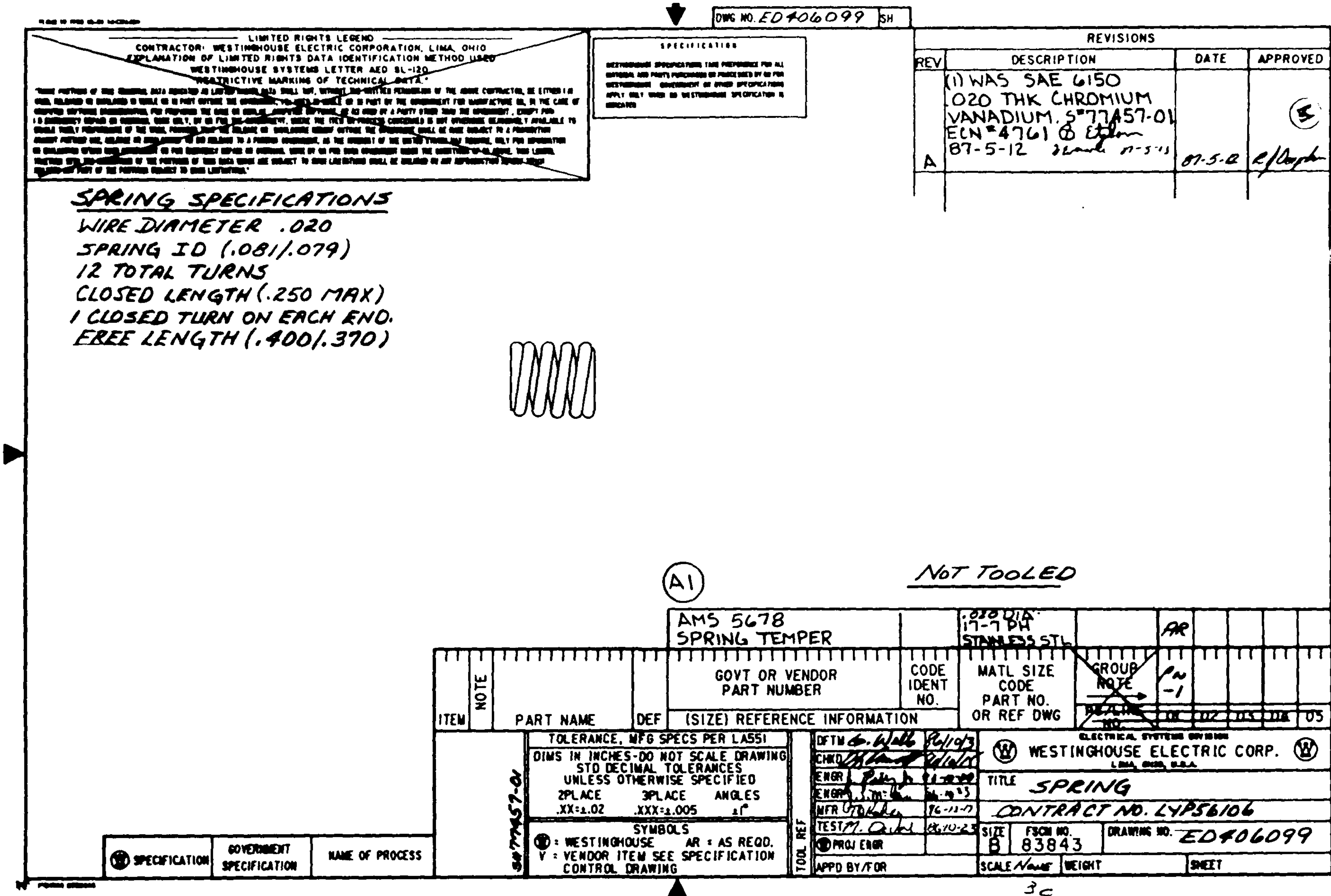


FIGURE 21
SPRING (ED406099)

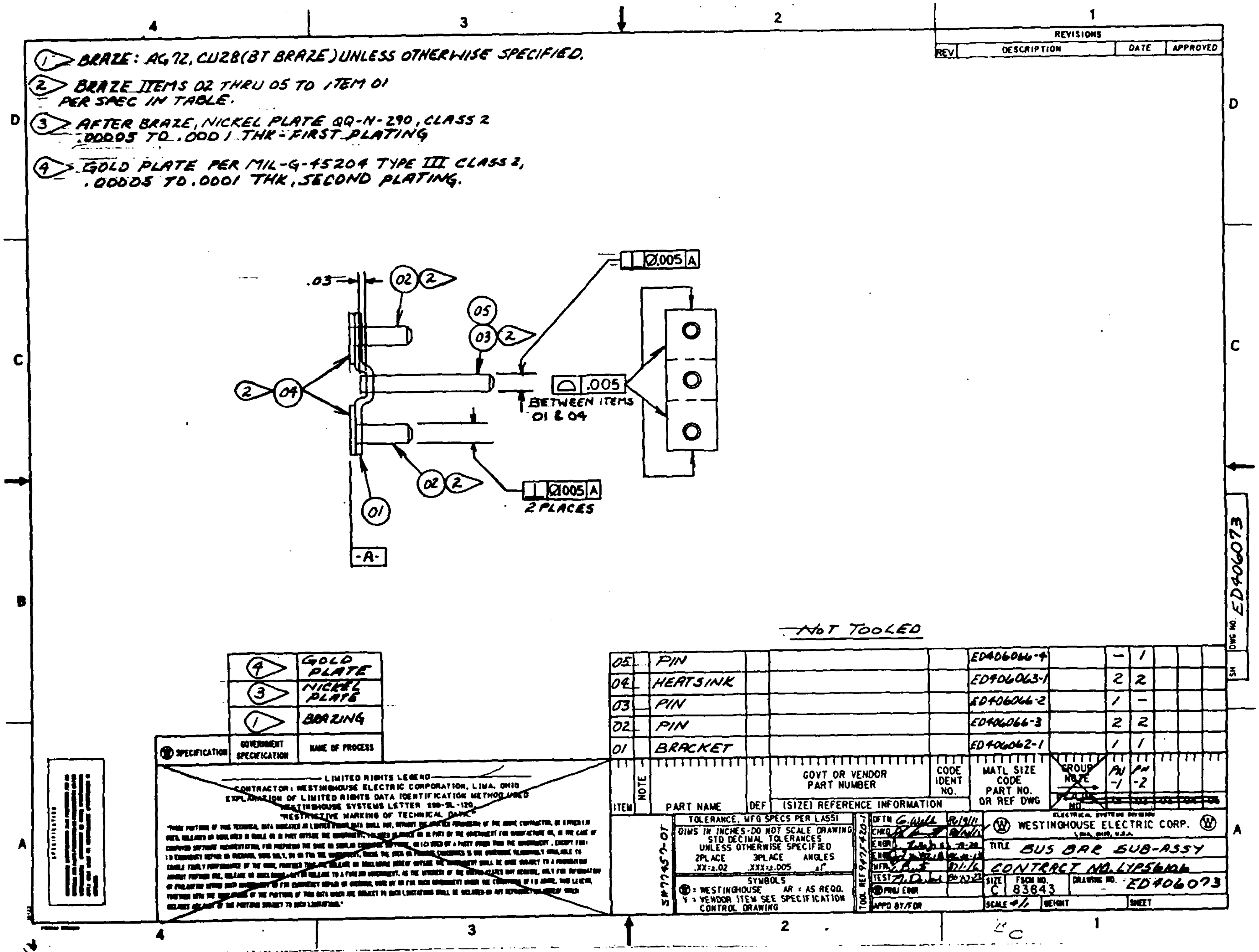


FIGURE 22
BUS BAR SUBASSEMBLY (ED406073)

Soft copper is used to electrically connect the top heat sinks on the diode chips. The 0.032 inch thick bus bar is brazed to the copper cored alloy 42-6 pins as shown in Figure 22 (ED406073). The brazing operation completely anneals the oxygen free copper. The bends further weaken this part so it does not produce a high lateral force to the top heat sinks and chips.

The conducting pins, Figure 23 (ED406066), are made from copper cored alloy 42-6. These are much less expensive than Molybdenum and have a similar expansion rate.

Alumina is chosen for the ceramic cap, Figure 24 (ED406069) since excellent thermal conduction is not needed on this part. Refactory metallization and plating are used on surfaces where metal is to be attached by brazing or soldering.

The final assembly, Figure 25 (ED405702), is soldered to seal the pins to the metallized alumina cap. The gold over nickel plating aids the wetting of the solder and protection against oxidation at high temperature. The assembly is vacuum baked and back filled with dry nitrogen before the final seal is made.

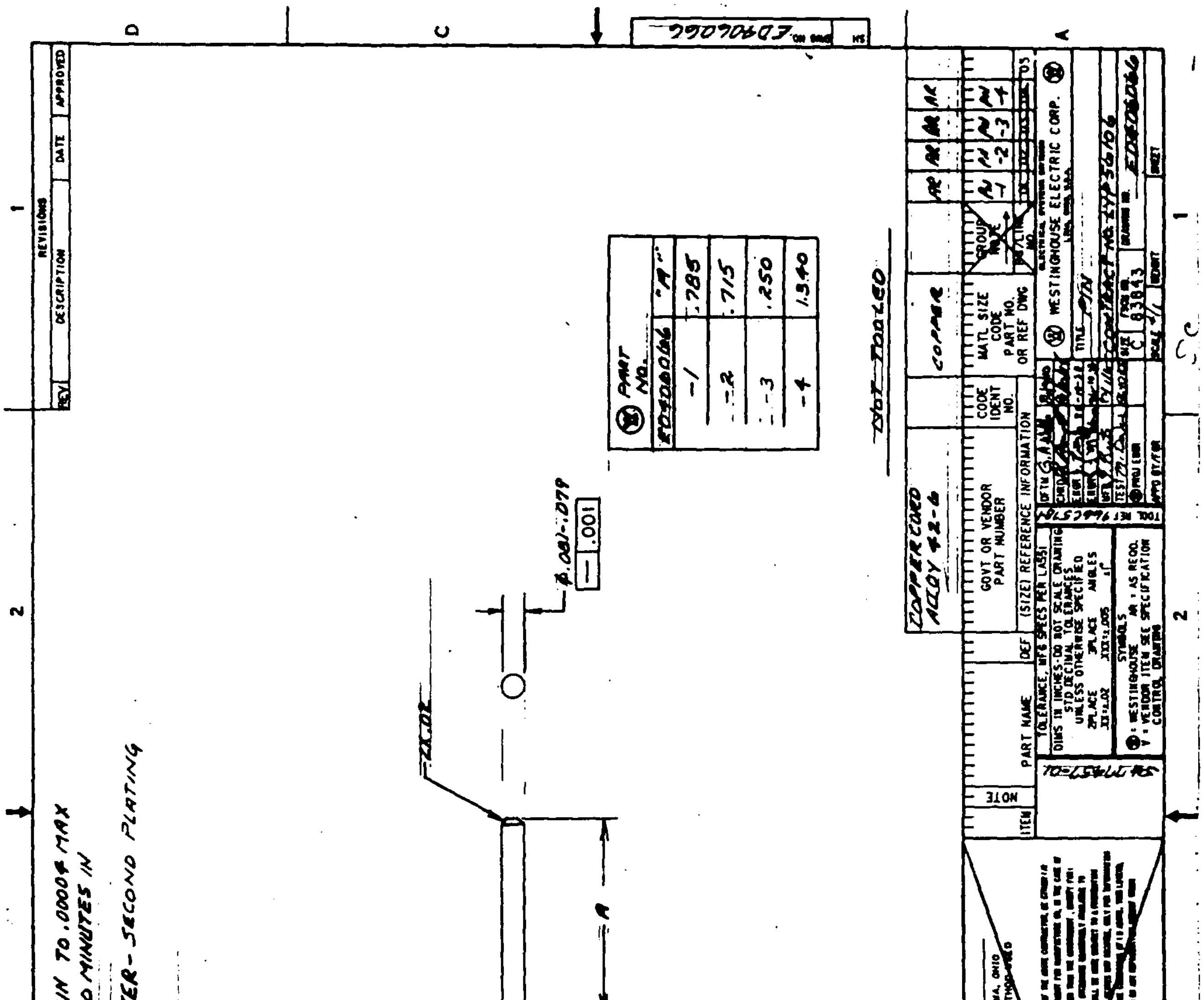


FIGURE 23
PIN (ED406066)

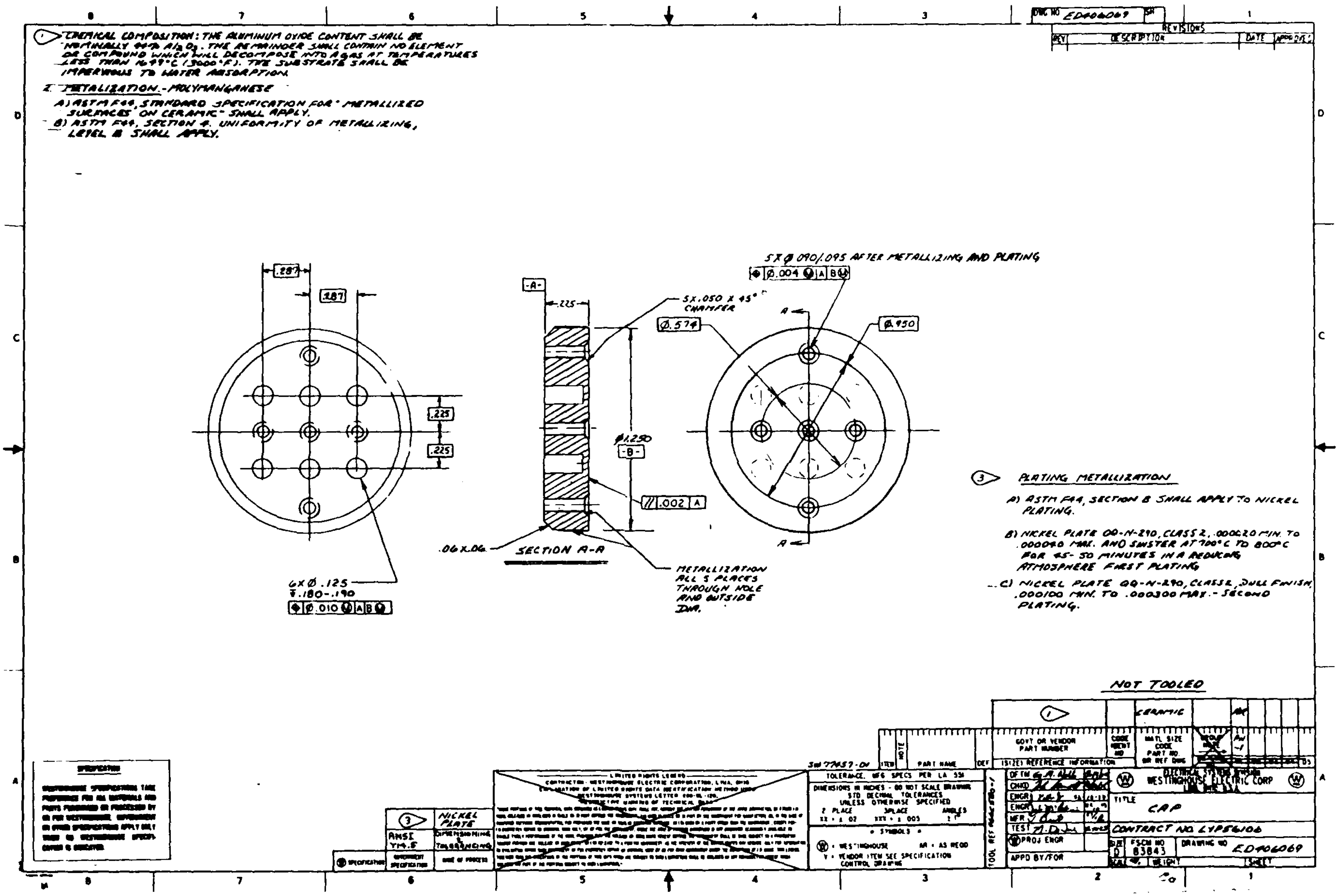


FIGURE 24
CAP (ED406069)

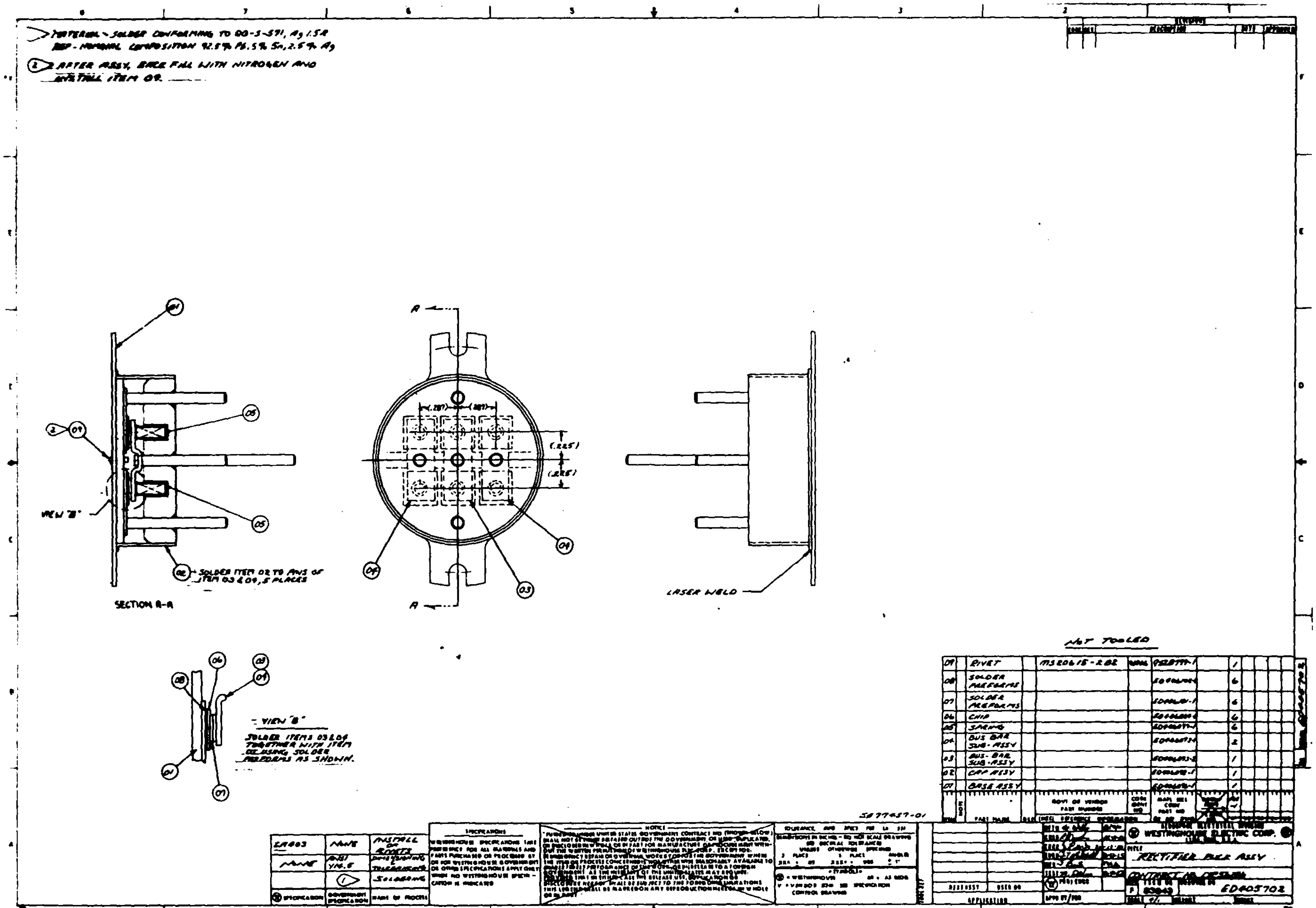


FIGURE 25
RECTIFIER PUCK ASSEMBLY (ED405702)

APPENDIX

TEST PROCEDURE

Westinghouse Electric Corporation
ELECTRICAL SYSTEMS DIVISION
LIMA, OHIO

HIGH TEMPERATURE VSCF
PHASE IV VERIFICATION TESTS

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APPROVED BY: R. Swanberg *R. H. Swanberg*

CHARGE: E2( )-5( )-LYP56106

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2893/ENGM

I. INTRODUCTION

The tests specified in this test letter are conducted to obtain the performance of the High Temperature VSCF Alternator and Inductor. All tests will be conducted at lab ambient conditions, with oil temperatures up to 200°C.

These tests will be conducted in two phases. The first set of tests will be with high temperature oil in (200°C) with slip rings and the newly developed high temperature rectifier assembly mounted externally. The second set of tests will be run with the high temperature rectifier assembly in the rotor and slip rings for measurement of rotor field voltage and current.

II. EQUIPMENT TO BE TESTED

The system under test will include the following equipment.

One 60kVA Generator (W) P/N 977J457-1

III. TEST EQUIPMENT

The laboratory will provide the necessary test equipment to properly conduct the tests called out in this test letter.

IV. STANDARD CONDITIONS

Unless otherwise specified herein, all verification testing shall be conducted in accordance with the parameters listed below.

The tests shall be run at lab ambient conditions.

Oil used shall be ML086-428 provided by AFWAL.

Oil-In-Temperature shall be 200°C +5, -10°C unless otherwise specified.

The system will provide the following safety provisions:

1. Automatic shutdown if input speed exceeds 28,600 rpm.
2. Automatic shutdown if ADE vibration exceeds 10 G's peak.
3. Automatic shutdown if loss of oil pressure.
4. Oil filter at oil inlet.

The system will utilize external pumps for cooling the generator and shall be capable of pumping 200°C oil on a continuous basis.

V HIGH OIL-IN TEMPERATURE (200°C) TESTS WITH SLIP RINGS AND WITH A STATIONARY HIGH TEMPERATURE RECTIFIER ASSEMBLY.

A. Purpose and Scope

The alternator for these tests will be identical to the generator to be used within the VSCF unit except the rotating rectifier will not be used. The three phase AC power from the excitor generator will be transferred through slip rings to a stationary prototype high temperature rectifier assembly. The assembly will be maintained at 100°C or less. Similarly, the DC power for main rotating field will be transferred through slip rings from a stationary source.

B. Resistance Measurements

The room temperature resistance of the main field winding, the excitor field winding, the excitor armature winding, and the permanent magnet stator winding will be recorded prior to the initiation of any rotating tests. These measurements are required to determine operating temperatures using the slip ring method.

C. Weight Measurements

The weight of the rotor, stator and generator shall be determined after these assemblies are completed.

D. Vibration

Vibration of the generator from 10,000 to 26,000 rpm without excitation with 200°C oil-in-temperature shall be recorded. Specific test points shall be determined by the design engineer. This test shall be used to insure components will not be damaged due to rotation of the generator at high temperature and high speed. These data will be compared with the low temperature data.

E. No-Load Voltage Test

A no-load voltage saturation curve for the main generator shall be obtained at 15,300 rpm with 200°C oil-in-temperature. This test will show the change in output voltage vs. change in excitation in main DC rotating field until the generator AC output voltage saturates.

F. Permanent Magnet Generator

Obtain PMG output voltage vs. output current regulation curves at 15,300 rpm and 26,000 rpm for various loads. This test will verify proper performance of the PMG.

G. Excitor Generator Performance

The rectified output from the excitor generator for various load resistances will be obtained, using an external, 3-phase, full-wave bridge composed of the special high temperature diodes at 15,300 rpm and 26,000 rpm. The rectifier bridge will be maintained at 100°C or less for this test.

H. Main Generator Load Test

The temperature of the stator winding and the average temperature of rotating field winding will be obtained for the following loads: 30, 60, and 90kVA at 15,300 rpm and .95 lagging power factor. These tests will be repeated at input speeds of 20,500 rpm and 26,000 rpm. Load shall be maintained until winding temperatures stabilize. Temperatures are considered stabilized when they do not change by more than 1°C in a 5 minute period.

I. Two Per Unit Overload

With the generator operating at 15,300 rpm connect a 120kVA load at .95 lagging power factor for 5 seconds to verify the generator will supply two p.u. load.

CAUTION: Do not apply the 120kVA load for more than 5 seconds. Allow generator to cool at no load for at least 5 minutes after this test.

VI HIGH TEMPERATURE TESTS WITH HIGH TEMPERATURE RECTIFIER MOUNTED IN THE ROTOR AND WITH SLIP RINGS INSTALLED TO MEASURE FIELD CURRENT AND VOLTAGE.

A. Purpose and Scope

The purpose of these tests is to verify proper operation of the generator with the high temperature rectifier assembly under high speed rotation.

B. Vibration

Vibration of the generator from 10,000 to 26,000 rpm without excitation with 100°C and 200°C oil-in-temperature shall be recorded. Specific test points shall be determined by the design engineer. This test shall be used to insure components will not be damaged due to rotation of the generator.

C. No-Load Voltage Test

A no-load voltage saturation curve for the main generator shall be obtained at 15,300 rpm with 200°C oil-in-temperature. This test will show the change in output voltage vs. change in excitation in main DC rotating field until the generator AC output voltage saturates.

D. Main Generator Load Test

The temperature of the stator winding and the average temperature of the rotating field winding will be obtained for the following loads: 30, 60, and 90kVA at 15,300 rpm and .95 lagging power factor. Repeat these tests at input speeds of 20,500 rpm and 26,000 rpm.

E. Two p.u. Overload Test

With the generator operating at 15,300 rpm, connect a 120kVA load for 5 seconds to verify the generator will supply two p.u. load.

CAUTION: Do not apply the 120kVA load for more than 5 seconds. Allow generator to cool at no load for at least 5 minutes after this test.

*U.S.Government Printing Office: 1989 —648-056/04415