FINAL REPORT
LMC-770901-A

MP

GEOTHERMAL HOT WATER PUMP

CONTRACT EY-76-C-03-1307

September 30, 1977

AC03-76ET28307

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CONTENTS

1.0	Introduction	1-1
2.0	System Concept	2-1
3.0	Design Requirements	3-1
4.0	Latching Mechanism	4-1
5.0	Pump	5-1
6.0	Electric Motor	6-1
6.1	Rotor	6-1
6.2	Stator.	6-5
7.0	Motor Cooling System	7-1
8.0	Compensating Chamber	8-1
9.0	Power Transmission and suspension Cable	9-1
10.0	Power Supply	10-1
11.0	Test Program	11-1
12.0	Conclusions	12-1
13.0	Recommendations	13-1

APPENDICES

A. Electric Motor Computer Analysis

ILLUSTRATIONS

Figure Number		Page
1.1	Program Schedule	1-2
2.1	LMC Geothermal Pump Installation	2-2
2.2	LMC Submersible Geothermal Pump	2-3
2.3	LMC Submersible Geothermal Pump	2-4
2.4	Motor-Pump Details for Both Hot and Cold Liquids . .	2-5
4.1	LMC Pump Installation Methods	4-2
4.2	Latching and Sealing System	4-3
4.3	Locking Sleeve	4-4
5.1	LMC Pump Impeller	5-2
5.2	Pump Discharge Housing - Radial Diffuser	5-4
5.3	Pump Discharge Housing - Axial Diffuser	5-5
5.4	Estimated Pump Performance	5-7
6.1	Electric Motor Rotor	6-2
6.2	Locating Ring	6-4
6.3	Stator Slot Details	6-6
7.1	Heat Exchanger Details	7-2
7.2	Heat Exchanger Details	7-3
10.1	High Frequency Power Supply	10-2
11.1	Motor Dynamometer Test Schematic	11-2
11.2	Motor Performance at 6,000 RPM	11-8
11.3	Motor Performance at 6,750 RPM	11-9
11.4	Motor Performance at 7,500 RPM	11-10
11.5	Lower Stator End Windings-Post Test	11-16
11.6	Electric Motor Rotor-Post Test	11-17
11.7	Thrust Bearing-Post Test	11-18
11.8	Mechanical Shaft Seal-Post Test	11-19
13.1	Pump Motor Test Assembly	13-2
13.2	Segmented Motor-End Winding Connection	13-5

TABLES

11.1	Instrumentation Requirements	11-3
11.2	Test Data Sheet	11-5
11.3	Low Speed Survey at 200 Hz	11-11
11.4	Low Speed Survey at 225 Hz	11-12
11.5	Low Speed Survey at 250 Hz	11-13

ABSTRACT

This report describes the design, testing and performance capabilities of a Geothermal Hot Water Pumping System being developed by LMC Corporation under contract from the Energy Research and Development Administration. The pumping system is intended to operate submerged in geothermal brine wells for extended periods of time. Such a system confines the hot brine in a closed-loop under pressure to prevent the liquid from flashing into steam, in addition to providing a means for reinjecting cooled water and the contaminants into a return well.

The LMC system consists of a single-stage centrifugal pump driven by an oil-cooled, high-speed electric motor with integral heat exchanger. For testing purposes a diesel engine driven 400 Hz generator is used for supplying power to the motor. In some areas where commercial power may not be available, the diesel-generator unit or either a rotating or solid state frequency converter may be used to produce the high frequency power required by the motor.

Fabrication of a prototype system and testing of the electric motor at frequencies up to 250 Hz was completed. While testing at 275 Hz it was necessary to terminate the testing when the motor stator was damaged as a result of a mechanical failure involving the motor-dynamometer drive adaptor.

Test results, although limited, confirm the design and indicate that the performance is as good, or better than predicted. These results also indicate that the motor is capable of achieving rated performance.

1.0 INTRODUCTION

This report provides technical information on the design, testing and performance capabilities of a Geothermal Hot Water Pumping System being developed by LMC Corporation. Information presented herein is a result of work accomplished under Contract EY-76-C-03-1307, from the Energy Research and Development Administration (ERDA). The original period of performance, was from August 9, 1976 through March 9, 1977. The completion date was later extended to September 30, 1977 by modification to the contract. The program schedule is shown in Figure 1.1.

The objective of the program is to develop a down-hole pumping system capable of operating for extended periods of time in the hostile environment of geothermal brine wells. The advantage of a down-hole pumping system is that it will permit the hot brine to be confined in a sealed circulation loop under sufficient pressure to prevent the liquid from flashing into steam. This also eliminates environmental contamination at the surface by permitting the cooled water and the associated dissolved solids and entrapped gases to be reinjected into a return well. Such a system will allow greater utilization of water-dominated geothermal resources as a source of energy, thus contributing to the National self-sufficient energy objective.

Development of the Geothermal Hot Water Pumping System was initiated in September, 1974, under research grant AER74-18753, from the National Science Foundation (NSF) to Lear Motors Corporation.

In 1976, responsibility for geothermal hardware development was transferred from NSF to ERDA. During this same period, Lear Motors Corp-

oration was involved in a merger resulting in the company's name being changed to LMC Corporation and the facilities being relocated. Work accomplished under grant from NSF and prior to the merger is contained in LMC Report 760504-A. (1)

- (1) "Geothermal Hot Water Pump", Lear Motor Corporation, Technical Report LMC 760504-A, May 30, 1976.

The LMC system shown pictorially in Figure 2.1, is a single-stage centrifugal pump driven by an oil-cooled high-speed electric motor. It may be lowered and seated in the well casing by a suspension cable, eliminating the need for discharge piping, thereby minimizing installation and service costs. The LMC system may be installed in wells having internal diameters as small as 8.0 in (20.3 cm). The basic elements of the pumping system, as shown in Figure 2.2 consists of:

Latching Mechanism

Pump

Motor

Heat Exchanger

Compensating Chamber

Power Transmission and Suspension Cable

Power Supply

A photograph of the pumping system is shown in Figure 2.3.

Depending on the temperature of the well fluid, the length of the heat exchanger may be greatly reduced, or eliminated, entirely.

The length of the compensating chamber would also be affected.

All other components would remain dimensionally unchanged. Figure 2.4 illustrates pumping systems for hot and cold well fluids.

FIGURE 2.1
LMC GEOTHERMAL PUMP INSTALLATION

FIGURE 2.2
LMC SUBMERSIBLE GEOTHERMAL PUMP

FIGURE 2.3

LMC SUBMERSIBLE GEOTHERMAL PUMP

FIGURE 2.4

MOTOR-PUMP DETAILS FOR BOTH HOT AND COLD LIQUIDS

DESIGN REQUIREMENTS

Design parameters, for the pumping system, were established on the basis of data collected from known geothermal reserves. To keep the hot brine from flashing into steam at the wellhead, the pump head must be greater than the vapor pressure of the brine, plus the flow losses incurred between the pump and wellhead. A conservative value of 1,150 ft. (350.5 m), or approximately 485 psi (34.1 Kg/cm²) was calculated from the vapor pressure of a 20% brine solution of 450°F (232°C) and allowing 15% for flow losses. A flow rate of 500,000 lbs/hr (226,800 Kg/hr) was selected as an optimum value for most wells. The following parameters represent design conditions based upon the above considerations:

Brine chemistry	20% salt solution
Brine temperature	450°F (232°C)
Brine density	60.8 lbs/ft ³ (974.4 Kg/m ³)
Pump flow rate	500,000 lbs/hr (226,800 Kg/hr)
Pump head rise	1,150 ft (350.5 m)
Pump net positive suction head	245 ft (74.7 m)
Service life	10,000 hrs (goal)

LATCHING MECHANISM

There are two methods as shown in Figure 4.1 for installing down-hole pumps. In the first method, the pump is lowered into the well casing and suspended by a pipe string, which is somewhat smaller than the well casing itself. This pipe then serves as the production tube and no seal is required between the pump and well casing. In the second method, which LMC uses, a suspension cable is used to lower the pump to a seating element or "shoe", which is attached to the well casing at the pump operating level. A special latching mechanism, shown in Figure 4.2, securely seats and seals the pump in the shoe. The locking sleeve, shown in Figure 4.3, seats first positioning the locking balls under the tip of the seating shoe. The power cable is clamped to the suspension cable as the pump is lowered. To retrieve the pump, tension is applied to the suspension cable at the wellhead, and the latching mechanism releases the pump. No pipe string is required, and thus installation and removal of a cable suspended pump requires a minimum of support equipment at the wellhead.

NOTE:
COLD LIQUID PUMPS
SHOWN. EITHER
INSTALLATION METHOD
COULD ALSO BE USED
FOR A HOT LIQUID
PUMP.

FIGURE 4.1

LMC PUMP INSTALLATION METHODS

LATCHING AND SEALING SYSTEM

FIGURE 4.2

PUMP DOWN WELL
LATCHING & SEALING SYSTEM

LMC CORPORATION

GEO THERMAL PUMP

FIGURE 4.3

LOCKING SLEEVE

The pumping unit itself consists of a close-coupled single-stage impeller and a stationary diffuser. This design eliminates any need for interstage wear rings, or bearings, in contact with the well fluid.

Specific pump design parameters were established, based on the representative well data and pump down-hole location considerations, as follows:

Flow rate	500,000 lb/hr (226,800 Kg/hr)
Net positive suction head, NPSH	245 ft (74.7 m)
Head rise	1,150 ft (135.5 m)
Fluid horsepower	290
Design envelope restrictions	7 in. (17.78 cm)

The temperature and pressure profile of the representative well represents a very severe requirement for cavitation-free pump operation. In conventional pump design, the cavitation limits for safe operation is related to the suction specific speed parameter, S . For single stage pumps, with the shaft running through the impeller inlet, such as the LMC design, S values from ≤ 6500 to 9000 are recommended. By selecting a very conservative suction specific speed value of approximately 6000, a nominal pump speed of 11,600 rpm, for rated conditions, results.

The impeller, shown in Figure 5.1, is unshrouded and consists of two dimensional circular arc blading, with a 90° exit angle. To

FIGURE 5.1

LMC PUMP IMPELLER

avoid premature boundary separation and subsequent low efficiencies, 33 blades are used. This high number of blades also lowers the blade loading.

To operate with minimum net positive suction head conditions, a streamlined inlet area, with no prerotation, is provided. A uniform velocity distribution, through the impeller eye, is also used.

The pump discharge housing, shown in Figures 5.2 and 5.3, consists of a radial diffuser, followed by a 90° turning zone to an axial diffuser. The radial diffuser is constructed of straight constant thickness vanes. A high number of vanes are used in the axial diffuser to prevent excessive losses.

The axial thrust generated on the back side of the pump impeller is the highest bearing load in the machine. This thrust load is supported by a self-aligning plain hydrodynamic bearing. Design load capability of the bearing is 1,000 lbs with a film thickness of 3 mils. During Phase I laboratory testing, the bearing demonstrated a load capability of 1,200 lbs at a film thickness of 1 mil. The rotating element of the bearing is made of hardened tool steel with the stationary self-aligning member made of hardened ductile iron. A pressure balanced face seal is the only dynamic seal used in the pumping system. This type of seal utilizes a rotating face made of martensitic stainless steel operating against a hydraulically balanced stationary member made of carbon. A film of oil between the fixed and rotating members helps prevent the pumped fluid from entering the motor cavity.

FIGURE 5.2

PUMP DISCHARGE HOUSING-RADIAL DIFFUSER

FIGURE 5.3

PUMP DISCHARGE HOUSING-AXIAL DIFFUSER

At a given speed, the amount of leakage across the seal is a function of the pressure differential between the oil inside the motor and the external well pressure. To insure proper operation, a constant positive pressure differential is maintained between the motor cavity and the well.

Based on calculations, the hydraulic efficiency of the pumping unit, is estimated to be 71%. An estimate of the performance, based on the known performance of pumps of similar design, is shown in Figure 5.4.

ESTIMATED PUMP PERFORMANCE

SPECIFIC SPEED = 1910
SHAFT SPEED = 11,600 RPM
HEAD RISE = 485 PSI
FLOW RATE = 500,000 LBS/HR
FLUID DENSITY = 60.8 LBS/FT³

FIGURE 5.4
ESTIMATED PUMP PERFORMANCE

ELECTRIC MOTOR

In developing the electric motor/centrifugal pump unit for submerged operation in hot brine wells, motor design presented the greatest challenge. Special sealed motors, with diameters much smaller than their lengths, have been used in oil and water wells for many years, however, they are limited to speeds and temperatures far below those required for optimum performance in geothermal wells. Aircraft motors, with more conventional geometry routinely operate at speeds up to 24,000 rpm and at temperatures up to 500°F (260°C). Development of the LMC pump motor has required a combination of these features, which had never before been integrated into a single design.

The LMC pump motor is a 4-pole squirrel cage induction machine built to operate submerged in 450°F (232°C) corrosive geothermal brine. It is designed to operate from 350 vac L-N three-phase power at frequencies between 200 and 400 Hz. It develops up to 400 shaft horsepower continuously at speeds up to 11,600 rpm. The physical size of the motor is only 6.5 in (16.5 cm) in diameter by 40 in (101.6 cm) long.

ROTOR

The rotor shown in Figure 6.1 is fabricated in two pieces from 0.014 in thick Vanadium Permendur punchings. These punchings are installed on a long shaft which has an oil pump section between the two rotor segments. Interlaminar insulation is provided by an

FIGURE 6.1

ELECTRIC MOTOR ROTOR

air oxide coating.

Since the motor is designed to operate at speeds between 6,000 and 12,000 rpm, dynamic support of the rotor is very important. However, the rotor must also be supported during startup and during acceleration. During startup, hydrodynamic forces are low, or non-existent, and magnetic forces dominate. When electrical power is applied to the stator windings, the radial magnetic forces are equal and the net force zero when the rotor/stator annular gap is uniform (rotor is centered) and increases in the direction of minimum gap as the rotor moves off center. To prevent the resultant radial magnetic force from becoming unmanageable and to prevent rotor/stator contact during the short startup period, locating rings were placed on the rotor shaft ends. These locating rings are simply loose fitting bearings designed to position the rotor assembly, within 10 mils of the stator bore center. The rings function dynamically, for a brief time. Once the rotor begins to turn, it achieves operating speed, within a few seconds. At speed, hydrodynamic forces center the rotor within the 10 mil clearance radius of the locating rings and they are effectively unloaded.

Problems were experienced at startup, during the early phases of the test program. When the rotor was excited, the magnetic forces caused the center section of the rotor shaft to contact the stator bore. Once contact was made between the rotor and the excited stator, a high current was required to "break loose" the rotor. To correct this problem, a locating ring shown in Figure 6.2 was installed at the axial center of the rotor to prevent rotor/stator contact.

FIGURE 6.2

LOCATING RING

STATOR

The motor stator is fabricated from 0.014 in thick Vanadium Permendur punchings. The insulation selected for the stator is a glass/polyimide/nomex system. An enlarged view of the stator slot is shown in Figure 6.3. In effect, the insulation system is all polyimide, since the glass and Nomex are porous materials that are impregnated with the polyimide. As shown, the slot liners are Nomex, the phase separators are glass cloth, the wire insulation is Kapton (Dupont trade name for polyimide film) and the top sticks are a composite of glass string and Nomex. The entire stator is vacuum impregnated and baked in polyimide varnish until the slot/winding structure is fully filled.

FIGURE 6.3
STATOR SLOT DETAILS
6-6

1	25	E204256 ASSY-MOTOR FRAME (COMP.)
2	36	LINER - SLOT 15 MIL NOMEX, TYPE 410 DUPONT NYLON PAPER
3	72	WIRE 160 MIL x 250 MIL ALUM. MAGNET WIRE WITH 3 MIL KAPTON WRAP-PHELPS DODGE
4	144	INSULATOR - PHASE, PYRE-MIL IMPREG. GLASS DUPONT PT-7010
5		TAPE, 3 MIL x 1 IN. WIDE KAPTON TAPE PERMACEL-221
6	36	LINER - TOP 15 MIL x .187 W. NOMEX TYPE 410 DUPONT NYLON PAPER
7	30	STICK - TOP 15 MIL x .270 W. NOMEX TYPE 410 DUPONT NYLON PAPER
8	50	FILLER - TOP .012 THK. x .125 W. NOMEX LACING TAPE, 4 STRANDS EACH

SECTION THRU MOTOR STATOR
(SHOWING (3) LONGITUDINAL GROOVES)

LMC CORPORATION	
ASSEMBLY-INSULATION SYSTEM STATOR CONDUCTORS	
R. FASSIG	B204311

MOTOR COOLING SYSTEM

The motor is completely filled with General Electric Versilube F-50, an additive-free silicone lubricant, which has excellent thermal stability at temperatures up to 600°F (315°C). A circulating system moves the fluid through the motor removing the heat generated by the mechanical and electrical losses. An integral heat exchanger then transfers the heat to the pumped brine.

Figure 7.1 shows a schematic of the motor cooling system. A small centrifugal pump, located on the tubular rotor shaft between the upper and lower rotor segments, moves the fluid into the annular space or gap between the rotor and stator. The flow is divided into approximately half moving up the gap and the remaining half down the gap toward the pump end of the motor. After emerging from the gap, the portion of fluid which passed through the lower rotor/stator gap then moves through and cools the lower stator conductor end turn region. It then moves upward between the outer diameter of the stator stack and the motor frame, cooling the stator and transferring some of the heat to the brine through the motor frame. On reaching the upper end of the stator/motor frame passage, it joins the fluid which has passed through the upper rotor/stator gap.

All of the fluid now passes through the upper stator conductor region, cooling the stator end turns and motor frame feed through terminals. At this point, the fluid has completed its motor cooling function and enters the heat exchanger. This heat exchanger shown in Figure 7.2, is of shell and tube construction, with the shell being the well casing and the heat transfer fluid flowing in the heat exchanger tube

FIGURE 7.1

COOLING FLUID FLOW SCHEMATIC

LMC CORPORATION

GEOHERMAL PUMP

2-13-76

DISCRIPTION	UNITS	SECTION				
		A	B	C	D	E
BRINE FLOW AREA (TOTAL)	IN ²	19.97	43.737	37.492	34.079	18.699
BRINE FLOW AREA (SHELL SIDE)	IN ²			30.133	26.87	
BRINE FLOW RESTRICTION	IN ³	30.057	6.29	12.535	15.126	31.328
BRINE FLOW VELOCITY	FT/SEC	16.06	7.33	8.56	9.41	17.16

TUBE DATA (5/16 O.D. x .020 WALL STAINLESS STL)		
DISCRIPTION	INDIV.	TOTAL
NUMBER OF TUBES		36
AREA	.053 IN ²	2.088 IN ²
VOLUME	8.12 IN ³	292.52 IN ³
SURFACE AREA (OUTSIDE)	.95 FT ²	34.36 FT ²
SURFACE AREA (INSIDE)	.83 FT ²	29.96 FT ²
LENGTH (BEFORE BENDING)	140.00"	5,040.0°

HEAT EXCHANGER

LMC CORPORATION
GEOTHERMAL PUMP

FIGURE 7.2

HEAT EXCHANGER DETAILS

bundle. As the fluid moves upward through the tube bundle, heat is transferred to the pumped brine. The cooled fluid then emerges from the heat exchanger and enters the pressure and temperature compensated fluid reservoir.

From the fluid reservoir, the fluid moves downward through a large (1-1/8" I.D.) structural tube located in the center of the heat exchanger, and into the upper rotor shaft support trunion. At this point, the fluid again begins its motor cooling function and enters the hollow rotor shaft. As it flows down the shaft, the fluid is again divided with approximately half flowing down to the pump drive end of the shaft, where it cools and lubricates the large thrust bearing and shaft seal before returning to the circulating pump. The other half flows directly to the circulating pump.

COMPENSATING CHAMBER

To insure proper operation of the motor shaft seal, a constant positive pressure differential must be maintained between the motor oil cavity and the well. A pressure and temperature compensating fluid reservoir was incorporated into the pumping system for this purpose.

The pressure/temperature compensating system utilizes a piston and diaphragm to separate the fluid-filled motor cavity from the sealed secondary chamber located above. The sealed chamber is vented to an annular space below the pump impeller on the well side of the mechanical seal. Venting of the secondary chamber to the brine is controlled by a differential pressure valve, while venting of brine to the secondary chamber is direct via a check valve.

The power transmission and suspension cable provides the means for transferring electrical power from the wellhead at ground level to the motor located 1,000 ft. or more down the well. The stranded copper conductors are insulated with a proprietary material originally developed for use in nuclear reactors. The stainless steel tension cable is capable of supporting its own weight, plus that of the pumping system. External armor is used to protect the cable during service and installation.

10.0 POWER SUPPLY

The power supply consists of a diesel engine-driven generator capable of producing 600KVA of 400 Hz 3-phase power. This combination, shown in Figure 10.1 provides the versatility for operating in remote areas. The same type of operation may be obtained with a gas turbine as the prime mover. In areas where commercial power is available, an electric motor-driven generator, or a solid state frequency convertor may be used to provide 400 Hz power to the pumping system.

The 28-pole synchronous generator used in the program is an older machine originally designed to product 60 Hz power, while turning at 257 rpm. To obtain the 400 Hz power, it was necessary to modify the generator and increase the speed to 1,713 rpm. Following modifications, which consisted of reconnecting the generator to a 4-in-parallel star circuit and reinsulating the field coils, the generator was coupled to the diesel engine and tested at speeds of 600, 800 and 1,000 rpm. The generator performed as predicted and no other electrical performance testing was done.

The modified generator was used successfully at speeds up to 1,070 rpm (250 Hz) during the initial motor testing program. Upon completion of these tests, an attempt was made to operate the generator at full speed. Severe unbalance was encountered between 1,300 and 1,500 rpm; subsequent inspection revealed that the laminations within the poles had begun to move outward in the region between the restraining cap screws. Apparently, the four rivets holding the individual laminations together did not have sufficient bending strength to prevent interlaminar shear movement under the centrifugal

FIGURE 10.1

1	KILLOWATTS PER PHASE 0-500KW
2	A.C. VOLTS PHASE 1 0-600V
3	A.C. VOLTS PHASE 2 0-600V
4	A.C. VOLTS PHASE 3 0-600V
5	FREQUENCY - RPM 0-2000 RPM
6	TEMPERATURE GENERATOR WINDINGS 0-500°F
7	A.C. AMPERES PHASE 1 0-1000 A
8	A.C. AMPERES PHASE 2 0-1000 A
9	A.C. AMPERES PHASE 3 0-1000 A
10	D.C. AMPERES GEN FIELD 0-100 A
11	D.C. VOLTS GEN FIELD 0-100V
12	220 VAC ON
13	220 VAC OFF
14	GENERATOR FIELD VOLTAGE RHEOSTAT
15	DIESEL FUEL ON-OFF
16	DIESEL START
17	DIESEL SPEED INCREASE
18	DIESEL SPEED DECREASE

HIGH FREQUENCY 500 KVA
POWER SUPPLY SCHEMATIC

forces encountered. No other indication of structural degradation was found.

Since there was no practical way to salvage the damaged poles, the decision was made to fabricate new poles from solid cast steel. Each solid cast steel pole was attached to the rim, with two high-strength cap screws exactly like the original poles were. Once installed, the generator was rebalanced and operated to 1,500 rpm, without further problems.

TEST PROGRAM

Basically, the test program consists of individual testing of each major component before conducting final system evaluation tests. During the early phases of this project, an engineering model of the electric motor was built and tested to verify the design concept. Testing of the full scale pump motor on a water brake dynamometer was also initiated. These tests included low speed (200 Hz) tests. It was following these tests that the generator was damaged while operating above 1,300 rpm.

Testing of the electric motor was resumed following rework of the generator poles. The motor was positioned vertically with its shaft driving a Kahn Model 061-112-284 water brake dynamometer, as shown schematically in Figure 11.1. The test was fully instrumented as shown in Table 11.1. All data was collected visually from the instrumentation and recorded manually on data sheets, shown in Table 11.2.

The motor test procedure consisted of setting the diesel engine to correspond to a motor frequency of about 200 Hz (6,000 rpm). At this frequency, the generator field is energized by a manually-controlled 208 vac 3-phase Variac. Output of the Variac is stepped down through a 2 to 1 transformer and rectified by a full wave bridge, which is used to produce variable DC excitation, in the range of 0 to 121 volts and 0 to 99 amps.

To start the motor, it was necessary to apply a current of 600 amps at a fast rate. After breaking loose, the motor accelerated very quickly. Once at speed, the voltage and frequency were adjusted to

FIGURE 11.1

MOTOR/DYNAMOMETER TEST SCHEMATIC

T1	OIL TEMP INTO MOTOR
T2	OIL TEMP OUT OF MOTOR
T3	OIL TEMP OUT OF HEAT EXCHANGER
T4	OIL TEMP SEAL
T5	WATER TEMP SUPPLY
T6	WATER TEMP OUT OF JACKET
T7	WATER TEMP OUT OF HEAT EXCHANGER
T8	WATER TEMP INTO JACKET
T9	TEMP MOTOR WINDINGS
T10	TEMP MOTOR FRAME
T11	WATER TEMP OUT OF DYNAMOMETER
T12	BEARING TEMP #1 DYNAMOMETER
T13	BEARING TEMP #2 DYNAMOMETER
T14	GENERATOR WINDING TEMP
T15	GENERATOR AMBIANT TEMP
P1	OIL PRESSURE OUT OF MOTOR 0-30 PSI
P2	WATER PRESSURE REGULATED TO DYNAMOMETER 0-100PSI
P3	DYNAMOMETER AIR OIL SPRAY PRESSURE
P4	WATER SUPPLY PRESSURE
FM1	OIL FLOW METER 0-42 GAL
FM2	COOLING WATER FLOW METER 2.4-13.2 GAL
	DORIC THERMOCOUPLE INDICATOR DS520
	HEATHKIT DIGITAL COUNTER 1B-1000 RPM
	DIGILIN 3200 TORQUE METER
	ENDEVCO ACCELEROMETER 2215E
	TEKTRONIX OSCILLOSCOPE 561B
	WESTON KW METER 905
	WESTON AMP METER 904
	WESTON VOLT METER 904

INSTRUMENTATION REQUIREMENTS			TEST LOCATION LMC CORPORATION - SPARKS, NV		PROJECT CONTRACT EY-76-C-03-1307		DATE August 1977	SHEET NO. 1 of 2
			DESCRIPTION OF TEST ITEM GEOTHERMAL ELECTRIC MOTOR		TEST PROCEDURE NO. LMC-770801A		PREPARED BY	
ITEM TO BE RECORDED	SYMBOL	UNITS	ANTICIPATED RANGE		REQUIRED ACCURACY	DESCRIPTION OF INSTRUMENTATION		
			MIN.	MAX.				
Time Data Recorded	T	Min	-	-	+ 10 sec	Digital Clock		
Motor Resistance	R	Ohms	0	2	+ 5%	Simpson Model 269 Microammeter		
Line Frequency	F	Hz	200	400	+ 2 Hz	Simpson Speed-Frequency Meter		
Motor Shaft Speed	N	RPM	5000	12000	+ 10 RPM	Heath kit Frequency Counter 1B-1100		
Motor Shaft Torque	τ	Lbs-Ft	0	500	+ 5 Lbs-Ft	Lebow Load Cell Model 3132 & Datronic Model 870 Data Module		
L-N Voltage @ Generator Ø1	V1	VAC	100	500	+ 5%	Weston Volt Meter Model 904		
L-N Voltage @ Generator Ø2	V2	VAC	100	500	+ 5%	Weston Volt Meter Model 904		
L-N Voltage @ Generator Ø3	V3	VAC	100	500	+ 5%	Weston Volt Meter Model 904		
Generator Field Voltage	VF	VDC	0	100	+ 5%	Variac		
Line Current Ø1	I1	AAC	0	1200	+ 1	Weston Amp Meter		
Line Current Ø2	I2	AAC	0	1200	+ 1	Weston Amp Meter		
Line Current Ø3	I3	AAC	0	1200	+ 1	Weston Amp Meter		
Generator Watts/Ø	W	KW	0	200	+ 5%	Weston KW Meter Model 905		
Generator Field Current	IF	ADC	0	100	+ 5%	Weston Amp Meter		
Motor Oil Flow Rate	Q1	GPM	2	42	+ 5%	Fisher & Porter Flowrotor		
Water Jacket Flow Rate	Q2	GPM	2	15	+ 5%	Fisher & Porter Flowrotor		
Motor Oil Pressure Out	P1	PSIG	5	15	+ 10%	Marsh Pressure Gauge		
Water Supply Pressure	P2	PSIG	30	60	+ 10%	Marsh Pressure Gauge		
Dyno Water Pressure In	P3	PSIG	50	100	+ 5%	Marsh Prssure Gauge		
Dyno Oil Mist Pressure	P4	PSIG	80	100	+ 5%	Marsh Pressure Gauge		
Motor Oil Temperature In	T1	°F	50	300	+ 1°	Type K Thermocouple & Doric Model DS-520	Digital Indicator	
Motor Oil Temperature Out	T2	°F	50	300	+ 1°	Type K Thermocouple & Doric Model DS-520	Digital Indicator	
HX Oil Temperature Out	T3	°F	50	300	+ 5°	Bulb Thermometer & Marsh Temperature Gauge		
Motor Frame Temperature	T4	°F	50	300	+ 5°	Type K Thermocouple & Doric Model DS-520	Digital Indicator	
Water Jacket Temperature In	T5	°F	50	100	+ 1°	Type K Thermocouple & Doric Model DS-520	Digital Indicator	
Water Jacket Temperature Out	T6	°F	50	200	+ 1°	Type K Thermocouple & Doric Model DS-520	Digital Indicator	

TABLE 11.1
INSTRUMENTATION
REQUIREMENTS
11-3

TABLE 11.1
INSTRUMENTATION
REQUIREMENTS
11-3

INSTRUMENTATION REQUIREMENTS

TEST LOCATION

LMC CORPORATION - SPARKS, NV

PROJECT

CONTRACT EY-76-C-03-1307

DATE _____

August 1977

SHEET NO.

2 of 2

[illegible]

GEO THERMAL ELECTRIC MOTOR

TEST PROCEDURE NO.	
--------------------	--

PREPARED BY	
-------------	--

[illegible]

TEST DATA SHEET			TEST LOCATION LMC CORPORATION-SPARKS, NV			PROJECT CONTRACT EY-76-C-03-1307			DATE August 1977		SHEET NO. 1 of 2	
			DESCRIPTION OF TEST ITEM GEOTHERMAL ELECTRIC MOTOR			TEST PROCEDURE NO. LMC - 770801A			PREPARED BY			
ITEM TO BE RECORDED	SYMBOL	UNITS	DATA POINT NUMBERS									
Time Data Recorded	T	Min										
Motor Resistance	R	Ohms										
Line Frequency	F	Hz										
Motor Shaft Speed	N	RPM										
Motor Shaft Torque		Lbs-Ft										
L-N Voltage @ Generator Ø1	V1	VAC										
L-N Voltage @ Generator Ø2	V2	VAC										
L-N Voltage @ Generator Ø3	V3	VAC										
Generator Field Voltage	VF	VDC										
Line Current Ø1	I1	AAC										
Line Current Ø2	I2	AAC										
Line Current Ø3	I3	AAC										
Generator Watts/Ø	W	KW										
Generator Field Current	IF	ADC										
Motor Oil Flow Rate	Q1	GPM										
Water Jacket Flow Rate	Q2	GPM										
Motor Oil Pressure Out	P1	PSIG										
Water Supply Pressure	P2	PSIG										
Dyno Water Pressure In	P3	PSIG										
Dyno Oil Mist Pressure	P4	PSIG										
Motor Oil Temperature In	T1	°F										
Motor Oil Temperature Out	T2	°F										
HX Oil Temperature Out	T3	°F										
Motor Frame Temperature	T4	°F										
Water Jacket Temperature In	T5	°F										
Water Jacket Temperature Out	T6	°F										

TABLE 11.2
TEST DATA SHEET
11-5

TEST DATA SHEET

TEST LOCATION
LMC CORPORATION-SPARKS, NY

PROJECT
CONTRACT EY-76-C-03-1307

DATE August 1977

SHEET NO.
2 of 2

DESCRIPTION OF TEST ITEM

GEOTHERMAL ELECTRIC MOTOR

TEST PROCEDURE NO.
LMC-770801A

PREPARED BY

[illegible]

the desired test values, and the dynamometer load applied.

The first series of tests was a repeat of the low speed survey performed earlier, to verify data and procedures prior to testing at high speed. Testing was completed for frequencies of 200, 225, and 250 Hz, corresponding to motor shaft speeds of 6000, 6750, and 7500 rpm, respectively. Total test time was 20 minutes. The water-brake dynamometer used for loading the motor is limited in operating range, so that at speeds less than 8000 rpm, it was only possible to test at torque values up to 100 lbs-ft. Data from these tests are presented in Figures 11.2 through 11.4, based on corresponding data in Tables 11.3 through 11.5. The data trends are in good agreement with those of the previous tests although the absolute values are lower, in some cases. For example, the power factor is considerably less than reported previously. In all probability, this is due to the instrument scale used.

The overall motor efficiency (including viscous drag) for this test series varied from about 71 to 84% at 100 lb-ft torque, while the power factor ranged from 44 to approximately 58%. Actual performance data was in good agreement with the performance predicted by the computer analysis reproduced as Appendix A.

It is significant to note that the temperature rise, from the winding to the cooling fluid remained approximately constant at 22°. The maximum winding temperature observed during this series of tests was 175°F.

Performance testing of the motor was initiated, following the low speed survey. While testing at a frequency of 275 Hz corresponding

MOTOR PERFORMANCE AT 6,000 RPM

LEGEND

- 1 CURRENT
- 2 HORSEPOWER
- 3 EFFICIENCY
- 4 POWER FACTOR

FIGURE 11.2
MOTOR PERFORMANCE AT 6,000 RPM

MOTOR PERFORMANCE AT 6,750 RPM

LEGEND

- 1 CURRENT
- 2 HORSEPOWER
- 3 EFFICIENCY
- 4 POWER FACTOR

FIGURE 11.3
MOTOR PERFORMANCE AT 6,750 RPM
11-9

MOTOR PERFORMANCE AT 7,500 RPM

LEGEND

- 1 CURRENT
- 2 HORSEPOWER
- 3 EFFICIENCY
- 4 POWER FACTOR

FIGURE 11.4
MOTOR PERFORMANCE AT 7,500 RPM
11-10

TABLE 11.3

LOW SPEED SURVEY

200 Hz

SHAFT SPEED, RPM	5,994	5,968
TORQUE, LB-FT	50	100
VOLTAGE, L-N	225	225
LINE CURRENT, AMPS	120	180
VA/PHASE	27,000	40,500
KW/PHASE	10	20
POWER INPUT, KW	30	60
POWER FACTOR, %	37	44
HORSEPOWER	57.1	113.6
POWER OUTPUT, KW	42.6	84.6
MOTOR EFFICIENCY, %	70.4	70.8

TABLE 11.4
LOW SPEED SURVEY
225 Hz

SHAFT SPEED, RPM	6,750	6,750
TORQUE, LB-FT	50	100
VOLTAGE, L-N	260	260
LINE CURRENT, AMPS	110	180
VA/PHASE	28,600	46,800
KW/PHASE	10	25
POWER INPUT, KW	30.	75
POWER FACTOR, %	34.9	53.4
HORSEPOWER	64.3	128.5
POWER OUTPUT, KW	47.98	95.9
MOTOR EFFICIENCY, %	62.5	78.2

TABLE 11.5

LOW SPEED SURVEY

250 Hz

SHAFT SPEED, RPM	7,482	7,514
TORQUE, LB-FT	50	100
VOLTAGE, L-N	281	280
LINE CURRENT, AMPS	115	185
VA/PHASE	32,315	51,800
KW/PHASE	14	30
POWER INPUT, KW	42	90
POWER FACTOR, %	43.3	57.9
HORSEPOWER	71.2	143.1
POWER OUTPUT, KW	53.1	106.8
MOTOR EFFICIENCY, %	79.1	84.3

to a motor speed of 8,250 rpm, severe vibration and excessive noise was experienced. The test was terminated in order to visually inspect the test hardware and facility support equipment. This inspection showed large amounts of oil leaking from the bottom end of the motor shaft. The rotor was checked and found free to rotate. The decision was made to remove the motor from the test stand for disassembly and further inspection. Duration of the performance test series prior to disassembly was 38 min.

During disassembly, foreign material, including some minute aluminum particles were found. The bottom stator end windings were completely burned through, as shown in Figure 11.5.

Although the rotor was free to rotate, there was some binding. This occurred during removal of the rotor from the stator after about ten inches of the rotor had been cleared. Close inspection of the components showed the rotor to be scored on the major diameter, with metal deposits formed on the lower end, from the arcing of the end turns, Figure 11.6. The stator contained pieces of insulation and showed signs of having been rubbed by the rotor.

Inspection of the spherical thrust bearing, shown in Figure 11.7, indicated that some upward movement occurred allowing the part to lift off of the anti-rotation pin and rotate. The thrust bearing plate showed no signs of wear.

The carbon face of the mechanical shaft seal was broken in several places, and showed signs of uneven wear, Figure 11.8. The seal housing and spring were found to be undamaged.

FIGURE 11.5

LOWER END STATOR WINDING-POST TEST

11-16

FIGURE 11.6

ELECTRIC MOTOR ROTOR-POST TEST

SCALE IN INCHES

LMC Corporation

FIGURE 11.7

THRUST BEARING-POST TEST

FIGURE 11.6

MECHANICAL SEAL-POST FLG

Both shaft keys used to drive the spline adaptor connecting the motor to the dynamometer had 0.06 in deep by 0.20 in long grooves in the upper end. These grooves were obviously caused by some rubbing although mating parts showed no signs of interference.

The motor lubricating oil was drained from the test loop and run through a strainer. No foreign particles were found, however, the amount of fluid recovered exceeded the amount started with by approximately one gallon. Since traces of water was also found inside the motor, it appears that there was some leakage in the facility oil-water heat exchanger.

The apparent cause of the failure was the upward and downward movement of the rotor when current was applied during startup. This oscillating movement was a result of changing tolerance stackup between the motor and dynamometer, probably caused by loosening of the retaining nut used to hold the spline to the motor shaft during the repeated startups.

This oscillating movement of the rotor allowed the spherical thrust bearing to lift off of the anti-rotation pin and rotate causing the pin to score the bearing face. As the rotor moved upward, the seal mating ring was displaced downward unloading the mechanical seal. With the seal mating ring displaced downward, the keys started to rub. As the rotor settled downward, there was some misalignment causing the carbon seal face to wear uneven and break off in some areas.

CONCLUSIONS

Although all of the specific goals of this program were not met, several important accomplishments were attained:

- a. The 28-pole synchronous generator was successfully modified to supply 400 Hz. power to the electric motor. The generator was operated to 1,500 rpm, without any problems. Operation at rated speed will require the rotor to be rebalanced.
- b. The electric motor was successfully tested at 250 Hz. Test results prove that the performance at low speeds is as good, or better than, predicted. These results indicate that the motor is capable of achieving rated performance.
- c. The addition of the centering ring to the rotor greatly reduced the problem of magnetic unbalance during startup.

RECOMMENDATIONS

Design information and test results indicate that development of a high-speed down-hole geothermal pump is technically feasible. Some problems were encountered, none of which were associated with the electro-magnetic design. There was some delay in completing the new test facility when LMC Corporation acquired Lear Motors Corporation and the lack of sufficient manpower at critical times.

It is strongly recommended, however, that development of the geothermal pump continue with the following tasks identified as critical to the successful demonstration of the concept:

- a. Conduct test of centrifugal pump using aircraft type high-speed electric motor as the power source and cold water as the test fluid. Commercial high-speed motors are readily available for conducting laboratory tests and could be assembled in a test configuration as shown in Figure 13.1. Although the single-stage centrifugal pump is of conventional design, it is recommended that testing be completed to demonstrate the performance of the diffuser system and suction characteristics of the impeller design.

The use of a commercial motor for pump testing will require some modification to the hydraulic test loop and a method of collecting the discharge, such as a volute is required. In addition, the facility capability should be evaluated to determine the best method for providing the required net positive suction head. This would require a detailed analysis of the structural capability of the water supply tank.

LMC PUMP

AIRCRAFT TYPE 400HZ MOTOR

LMC CORPORATION

PUMP MOTOR TEST ASSEMBLY

FIGURE 13.1
PUMP MOTOR TEST ASSEMBLY
13-2

- b. Refurbish geothermal electric motor, consisting of rewinding the stator and replacing worn or damaged components, such as, seals and bearings.
- c. Instrument high-frequency power supply and electric motor with adequate vibration monitoring equipment including visual readout and automatic alarm and shut down.
- d. Modify method of controlling diesel engine frequency to include either all electronic or electronic-hydraulic. The response time of the present system which is an electric motor driven friction cam is too slow for control when loading the dynamometer.
- e. Test high-frequency power supply at rated conditions. Although this system has operated satisfactorily at 1,500 rpm, it is recommended that it be tested to 1,713 rpm with sufficient vibration monitoring equipment installed for machine protection.
- f. Modify electric motor test facility to include filters on motor cooling oil system and increase water supply system to dynamometer, water jacket and heat exchanger. Present system was found to be inadequate to maintain correct flow and pressure during tests. Improvements should also include the acquisition of automatic data recording equipment, so that a continuous permanent record can be made of the measured parameters. This will permit trends and response times to be evaluated during post-test analysis.
- g. Complete motor performance testing at high speeds on dynamometer stand using high-frequency power supply as source of power.
- h. Conduct design studies to evaluate the segmented motor concept

consisting of multiple short motors connected in series. Although the center locating ring design reduced the problem of magnetic unbalance during startup, a shortened rotor supported by bearings at each end would further reduce the flexibility of the high L/D ratio design. A typical segmented motor design, shown in Figure 13.2, would consist of multiple motor units joined together by an adaptor section. This section provides the rotor bearing support, a stub drive shaft and a means for connecting the end windings. A slotted configuration similar to the stator slots would be used where conductor pairs could be welded and insulated. The multiple motor concept not only reduces the magnetic unbalance further, but is more amenable to tailoring the motor size to a given application.

LMC CORP	
476 Dunn Circle	Sparks, Nevada
TITLE	
SEGMENTED MOTOR- END WINDING CONNECTION	
CODE IDENT.	NUMBER
	206C
SCALE	

FIGURE 13.2
SEGMENTED MOTOR-END WINDING
CONNECTION
13-5

APPENDIX A

ELECTRIC MOTOR COMPUTER ANALYSIS

The following information is in support of the Geothermal Hot Water Pump Report (LMC-770901-A) prepared under Contract EY-76-C-03-1307 from the Energy Research and Development Administration.

The method of analysis used in the computer program is shown below and on the following pages.

The program was utilized to study many possible motor configurations with the final selection defined in Section 6.0.0. Trade off parameters included different materials, number of slots, air gap, etc. As might be expected, many of the motor's parameters were selected in part based upon mechanical considerations.

The following set of graphs and equations is based on those actually used in the computer program. The selected parameters and dimensions are for the machine that was selected and built.

The analysis procedure given below results in the calculation of one operating point only. The computer program repeats portions of the calculations in order to predict motor performance curves.

Data presented in graphical form for the calculations below is stored in tabular form in the computer program.

Input data for the analysis includes the following rotor and stator punching drawings, vanadium permendur core loss and magnetizing curves, amortisseur bar drawing and winding and input data.

For the analysis, the following assumptions are made.

rpm = 11,450

VL-N = 450 volts

freq. = 400 Hz

Winding temp. = 300°C

Windage = 56,000 watts

Friction = 100 watts

Pole Face Loss = 2,400 watts

Stray Load = 2,400 watts

Slots Skewed = 1

Gap = .020

Stack Length = 28 inches (rotor and Stator HI

Rating = 400 hp

Stacking Factor = 0.95 (95%)

Winding = 1 T/X, 1 circuit, 2/3 pitch, 4 poles

Winding Conductor = 0.160" x 0.250" aluminum

65% conductivity

(.314 ohms/1,000 ft. at 20°C)

End rings 60% conductivity = 2.0" ID x 3.5" OD x

0.5" thk

EQ 1

Stator Winding MLT (Mean Turn Length - Feet)

$$MLT = [2 \times HI + \frac{2 \text{ (coil span slots)}}{S1} \pi (ID_1 + D_1) + 3] / 12$$

$$MLT = [2 \times 28 + \frac{2 \times 6}{36} \pi (3.875 + .66) + 3] / 12$$

$$MLT = 5.312 \text{ ft.}$$

EQ 2k_pk_d. (fundamental pitch & distribution factors)For 2/3 pitch 60° phase belt winding k_p = 0.866and k_d = 0.96

$$\therefore k_{pkd} = 0.96 \times 0.866 = 0.831$$

EQ 3

TAE (Stator Effective Turns Per Phase)

$$TAE = (T/C \times S1 \times k_{pkd}) / (\text{phases} \times \text{circuits})$$

$$TAE = (1 \times 36 \times .831) / (3 \times 1) = 9.972$$

EQ 4

CKW = Series Conductors/Phase

$$CKW = TAE \times 2$$

$$CKW = 9.972 \times 2 = 19.944$$

EQ 5R₁ (Resistance Cold Stator per Phase)

$$R_1 = MLT \times (S1/\text{phases}) \times T/C \times (\rho/1000' / 1000)$$

$$R_1 = 5.312 \times (36/3) \times 1 \times (0.314/1000) = 0.020 \Omega/\text{phase cold}$$

EQ 6R_{1H} = Stator resistance hot

$$R_{1H} = R_1 \text{ cold} [1 + .00393 \times (\text{temp } ^\circ\text{C} - 20)]$$

$$R_{1H} = .020 \times (1 + .00393 \times (300 - 20))$$

$$R_{1H} = 0.042 \Omega/\text{phase}$$

STATOR PUNCHING
 $S_1 = 36$ SLOTS - NO SKEW

LMC CORPORATION
 GEOTHERMAL PUMP

ROTOR PUNCHING
(44 SLOTS W/ ONE SLOT SKEW)

AMORTISSEUR BAR
BAR AREA = .081 IN²
BAR LENGTH = 30.0"

LMC CORPORATION
GEOTHERMAL PUMP

A-6

EQ 9

I_1 = estimated motor current

$$I_1 = \frac{HP \times 746}{3 \times V_{L-N} \times PF \times eff}$$

PF = estimated power factor
eff = estimated efficiency

$$I_1 = \frac{400 \times 746}{3 \times 450 \times .85 \times .75} = 347 \text{ amps}$$

EQ 10

H = mmf to saturate rotor bridge

$$H = \frac{CK_w \times M \times I_1}{S_1 \times a_1}$$

a_1 = width of rotor slot

$$H = \frac{19.944 \times 3 \times 347}{36 \times 0.17} = 3392 \text{ amp turns}$$

EQ 11

$KS_2 = K_{sp}'' + \phi \frac{b}{a_2}$; ϕ from graph used in EQ 7
and K_{sp}'' from the graph below:

$$KS_2 = 2 + .14 \frac{.70}{.075} = 3.307$$

EQ 12

 K_2 = rotor slot fringing coefficient

$$K_2 \approx \frac{\lambda^2(5g + W_{20})}{\lambda^2(5g + W_{20}) - W_{20}^2}$$

where λ = rotor slot pitch = $\frac{3.835 \times \pi}{44 \text{ slots}} = 0.274"$

$$W_{20} \approx 2 \times t_{kb} = 2 \times .014 = .028$$

$$K_2 = \frac{.274 (5 \times .02 + .028)}{.274 (5 \times .02 + .028) - .028^2} = 1.030$$

EQ 13

 N_{sp} (average number of slots per pole)

$$N_{sp} = (S_1 + S_2)/2P$$

$$N_{sp} = (36 + 44)/(2 \times 4) = 10$$

EQ 14

Read K_B (belt leakage constant from graph below)

$$\therefore K_B = 1.55$$

EQ 15

 α (skew in electrical degrees)

$$\alpha = 180 \times \frac{\text{slots skewed}}{(S_1/P)}$$

S_1 = whichever is skewed, i.e.
44 for 1 slot skewed in rotor

$$\alpha = 180 \times \frac{1}{(44/4)} = 16/36^\circ$$

EQ 16 C_{SK} (skew factor)

$$C_{SK} = \frac{\sin x/2}{\pi x/360} = \frac{.1410}{.1428} = .987$$

EQ 17 Q (2nd skew factor)

$$Q = 1 - (C_{SK})^2 = 1 - .974 = .026$$

EQ 18 $D_i/D_r = \frac{\text{amortisseur ring ID}}{\text{amortisseur ring OD}} = \frac{2}{3.5} = 5.72$

EQ 19 Select K_{ring} (ring resistance correction factor)
from graph below:

$$\therefore K_{ring} = 1.06$$

EQ 20 R_2 cold (cold reflected rotor resistance)

$$R_2 = [(CK_w)^2 \times 10^{-6} \times 2.079] \frac{\sqrt{L_2^2 + SK^2} \times 100}{S_2 A_b \times \% \text{ cond bar}} + \frac{K_{ring} \times .637 D_r \times 100}{A_r p^2 \times \% \text{ cond ring}}$$

where L_2 = bar length = 30 inches

SK = skew in rotor in inches = .274"

A_b = bar cross sectional area = .081 in²

D_r = ring diameter = 3.5

A_r = ring area = 0.75" x 0.5" = .375 in²

S_2 = rotor slots = 44

$$R_2 = [(19.944)^2 \times 10^{-6} \times 2.079] \frac{\sqrt{30^2 + .274^2} \times 100}{44 \times .081 \times 55} + \frac{1.06 \times .637 \times 3.5 \times 100}{.375 \times 4 \times 60}$$

R_2 = .0132 Ω reflected cold

EQ 21 R_2 hot = R_2 cold $\times (1 + \frac{.00393 \times (\text{temp } ^\circ\text{C} - 20)}{1})$

$$R_2 \text{ hot} = .0132 \times (1 + .00393 \times (300 - 20)) = .0277 \Omega$$

EQ 22 λ_p = pole pitch = $\pi (OD_2 + g)/P$

$$\lambda_p = \pi (3.835 + .020)/4 = 3.028"$$

EQ 23 $K\phi_1$ = flux factor = $\frac{V - I_1 R_1}{V} PF_1$

I_1 and PF_1 estimated current and power factor

$$K\phi_1 = \frac{450 - (347 \times .042 \times .85)}{450} = \frac{437.6}{450} = .972$$

EQ 24 ϕ = flux (kilolines) per pole

$$\phi = \frac{45000 \times V}{F \times C_{KW}} \times K\phi = \frac{45000 \times 450}{400 \times 19.944} \times .972 = 2467 \text{ KL}$$

EQ 25

$$A_1 = \text{stator core area} = 2FL_1DY_1$$

where F = stacking factor = 0.95

L_1 = Height of iron = 28.0"

$$DY_1 = Y_1 = 0.35"$$

$$A_1 = 2 \times .95 \times 28.0 \times 0.35 = 18.62 \text{ in}^2$$

EQ 26

$$BY_1 = \text{stator yoke flux density (KL/in}^2\text{)}$$

$$BY_1 = \frac{\phi}{A_1} = \frac{2467}{18.62} = 132.5 \text{ KL/in}^2 \\ (\text{or } 20.54 \text{ KG})$$

EQ 27

$$A_2 = \text{stator tooth area} = \frac{FL_1S_1T_1}{P}$$

where T_1 = tooth width for saturation

$$A_2 = .95 \times 28.0 \times 36 \times 0.14/4 = 33.52 \text{ in}^2$$

EQ 28

$$Bt_1 = \text{stator tooth flux density (KL/in}^2\text{)}$$

$$Bt_1 = \frac{\phi}{.637 \times A_2} = \frac{2467}{.637 \times 33.52} = 115.54 \text{ KL/in}^2 \\ (17.91 \text{ KG})$$

EQ 29

$$A_3 = \text{rotor yoke area}$$

$$A_3 = 2 \times F \times L_2 \times dy_2$$

$$A_3 = 2 \times .95 \times 28.0 \times .404 = 21.49 \text{ in}^2$$

EQ 30

$$BY_2 = \text{flux density in rotor yoke (KL/in}^2\text{)}$$

$$BY_2 = \frac{\phi \times K_D}{A_3} = \frac{2467 \times .96}{21.49} = 110.2 \text{ (KL/in}^2\text{)} \\ (17.09 \text{ KG})$$

EQ 31

$$A_4 = \text{area of rotor teeth} = \frac{F \times L_2 \times S_2 \times t_2}{P}$$

$$A_4 = \frac{.95 \times 28 \times 44 \times .095}{4} = 27.797 \text{ in}^2$$

EQ 32

Bt_2 = rotor tooth flux density (KL/in²)

$$Bt_2 = \frac{\phi \times K_p}{.637 \times A_4} = \frac{2467 \times .96}{.637 \times 27.797} = 133.75 \text{ KL/in}^2 \\ (20.74 \text{ KG})$$

EQ 33

A_5 = air gap area = $L \lambda_p = 28 \times 3.028 = 84.78 \text{ in}^2$

EQ 34

B_g = air gap flux density

$$B_g = \frac{\phi \times K_p}{.637 \times A_5} = \frac{2467 \times .96}{.637 \times 84.78} = 43.85 \text{ KL/in}^2 \\ (6.80 \text{ KG})$$

EQ 35

LY_1 = magnetic path length of stator yoke (inches)

$$LY_1 = \pi(OD_1 - dy_1)/2P = \pi(6 - .35)/8 = 2.219"$$

EQ 36

LY_2 = magnetic path length of rotor yoke

$$LY_2 = \pi(ID_2 + dy_2)/2P = \pi(1.621 + .404)/8 = 0.795"$$

EQ 37

Look up steel amps turns for Y_1 , Y_2 , t_1 , t_2
using the curve on page 15 ($2.02AT = 1$ oersted)

$$\text{Stat. teeth AT/inch} = 3.5 \times 2.02 = 7.07 \text{ AT/in}$$

$$\text{Rotor teeth AT/inch} = 8.5 \times 2.02 = 17.17 \text{ AT/in}$$

$$\text{Stat. yoke AT/inch} = 8.0 \times 2.02 = 16.04 \text{ AT/in}$$

$$\text{Rotor yoke AT/inch} = 2.6 \times 2.02 = 5.25 \text{ AT/in}$$

EQ 38

Multiply AT/in x magnetic path length for each
steel component to obtain total steel amp turns.

$$LY_1 \times AT_{y1} = 2.219" \times 16.04 = 35.59$$

$$LT_1 \times AT_{t1} = 0.66" \times 7.07 = 4.67$$

$$LY_2 \times AT_{y2} = 0.795" \times 5.25 = 4.17$$

$$LT_2 \times AT_{t2} = 0.695" \times 17.17 = 11.93$$

$$\text{TOTAL STEEL AT} = 56.36$$

EQ 39

$$g_e = \text{effective gap length} = gK_1K_2$$

$$g_e = .020 \times 1.203 \times 1.030 = .0248"$$

EQ 40

$$g_{AT} = \text{gap amp turns} = g_e \times 313 \times B_g$$

$$g_{AT} = .0248 \times 313 \times 43.85 = 340.38 \text{ AT}$$

EQ 41

$$SF = \text{saturation factor} = (g_{AT} + \text{steel AT})/g_{AT}$$

$$SF = (340.38 + 56.36)/340.38 = 1.166$$

EQ 42

$$C_x = \text{reactance factor} = 0.25(3p + 1)$$

where p = pitch in fractional form

$$C_x = 0.25(3 \times \frac{2}{3} + 1) = 0.75$$

EQ 43

$$K_s = \text{combined slot leakage factor} = KS_1 C_x + \frac{S_1}{S_2} KS_2$$

$$K_s = (.75 \times 1.316) + (\frac{36}{44} \times 3.307) = 3.693$$

EQ 44

$$K_{zz} \text{ (zig-zag leakage reactance factor)}$$

$$K_{zz} = \frac{(t_{10} + t_{20})^2}{4(\lambda_1 + \lambda_2)} \text{ where } \begin{aligned} t_{10} &= \text{stator tooth face} = 0.228" \\ t_{20} &= \text{rotor tooth face} = 0.274" \\ \lambda_1 &= \text{stator tooth pitch} = 0.338" \\ \lambda_2 &= \text{rotor tooth pitch} = 0.274" \end{aligned}$$

$$K_{zz} = \frac{(0.228 + 0.274)^2}{4 \times (.338 + .274)} = 0.103$$

EQ 45

$$K_m = \text{gap permeance factor} = \frac{A_g}{g_e \times SF \times P}$$

$$K_m = \frac{84.78}{.0248 \times 1.166 \times 4}$$

$$K_m = 732.96$$

EQ 46

$$K_x = \text{reactance multiplier} = 2\pi f (XK_w)^2 \times 10^{-8}$$

$$K_x = 2\pi \times 400 \times (19.944)^2 \times 10^{-8} = .00999$$

EQ 47

$$SL_1 = \text{slot leakage permeance}$$

$$SL_1 = \frac{9.57 \times K_s \times L_1}{S_1} = \frac{9.57 \times 3.693 \times 28}{36} = 27.488$$

EQ 48

$$ZZ = \text{zig zag permeance} = \frac{1.065 \times 3 \times L_1 \times K_{zz}}{S_1 \times g}$$

$$ZZ = \frac{1.065 \times 3 \times 28 \times .103}{36 \times .020} = 12.798$$

EQ 49

$$\text{End} = \text{End permeance} = \frac{4.71 \times D_e \times \text{ACT}}{S_1 P}$$

where D_e = ave end turn diameter = 4.535"

ACT = average coil throw = 6 slots

$$\text{End} = \frac{4.71 \times 4.535 \times 6}{36 \times 4} = .890$$

EQ 50

$$\text{Belt} = \text{belt permeance} = .00254 \times K_m \times K_B$$

$$\text{Belt} = .00354 \times 732.96 \times 1.55 = 4.022$$

EQ 51

$$\text{Skew} = \text{Skew permeance} = .9702 \times K_m \times K_p \times Q$$

$$\text{Skew} = .9702 \times 732.96 \times .96 \times .026 = 17.75$$

EQ 52

P_L = total leakage permeance =

$$P_L = SL_1 t_{ZZ} + \text{End} + \text{Belt} + \text{Skew}$$

$$P_L = 27.488 + 12.798 + .89 + 4.022 + 17.75 = 62.948$$

EQ 53

P_m = Open permeance

$$P_m = .9702 \times K_m \times C_{sk}$$

$$P_m = .9702 \times 732.96 \times .987 = 701.87$$

EQ 54

P_o = reflected open CKT perm

$$P_o = P_m + P_L/2 = 701.87 + \frac{62.948}{2} = 733.34$$

EQ 55

$$X = \text{stall reactance} = K_X P_L = .00999 \times 62.948 = .629 \Omega$$

EQ 56

$$X_o = \text{no load reactance} = K_X P_o = .00999 \times 733.34 = 7.326 \Omega$$

At this point the standard equivalent circuit for an induction motor may be utilized to predict the machine's performance. In addition to the machine's constants that have been calculated, such items as core loss and windage should be calculated.

The method discussed below gives an approach to core loss calculation.

EQ 57

W_T = stator tooth weight

$$W_T \approx S_1 \times t_1 \times d_1 \times H_1 \times 0.29 \text{ lb/in}^3$$

$$W_T = 36 \times .14 \times .66 \times 28 \times 0.29 = 27 \text{ lbs}$$

EQ 58

W_y = stator yoke weight

$$W_y \approx dy_1 \times \pi \times (OD_1 - dy_1) \times H_1 \times 0.29$$

$$W_y = .35 \times \pi \times (6.5 - .35) \times 28 \times .29 = 54.91 \text{ lbs.}$$

EQ 59

From the core loss table, look up watts/lb for the tooth density then including harmonic effects:

$$\begin{aligned}\text{Stator tooth core loss} &\approx 2 \times W_{pp} \times 27 \text{ lbs} \\ &= 2 \times 35 \times 27 = 1890 \text{ watts}\end{aligned}$$

EQ 60

From the same graph the yoke core is:

$$\begin{aligned}1.5 \times W_{pp} \times 54.91 \text{ lbs} &= \\ 1.5 \times 50 \times 54.91 &= 4118 \text{ watts}\end{aligned}$$

EQ 61

$$\text{Total core loss} = 1890 + 4118 = 6003 \text{ watts}$$

EQ 62

An actual value for K_p may now be calculated:

$$K_p = \sqrt{\frac{X_o - X}{X_o}} = \sqrt{\frac{7.326 - .629}{7.326}} = 0.956 \text{ (0.96 was assumed)}$$

EQ 63

$$I_{NL} = \text{No load current} = \frac{V_{L-N}}{X_o} = \frac{450}{7.326} = 61.42 \text{ amps}$$

EQ 64

$$r_m = \text{representative core loss resistor} = \frac{\text{core loss}}{3 \times I_o^2}$$

$$r_m = \frac{6008}{3 \times (61.42)^2} = .531$$

EQ 65

$$F_3 = \text{calculation constant} = r_2 \frac{r_1 + r_m}{X_o}$$

$$F_3 = .0277 \frac{.042 + .531}{7.326} = .00216$$

EQ 66

$$F_1 = \text{calculation constant} = X - \frac{r_m}{X_o} \times r_1$$

$$F_1 = .629 - \frac{.531}{7.326} \times .629 \times .042 = .627$$

EQ 67

$$F_4 = \text{calculation constant} = r_1 + \frac{r_m}{X_0} \times$$

$$F_4 = .042 + \frac{.531}{7.326} \times .629 = .0875$$

EQ 68

$$F_5 = \text{calculation constant} = I_o r_m$$

$$F_5 = 61.42 \times .531 = 32.61$$

EQ 69

$$F_6 = I_o r_2 = \text{calculation constant}$$

$$F_6 = 61.42 \times .0277 = 1.701$$

EQ 70

$$F_7 = \text{calculation constant} = VK_p$$

$$F_7 = 450 \times .956 = 430.20$$

The following set of equations (EQ 71 - EQ 92) can be repeated for several speeds to obtain a complete performance map. At higher values of slip the reactance or deep bar effects of the rotor conductors must be taken into account.

EQ 71

$$\text{Synch speed} = N_s = \frac{120f}{P} = \frac{120 \times 400}{4} = 12000$$

EQ 71A

$$\text{Slip (s)} = \frac{-\text{RPM}}{N_s} + 1$$

$$s = \frac{-11450}{12000} + 1 = 0.046$$

EQ 72

$$= 1/s = 1/.046 = 21.72$$

EQ 73

$$= 1-s = 1-.046 = .954$$

EQ 74

$$F_3 \times (1/s) = .00216 \times 21.72 = 0.047$$

$$\text{EQ 75} \quad = U = \text{EQ 74} - F_1 = 0.047 - .627 = -.580$$

$$\text{EQ 76} \quad = r_2 \times 1/S = .0277 \times 21.72 = 0.602$$

$$\text{EQ 77} \quad = W = F_4 + \text{EQ 76} = .0875 + .602 = .6895$$

$$\text{EQ 78} \quad = X = \sqrt{U^2 + W^2} = \sqrt{-.582 + .6895^2} = 0.901$$

$$\text{EQ 79} \quad = F_6 \times 1/S = 1.701 \times 21.72 = 36.95$$

$$\text{EQ 80} \quad F_5 + \text{EQ 79} = 32.61 + 36.95 = 69.56$$

$$\text{EQ 81} \quad = \sqrt{(\text{EQ 80})^2 + V^2} = \sqrt{69.56^2 + 450^2} = 455.34$$

$$\text{EQ 82} \quad = I_1 = \text{input current} = \text{EQ 81}/X = 455.34/.901 = 505 \text{ amps}$$

$$\text{EQ 83} \quad = I_2 = \text{rotor reflected current} = F_7/X = 430.2/.901 = 477.5 \text{ amps}$$

$$\text{EQ 84} \quad = \text{Pri } I^2R \text{ loss} = I_1^2 \times 3 \times R_1 = (505)^2 \times .042 \times 3 = 32,133 \text{ watts}$$

$$\text{EQ 85} \quad = \text{Sec (rotor)} I^2R = I_2^2 \times 3 \times R_2 = (477.5)^2 \times 3 \times .0277 = 18,947 \text{ watts}$$

$$\begin{aligned} \text{EQ 86} \quad &= \text{Rotor output} = \text{Rotor } I^2R \times 1/S \times (1-S) \\ &= 18,947 \times 21.72 \times .954 = 392,598 \text{ watts} \end{aligned}$$

$$\begin{aligned} \text{EQ 87} \quad &= \text{Input} = \text{EQ 84} + \text{EQ 85} + \text{core loss} + \text{EQ 86} \\ &\text{Input} = 32,133 + 18,947 + 6008 + 392,598 \\ &\text{Input} = 449,686 \text{ watts} \end{aligned}$$

$$\begin{aligned}\text{EQ 88} &= \text{Output} = \text{EQ 86} - \text{friction \& windage, etc.} \\ &= 392,598 - 56000 - 4900 = 331,698 \text{ watts}\end{aligned}$$

$$\text{EQ 89} = \text{Torque} = \frac{7.04 \times \text{output}}{\text{RPM}} = \frac{7.04 \times 331698}{11450} = 204 \text{ lb-ft}$$

$$\text{EQ 90} = \text{EFF} = \frac{\text{EQ 88}}{\text{EQ 87}} = \frac{331698}{449686} = 74\%$$

$$\begin{aligned}\text{EQ 91} &= P_1 F_1 = \text{EQ 87} / (I_1 \times V_1 \times 3) \\ \text{PF} &= 449686 / (505 \times 450 \times 3) = 0.66\end{aligned}$$

$$\text{EQ 92} = \text{HP} = \frac{\text{torque} \times \text{RPM}}{5253} = \frac{204 \times 11450}{5253} = 445 \text{ HP}$$

One of the major efforts on this phase of the geothermal program included the reprogramming of an induction motor performance analysis computer program written in Super Basic.

The program calculates motor electromagnetic constants, speed torque data, efficiency, power factor, and other related parameters over a complete range of slip values from stall to no load conditions.

This section contains the input format for the program, the complete program listing, program outputs for selected operating conditions, and comparison data between predicted motor performance and test data.

The input format consists of motor electromagnetic geometry, wire data, winding data and some data derived from curves. This input format is given on pages C21 thru C27. Pages C28 thru C36 give the complete program listing as utilized for the geothermal motor analysis. Actual outputs are shown on pages C37 thru C56.

The first page of each run of the program contains a print out of input data such as operating voltage, frequency, etc.

The program output begins on the second page with calculated parameters such as temperature factor, resistances and reactances. The parameters are as shown in the electromagnetic section of this report. Performance parameters start on the third page with speed, torque, current and efficiency. These performance parameters are completed on the fourth page with rotor and stator losses and power factor. The fifth page is the final output and shows miscellaneous data such as motor parametric ratios, stresses and areas.

DATA FORMAT

```

1000      DATA      A1, A2, A3, A4, A5
                A1 = Rated hp
                A2 = Rated rpm
                A3 = Rated voltage L-N rms
                A4 = Input frequency Hz
                A5 = Number of poles

031       PRINT     "MONTH DAY, YEAR"

1002      DATA      A6, A7, A8, A9, B1
                A6 = Winding temp °C
                A7 = Rotor windage watts
                A8 = Motor friction watts
                A9 = Pole face (or surface) watts loss
                B1 = Stray load losses watts loss

1004      DATA      B2, B3, B4, B5, B6
                B2 = Frame OD inches
                B3 = Motor total length
                B4 = Air gap length
                B5 = Skew in slots
                B6 = End turn length

065       PRINT     "ROTOR SLOT IS _____" }
067       PRINT     "STATOR SLOT IS _____" } open trapazoid,
                                                    rounded bottom,
                                                    round closed, etc.

1006 } DATA 0, 0, 0, B(23), H(23), core loss wpp (23)
1008 }          (x(I)), y(I)), (z(I))
1010 }
1012 }
1014 }
1016 }
1018 }
1020 }

1022 } Reserved for future steel tables
1099 }

1100      DATA      B7, B8, B9, C1, C2
                B7 = Stator stacking factor (1.0 or less)
                B8 = Stator height of iron
                B9 = Stator steel density lbs/in3
                C1 = stator slot opening width e (Graph 1 or 2)
                C2 = Stator slot opening depth d (Graph 1 or 2)

```

202 PRINT "STATOR STEEL IS _ _ _ _ _"

1102 DATA C3, C4, C5, C6, C7 (Graph 1 or 2)
 C3 = Depth of opening taper C (Stator)
 C4 = Main slot depth B (Stator)
 C5 = " " width near surface = A1 (Stator)
 C6 = " " " " yoke = A2 (Stator)
 C7 = " " radius R (Stator)

1104 DATA C8, C9, D1, D2, D3
 C8 = KSI for stator slot (Graph 1 or 2)
 C9 = $t^{1/3}$ for saturation (Stator punching drawing)
 D1 = Stator OD
 D2 = Stator ID
 D3 = Stator Y1

1106 DATA D4, D5, D6, D7
 D4 = Number of stator slots
 D5 = Punching thickness (Stator)
 D6 = λ_1 (Stator slot pitch)
 D7 = Stator core loss multiplier (1.0 for steel table in data)

1108 DATA D8, D9, E1, E2, E3
 D8 = Stator square mills/cond
 D9 = Turns per coil
 E1 = Winding pitch in slots
 E2 = $KP_1 Kd_1$
 E3 = Percent conductivity compared to copper

1110 DATA E4, E5, E6, E7
 E4 = Skew constant CSK (Graph 5)
 E5 = Belt Leakage constant K_g (Graph 4)
 E6 = Stator wire lbs/1000'
 E7 = Stator wire $\sim$ /1000' at 20°C
 E8 = Skew constant Q (Graph 5)

1112 DATA E9, F1, F2, F3, F4
 E9 = Rotor stacking factor (1.0 or less)
 F1 = Rotor stack length
 F2 = Rotor steel density lbs/in³
 F3 = Rotor slot opening width (Graph 1 or 2)
 F4 = Rotor slot opening depth (Graph 1 or 2)

GRAPH 1

VARIABLES		GRAPH 1 SYMBOL	DESCRIPTION
ROTOR	STATOR		
F3	C1	e	Slot opening width
F4	C2	d	Slot opening depth
F5	C3	c	Depth of opening taper
F6	C4	b	Main slot depth
F7	C5	a1	Main slot width near surface
F8	C6	a2	Main slot width near yoke
F9	C7	R	Main slot radius

GRAPH 2

GRAPH 3

GRAPH 4

GRAPH 5

1114 DATA F5, F6, F7, F8, F9 (Graph 1)
 F5 = Rotor slot depth of opening taper (C)
 F6 = Main rotor slot depth (b)
 F7 = Main rotor slot width near surface (A1)
 F8 = Main rotor slot width near yoke (A2)
 F9 = Main rotor slot radius (R)

271 PRINT "ROTOR MATERIAL IS _ _ _ _ _"

1116 DATA G1, G2, G3, G4, G5
 G1 = Rotor KS2 (Graphs 1 or 2 and 3)
 G2 = Rotor t 1/3 (Rotor tooth width from rotor
 G3 = Rotor OD punching drawing)
 G4 = Rotor ID
 G5 = Rotor yoke Y2

1118 DATA G6, G7, G8
 G6 = Number of rotor slots
 G7 = Rotor punching thickness inches
 G8 = Rotor slot pitch at gap inches = $\lambda 2$

1120 DATA G9, H1, H2, H3, H4
 G9 = Rotor skew in inches
 H1 = Rotor bar length in inches
 H2 = Rotor bar area in square inches
 H3 = Bar conductivity compared to copper = 100% @ 20°C
 H4 = Resistance correction factor at stall cdbx (Graph 10)

1122 DATA H5, H6, H7, H8, H9
 H5 = Reactance factor for bar at stall cdbx (Graph 10)
 H6 = Ring OD
 H7 = Ring ID
 H8 = Ring cross section area in²
 H9 = Ring conductivity compared to 20°C copper = 100%

1124 DATA I1, I2, I3, I4
 I1 = K-ring (Graph 9)
 I2 = Bar mat'l lbs/in³
 I3 = Ring mat'l lbs/in³
 I4 = Ring axial length

GRAPH 9

GRAPH 10

```

001 PRINT"THREE PHASE INDUCTION MOTOR"
002 DIM X(25),Y(25),Z(25)
003 PRINT"ANALYSIS AND PREFORMANCE PROGRAM"
004 DIM A(50),B(50),C(50),D(50),E(50),F(50),G(50)
005 PRINT" "
006 DIM R(50)
007 PRINT"ASSUMPTIONS"
008 FOR Y=2 TO 11
009 PRINT"1-SINGLE STAR CONNECTION"
010 PRINT" "
011 PRINT"2-ONE IN HAND WINDING"
012  $A(X,Y)=(A(X-1,Y+1)+A(X+1,Y+1)+A(X-1,Y-1)+A(X+1,Y-1))/4$ 
013 PRINT"3-NO STATOR WIRE SKIN EFFECT"
014 NEXT X
015 PRINT"4-NO HARMONIC EFFECTS"
016 NEXT Y
017 PRINT"5-PITCH FROM 0.33 TO 1.0P.U."
018 PRINT"6-60 ELEC. DEG. PHASE BELTS"
019 PRINT" "
020 PRINT" "
021 PRINT "GENERAL DESCRIPTION"
022 DIM R(12,12)
023 READ A1,A2,A3,A4,A5
024 FOR Y=2 TO 11
025 PRINT" "
026 FOR X= 2 TO 11
027 PRINT"HP","RPM","V(LN)","FRECO","POLES"
028  $R(X,Y)=(R(X-1,Y+1)+R(X+1,Y+1)+R(X-1,Y-1)+R(X+1,Y-1))/4$ 
029 PRINT A1,A2,A3,A4,A5
030 FOR I= 1 TO 4
031 PRINT"MARCH 5,1975"
032 NEXT Y
033 PRINT" "
034 P1=R(6,5)
035 PRINT"OPFRATING CONDITIONS"
036 D=P1-A1
037 PRINT"TEMP","WINDAGE","FRICTION"
038 IF D < .02 THEN 101
039 PRINT"DEG C","WATTS","WATTS"
040 NEXT I
041 READ A6,A7,A8,A9,P1
043 PRINTA6,A7,A8
045 PRINT"POLE FACE WATTS=",A9
047 PRINT"STRAY LOAD WATTS=",P1
049 PRINT" "
050  $X(J)=SIN((C(J)-1)*P*11)$ 
051 PRINT"INPUT DIMENSIONS"
053 READP2,P3,P4,P5,P6
055 PRINT"FRAME OD=",P2
057 PRINT"MOTOR TOTAL LENGTH=",P3
059 PRINT"GAP LENGTH=",P4
060 NEXT J
061 PRINT"SLOTS SKEWED=",P5
063 PRINT"END TURN LENGTH=",P6
065 PRINT"ROTOR SLOT IS CLOSED BRIDGE TKR=.014"

```

```

067 PRINT"STATOR SLOT IS OPEN TRAPAZOID WITH OVERHANG"
069 PRINT" "
070 F=0
075 FOR K=1 TO A
080 F=F+X(K)
085 F=F+Y(K)
090 NEXT K
095 F=E/A
100 F=F/A
101 FOR I=1 TO 23
102 READ X,Y,Z
103 X(I)=X
104 Y(I)=Y
105 Z(I)=Z
106 NEXT I
110 G=G+0.5
111 G=G/H
115 IF H<3 THEN 160
120 IF H<5 THEN 180
125 IF H<7 THEN 200
130 IF H<9 THEN 220
135 IF H<11 THEN 240
140 IF H<13 THEN 260
145 IF H<15 THEN 280
150 IF H<17 THEN 300
155 IF H<19 THEN 320
157 GO TO 340
160 PRINT"KP1KD1=",G
165 H=3
170 PRINT" "
175 GO TO 045
180 PRINT"KP3KD3=",G
185 H=5
190 PRINT" "
195 GO TO 045
200 READ B7, B8, B9, C1, C2
202 PRINT"STATOR STEEL IS VANADIUM PERMENTUR"
203 STOP
205 PRINT "STACK", "STACK", "STEFL", "SLOT", "SLOT"
207 PRINT "FACT", "LEN", "LRS/IN", "E", "D"
209 PRINT B7, B8, B9, C1, C2
210 PRINT" "
211 READ C3, C4, C5, C6, C7
213 PRINT "SLOT", "SLOT", "SLOT", "SLOT", "SLOT"
215 PRINT "C", "E", "A1", "A2", "R"
217 PRINT C3,C4,C5,C6,C7
219 READ C8, C9, D1, D2, D3
220 PRINT"KP7KD7=",G
221 PRINT "KS1", "T1/3", "OP1", "ID1", "Y1"
223 PRINT C8,C9,D1,D2,D3
225 READ D4, D5, D6, D7
227 PRINT "S1", "T LAM", "SSP", "CLX"
229 PRINT D4, D5, D6, D7
230 PRINT" "
231 PRINT " "
233 PRINT "STATOR WINDING DATA"
235 READ D8, D9, E1, E2, E3

```

```

237 PRINT "SQUARE", "TURNS", "SLOTS", " ", "PERC"
239 PRINT "MILLS", "COIL", "PITCH", "KP9KD9=", "COND"
240 PRINT "KP9KD9=", G
241 PRINT D8, D9, E1, F2, F3
243 READ E4, E5, E6, E7, E8
245 PRINT "SKEW", "BELT", "LPS/", "O4MS/", "SKEW"
247 PRINT "CSK", "CST", "1000", "1000", "0"
249 PRINT E4, E5, E6, E7, E8
250 PRINT " "
251 PRINT " "
252 GO SUB 2000
253 PRINT "ROTOR MAGNETIC GEOMETRY OR PUNCHING DATA"
255 READ F9, F1, F2, F3, F4
257 PRINT "STACK", "ROTOR", "STEEL", "ROTOR", "ROTOR"
259 PRINT "FACT", "HI", "LR/IN", "E", "F"
260 PRINT "KP11KD11=", G
261 PRINT E9, F1, F2, F3, F4
263 READ F5, F6, F7, F8, F9
265 PRINT "ROTOR", "ROTOR", "ROTOR", "ROTOR", "ROTOR"
267 PRINT "C", "R", "A1", "A2", "R"
269 PRINT F5, F6, F7, F8, F9
270 PRINT " "
271 PRINT "ROTOR MATERIAL IS VANADIUM PERMENDUE"
273 READ G1, G2, G3, G4, G5
275 PRINT "ROTOR"
277 PRINT "KS2", "T1/3", "OD2", "ID2", "Y2"
279 PRINT G1, G2, G3, G4, G5
280 PRINT "KP13KD13=", G
281 READ G6, G7, G8
283 PRINT "S2", "ELAM", "RSP"
285 PRINT G6, G7, G8
287 PRINT " "
289 PRINT "AMORTISSEUR BAR AND END RING(S) DATA"
290 PRINT " "
291 READ G9, H1, H2, H3, H4
293 PRINT "ROTOR", "BAR", "BAR", "BAR", "BAR"
295 PRINT "SKEW", "LONG", "IN2", "COND", "CFRR"
297 PRINT G9, H1, H2, H3, H4
299 READ H5, H6, H7, H8, H9
300 PRINT "KP15KD15=", G
301 PRINT "BAR", "RING", "RING", "RING", "RING"
303 PRINT "CDEX", "OD", "ID", "AREA", "COND"
305 PRINT H5, H6, H7, H8, H9
307 READ I1, I2, I3, I4
309 PRINT "K", "BAR", "RING", "RING"
310 PRINT " "
311 PRINT "RING", "LR/IN", "LR/IN", "LENC"
313 PRINT I1, I2, I3, I4
315 PRINT " "
317 PRINT "INPUT COMPLETE PER ABOVE"
319 PRINT " "
320 PRINT "KP17KD17=", G
321 PRINT "OUTPUT BELOW"
325 H=19
330 PRINT " "
335 GO TO 045

```



```

340 PRINT"KP19KD19=",G
345 PRINT" "
350 PRINT " "
352 I5=1.0+(A6* .00393)
354 I6= 2.0* E1 *3.1416 *(D2+C4)
356 I6=I6/D4
358 I6=I6+3.0+(2*R8)
360 I6=I6/12.0
362 I7=I6*D9*D4/3.0
364 I8=I5* I7*E7/1000.0
366 I9=I7*E7/1000.0
368 J1= I7*3*E6/1000.0
370 PRINT "TEMP", "MLT", "R1", "R1", "STATOR"
372 PRINT "FACT", "FT", "COLD", "HOT", "CWLT"
374 PRINT I5 ,I6, I9, I8, J1
376 J2=(D9*D4/3)*E2
378 J3=J2*2
380 J4=J3*J3*.000002079
382 J5=((F1*F1)+(G9*G9))+0.5
384 J5=J5*100/(G6*H2*H3)
386 J6=J5*I5*H4*J4
388 J7=I1*0.637*((H6+H7)/2.0)*100
390 J7=J7/(H8*A5*A5*H9)
392 J8=J7*I5*J4
394 J9=J6+J8
396 K1=J9/I5
398 PRINT"PHASE","BAR","RING","R2","R2"
400 PRINT "CKW", "COLD", "COLD", "COLD", "HOT"
402 PRINT J3,J5,J7,K1,J9
404 PRINT "NOTE:DEEP BAR R2 FACTOR NOT INCLUDED"
406 PRINT"IN BAR COLD BUT INCLUDED IN R2 HOT AND COLD"
408 K2=H1*H2*G6*I2
410 K3=(0.7854*H6*H6)-(0.7854*H7*H7)
412 K3=K3*2.0*I4*I3
414 K4=(D6-C1)*C2
416 K4=K4+((C3+C4)*C9)
418 K4=K4*B8*B7*D4*B9
420 K5=(0.7865*D1*D1)-(0.7854*(D1-D3-D3)*(D1-D3-D3))
422 K5=K5*B8*B7*B9
424 K6=((G3-F3)*F4)+((F5+F6)*G2)
426 K6=K6*G6*F1*E9*F2
428 PRINT "BARS", "RINGS", "ST", "SY", "RT"
430 PRINT "LRS", "LRS", "LRS", "LRS", "LRS"
432 PRINT K2,K3,K4,K5,K6
434 K7=0.7854*(C3-F6-F6)*(G3-F6-F6)
436 K7=K7-(0.7854*G4*G4)
438K7=K7*F1*E9*F2
440 K8=J1+K4+K5
442 K9=K2+K3+K6+K7
444 L1=K8+K9
446 L2=(C5+C6)*C4/2
448L3=D8*D9*2/(1000*1000)
450 L4=L3/L2
452 PRINT"RY","STAT","ROTOR","TOT","WIND"
454 PRINT"LRS","LRS","LRS","EMWT","FF"

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456 PRINTK7,K8,K9,L1,L4
458 PRINT" "
460 PRINT"MAGNETIC PARAMETERS BELOW"
462 PRINT" "
500 L5=A1*311/A3
502 L6=D6*((5*R4)+C1)
504 L6=L6/((D6*((5*R4)+C1))-(C1*C1))
506 L7=G8*((5*R4)+F3)
508 L7=L7/((G8*((5*R4)+F3))-(F3*F3))
510 L8=A3-(L5*18*.5)
512 L8=L8/A3
514 L9=45000*A3*L8/(44*J3)
516 PRINT"GUESS","CARTER","CARTER","GUESS","FLUX"
518 PRINT"AMPS","STAT","EOTOR","KPHI","KL"
520 PRINTL5,L6,L7,L8,L9
522 GO SUB 2000
524 M1=2*B7*B8*D3
526 M2=L9/M1
528 M3=B7*B8*D4*C9/A5
530 M4=L9/(0.637*M3)
532 M5=2*E9*F1*G5
534 M6=L9*((100-A5)/100)
536 M7=M6/M5
538 M8=F9*F1*G6*G2/A5
540 M9=L9*((100-A5)/100)/(0.637*M8)
542 N1=3.1416*(G3+R4)/A5
544 N2=(B8+F1)/2
546 N3=N1*N2
548 N4=L9*((100-A5)/100)/(0.637*N3)
550 PRINT"FLUX DENSITIES IN KL/IN2"
552 PRINT"BY1","BT1","BY2","BT2","PC"
554 PRINT M2,M4,M7,M9,N4
556 A=M2
558 GO SUB 3000
560 P3=B
562 P4=C
564 A=M4
566 GO SUB 3000
568 P5=B
570 P6=C
572 A=M7
574 GO SUB 3000
576 P7=B
578 A=M9
580 GO SUB 3000
582 P8=B
584 P9=3.1416*(D1-D3)/(2*A5)
586 Q1=P9*P3
588 Q2=(Q2+C3+C4)*P5
590 Q3=3.1416*(G4+G5)/(2*A5)
592 Q4=Q3*P7
594 Q5=P8*(F4+F5+F6)
596 Q6=P4*L6*L7*313*N4
598 Q7=Q1+Q2+Q4+Q5+Q6
600 Q8=Q7/Q6

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602 PRINT"MAGNETIZING AMP TURNS"
604 PRINT"SYOKE","ST","RYOKE","RT","GAP"
606 PRINT Q1,Q2,Q4,Q5,Q6
608 Q9=P4*K5
610 R1=P6*K4
612 PRINT"SATURATION FACTOR=",Q8
614 PRINT"STATOR TEETH CORE LOSS WATTS=",R1
616 PRINT"STATOR YOKE CORE LOSS WATTS=",Q9
650 PRINT" "
652 PRINT"REACTANCE CALCULATIONS BELOW"
654 PRINT" "
656 R2=D4/A5
658 R3=E1/R2
660 IF R3>.66 THEN 666
662 R4=0.25*((6*R3)-1)
664 GO TO 668
666 R4=0.25*((3*R3)+1)
668 R5=(C8*R4)+((D4/G6)*G1)+(0.25*C8*(1-R4))
670 R6=((C1+F3)*(C1+F3))/(4*(G8+D6))
672 R7=N3/(L6*L7*R4*Q8*A5)
674 R8=(6.2832*A4*J3*J3)/(1000*1000*100)
676 PRINT"CX","KS","KZZ","KM","KX"
678 PRINT R4,R5,R6,R7,R8
680 R9=D2+C2+C3+C4
682 S1=9.57*R5*B8/D4
684 S2=3.195*R8*R6/(D4*R4)
686 S3=4.71*R9*E1/(D4*A5)
688 S4=0.0035*R7*F5
690 S5=0.9702*R7*((100-A5)/100)*E8
692 PRINT"PERMEANCES"
694 PRINT"SLOT","ZZ","END","BELT","SKEW"
696 PRINT S1,S2,S3,S4,S5
698 S6=S1+S2+S3+S4+S5
700 S7=.9702*R7*E4
702 S8=S7+(S6/2)
704 S9=R8*S6
706 T1=R8*S8
708 PRINT"PL","PM","PO","X","XO"
710 PRINT S6,S7,S8,S9,T1
712 PRINT"X=S.C. REACT/PHASE, XO=O.C. REACT/PHASE"
714 T2=((T1-S9)/T1)*0.5
716 T3=A3/T1
718 T4=(Q9+R1)/(3.0*T3*T3)
720 T5=(J9*(I8+T4))/T1
722 T6=S9-((T4*I8)/T1)
724 PRINT"KP","INL","RM","F3","F1"
726 PRINT T2,T3,T4,T5,T6
728 T7=I8+(T4*S9/T1)
730 T8=T3*T4
732 T9=T3*J9
734 U1=A3*T2
736 PRINT"F4","F5","F6","F7"
738 PRINT T7,T8,T9,U1
740 GO SUB 2000
744 PRINT"MOTOR PREFORMANCE DATA BFLOW"
750 FOR L=1 TO 50

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752 K=1.01-(L*0.02)
754 U2=1.0/K
756 U3=1.0-K
758 U4=T6
760 U5=T5*U2
762 U6=U5-U4
764 U7=T7
766 U8=J9*U2
768 U9=U7+U8
770 V1=((U6*U6)+(U9*U9)):0.5
772 V2=T8
774 V3=T9*U2
776 V4=V2+V3
778 V5=((V4*V4)+(A3*A3)):0.5
780 A(L)=V5/V1
782 V6=U1/V1
784 B(L)=A(L)*A(L)*18*3.0
786 C(L)=V6*V6*J9*3.0
788 V7=R1+Q9
790 V8=C(L)*U2*U3
792 V9=B(L)+C(L)+V7+V8
794 X1=A7+A8
795 X1=X1*U3*U3
796 X2=V8-X1
798 D(L)=U3*120.0*A4/A5
800 E(L)=7.04*X2/D(L)
802 F(L)=(X2/V9)*100.0
804 G(L)=V9*100.0/(A3*A(L)*3.0)
806 NEXT L
810 PRINT"SPEED","TORQ","INPUT"
812 PRINT"RPM","LB-FT","AMPS","EFF"
814 FOR M=1 TO 50
816 PRINTD(M),E(M),A(M),F(M)
818 NEXT M
820 GO SUB 2000
822 PRINT"SPEED","STAT","ROTOR"
824 PRINT"RPM","I2R","I2R","PF"
826 FOR N=1 TO 50
828 PRINT D(N),R(N),C(N),G(N)
830 NEXT N
832 A1=A1
833 GO SUB 2000
834 PRINT" MISC. OUTPUT BELOW"
836 GO SUB 4000
838 A1=A1
840 PRINT" "
842 PRINT" "
844 PRINT" LEAR MOTORS CORP"
846 PRINT"5980 ALPHA AVE"
848 PRINT"RENO,NEV. 89506"
850 PRINT
852 PRINT" "
854 PRINT"END-----END-----END-----END-----END"
1000 DATA 380,12000,450,400,4
1002 DATA 371,56000,100,2400,2400
1003 Z3=A(3,3)

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1004 DATA 6.5,42,.020,1,3
1005 Z5=A(5,5)
1006 DATA 0,0,0,45,2.5,13.5,50,2.6,15,55,2.67,16.6
1008 DATA 60,2.8,18.5,65,2.9,21,70,3.05,23
1010 DATA 75, 3.2, 26, 80, 3.4, 29, 85, 3.65, 32
1011 W1=A(7,7)
1012 DATA 90, 3.95, 36, .95, 4.4, 39, 100, 4.8, 46
1013 W3=A(7,9)
1014 DATA 105, 5.5, 48, 110, 6.2, 54, 115, 7.4, 56.5
1015 W5=A(7,11)
1016 DATA 120, 8.8, 63, 125, 10.5, 66.5, 130, 13.5, 72
1018 DATA 135, 20, 78, 140, 36, 85, 145, 100, 92
1020 DATA 150,1000,116
1100 DATA .95,28,.29,.11,.03
1102 DATA .02,.6626,.235,.235,.01
1104 DATA 1.33,.14,6,3.875,.35
1106 DATA 36,.014,.3381,1.0
1108 DATA 39200,1,6,.831,66
1110 DATA .9965,1.55,42.5,.314,.006
1112 DATA .95,28,.29,.005,.014
1114 DATA .085,.7,.17,.075,.0375
1116 DATA 3.1,.095,3.835,1.625,.404
1118 DATA 44,.014,.2738
1120 DATA .2738,35,.075,66,1
1122 DATA 1,3.5,2,.375,66
1124 DATA 1.06,.11,.11,.5
1998 GO TO 9999
2000 PRINT " "
2002 A(3,2)=Z2
2003 A(3,3)=Z3
2004 PRINT " "
2005 A(5,5)=Z5
2006 PRINT " "
2008 PRINT " "
2010 PRINT " "
2011 A(7,7)=W1
2012 PRINT " "
2013 A(7,9)=W3
2014 PRINT " "
2015 A(7,11)=W5
2016 PRINT " "
2020 PRINT " "
2022 PRINT " "
2024 PRINT " "
2026 PRINT " "
2028 PRINT " "
2030 RETURN
3000 A=A
3002 J=1
3004 IF X(J)>A THEN 3012
3006 IF J>22 THEN 3032
3008 J=J+1
3010 GO TO 3004
3012 N5=X(J)-X(J-1)
3014 N6=Y(J)-Y(J-1)
3016 N7=Z(J)-Z(J-1)

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3018 N8=A-X(J-1)
3020 N9=N8/N5
3022 P1=N9*N6
3024 P2=N9*N7
3026 B=Y(J-1)+P1
3028 C=Z(J-1)+P2
3030 GO TO 3034
3032 PRINT"FLUX DENSITY OFF TABLE"
3034 RETURN
4000 R(1)=D1*D1*P8
4002 R(2)=G3*G3*F1
4004 R(3)=5.7/K9
4006 R(4)=5.7/K8
4008 R(5)=(K2+K3+J1)/(K4+K5+K6+K7)
4010 PRINT "STATOR D SQ L=",R(1)
4012 PRINT "ROTOR D SQ L=",R(2)
4014 PRINT"ROTOR RISE DEG C/KW/SEC=",R(3)
4016 PRINT"STATOR DEG C/KW/SEC=",R(4)
4018 PRINT"RATIO CU WT/FE WT=",R(5)
4020 R(6)=L5 * 1000*1000/D8
4022 R(7)=I8/J9
4024 R(8)=J9/S9
4026 R(9)=E1/D4
4027 R(9)=R(9)*A5
4028 R(10)=G3/F1
4030 PRINT" "
4032 PRINT"STATOR AMPS/SQ IN AT EST CURRENT. =",R(6)
4034 PRINT"R1/R2 HOT STALL=",R(7)
4036 PRINT"R2/X HOT STALL=",R(8)
4038 PRINT"P.U. STATOR PITCH=",R(9)
4040 PRINT"ROTOR D/L RATIO=",R(10)
4042 R(11)=3.1416*G3*(F1+I4+I4)
4044 R(11)=R(11)+(1.57*G3*G3)
4046 R(12)=3.1416*D1*(B8+P6+P6)
4048 R(13)=3.1416*D2*(P8+P6+P6)
4050 R(14)=1.57*((D1*D1)-(D2*D2))
4052 R(15)=R(12)+R(13)+R(14)
4054 PRINT "MOTOR SURFACE AREAS(INCHES SQ)"
4056 PRINT"ROTOR","STOP","STID","STEND","STTOT"
4058 PRINT R(11),R(12),R(13),R(14),R(15)
4060 R(16)=R(15)+R(11)
4062 PRINT"TOTAL MOTOR SURFACE AREA=",R(16)
4064 R(17)=K2/(H1*G6)
4066 R(18)=(G4/2)+G5+(F6/2)
4068 R(19)=A2*A2
4070 R(20)=0.0000284*R(17)*R(18)*R(19)
4072 PRINT"FORCE ON BAR (LBS)=",R(20)
4074 R(21)=K6/(H1*G6)
4076 R(22)=0.0000284*R(21)*R(18)*R(19)
4078 PRINT"FORCE ON TOOTH ROOT DUE TO TOOTH ONLY=",R(22)
4080 R(23)=(3.1416*(G4+G5+G5)/G6)-F8
4082 R(24)=(R(20)+R(22))/R(23)
4084 PRINT" TOOTH ROOT STRESS(PSI)=",R(24)
4086 RETURN
9999STOP
10000END
>

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THREE PHASE INDUCTION MOTOR,
ANALYSIS AND PERFORMANCE PROGRAM

ASSUMPTIONS

- 1-SINGLE STAR CONNECTION
- 2-ONE IN HAND WINDING
- 3-NO STATOR WIRE SKIN EFFECT
- 4-NO HARMONIC EFFECTS
- 5-PITCH FROM 0.33 TO 1.0P.U.
- 6-60 ELEC. DEG. PHASE BELTS

GENERAL DESCRIPTION

HP	RPM	VOLTS	FREQ	POLES
350	12000	450	400	4

OPERATING CONDITIONS

TEMP	WINDAGE	FRICTION
DEG C	WATTS	WATTS
371	56000	1000
POLE FACE WATTS=		1000
STRAY LOAD WATTS=		1000

INPUT DIMENSIONS

FRAME OD= 6.5
MOTOR TOTAL LENGTH= 42
GAP LENGTH= 2E-02
SLOTS SKEWED= 1
END TURN LENGTH= 3
ROTOR SLOT IS CLOSED BRIDGE TCR=.014
STATOR SLOT IS OPEN TRAPAZOID WITH OVERHANG

STATOR STEEL IS VANADIUM PERMENDUR

STACK	STACK	STEEL	SLOT	SLOT
FACT	LEN	LBS/IN	E	D
.95	28	.29	.11	3E-02
SLOT	SLOT	SLOT	SLOT	SLOT
C	R	A1	A2	R
2E-02	.6626	.235	.235	1E-02
KS1	T1/3	OD1	ID1	Y1
1.316	.14	6	3.875	.35
S1	T LAM	SSP	CLX	
36	1.4E-02	.3381	1	

STATOR WINDING DATA

SQUARE	TURNS	SLOTS	KPKD	PFRC
MILLS	COIL	PITCH		COND
39200	1	6	.831	66
SKEW	BELT	LBS/	OHMS/	SKEW
CSK	CST	1000	1000	C
.967	1.55	42.5	.314	6E-03

ROTOR MAGNETIC GEOMETRY OR PUNCHING DATA

STACK	ROTOR	STEEL	ROTOR	ROTOR
FACT	H1	LB/IN	E	D
.95	28	.29	5E-03	1.4E-02
ROTOR	ROTOR	ROTOR	ROTOR	ROTOR
C	R	A1	A2	R
8.5E-02	.7	.17	7.5E-02	3.75E-02

ROTOR MATERIAL IS VANADIUM PERMENDUR

ROTOR				
KS2	T1/3	OD2	ID2	Y2
3.307	9.5E-02	3.835	1.625	.404
S2	RLAM	RSP		
44	1.4E-02	.2738		

AMORTISSEUR BAR AND END RING(S) DATA

ROTOR	BAR	BAR	BAR	BAR
SKEW	LONG	IN2	COND	CDBR
.2738	30	7.5E-02	55	1
BAR	RING	RING	RING	RING
CDBX	OD	ID	AREA	COND
1	3.5	2	.375	60
K	BAR	RING	RING	
RING	LB/IN	LB/IN	LFNG	
1.06	.11	.11	.5	

INPUT COMPLETE PER ABOVE

OUTPUT BELOW

TEMP	MLT	R1	R1	STATOR
FACT	FT	COLD	HOT	CUNT
2.45803	5.3126479	2.0018057E-02	4.9204985E-02	8.1283513
PHASE	BAR	RING	R2	R2
CKW	COLD	COLD	COLD	HOT
19.944	15.427735	.51579306	1.3184493E-02	
3.240788E-02				

NOTE: DEEP BAR R2 FACTOR NOT INCLUDED
IN BAR COLD BUT INCLUDED IN R2 HOT AND COLD

BARS	RINGS	ST	SY	RT
LBS	LBS	LBS	LBS	LBS
10.89	.7127505	28.438834	48.228807	26.589238
RY	STAT	ROTOR	TOT	WIND
LBS	LBS	LBS	FMWT	FF
19.924232	84.795992	58.116221	142.91221	.50349686

MAGNETIC PARAMETERS BELOW

GUESS	CARTER	CARTER	GUESS	FLUX
AMPS	STAT	ROTOR	KPH1	KL
262.62222	1.2054294	1.0008704	.98564186	2801.2112
FLUX DENSITIES IN KL/IN2				
BY1	BT1	BY2	BT2	BS
134.36688	117.18723	111.75067	135.64562	44.476479
MAGNETIZING AMP TURNS				
SYOKE	ST	RYOKE	RT	GAP
1842.8389	117.46527	83.916461	748.77109	335.9111
SATURATION FACTOR=		9.3146752		
STATOR TEETH CORE LOSS WATTS=		125.66333		
STATOR YOKE CORE LOSS WATTS=		316.14138		

REACTANCE CALCULATIONS BELOW

CX	KS	KZZ	KM	KX
.75	3.7749773	5.4032522E-03	94.29659	
9.9969013E-03				
PERMEANCES				
SLOT	ZZ	END	BELT	SKEW
28.098414	.67135408	.9003165	.511559	.52696950
PL	PM	PO	X	XO
30.708606	90.297226	105.65153	.30699091	1.0561879
X=S.C. REACT/PHASE, XO=O.C. REACT/PHASE				
KP	INL	RM	F3	F1
.84222363	426.06055	8.1127194E-04	1.5346898E-03	.30695211
F4	F5	F6	F7	
4.9440789E-02	.34565097	13.807719	379.00063	

MOTOR PERFORMANCE DATA BELOW

SPEED RPM	TORQUE LB-FT	INPUT AMPS	EFF
120	82.403488	1423.5729	.31877717
360	83.363141	1422.9487	.96198112
600	84.387348	1422.293	1.6134955
840	85.47997	1421.6032	2.2742996
1080	86.645176	1420.8769	2.9454284
1320	87.887472	1420.1111	3.6279769
1560	89.21174	1419.3027	4.3231044
1800	90.623274	1418.4482	5.0320394
2040	92.127825	1417.5437	5.7560842
2280	93.731648	1416.5849	6.4966211
2520	95.441556	1415.567	7.2551182
2760	97.264989	1414.4847	8.0331361
3000	99.210074	1413.332	8.8323353
3240	101.28571	1412.1022	9.6544838
3480	103.50167	1410.7875	10.501466
3720	105.86866	1409.3796	11.375292
3960	108.39851	1407.8686	12.27811
4200	111.10422	1406.2435	13.212212
4440	114.00019	1404.4917	14.180053
4680	117.10232	1402.5986	15.184262
4920	120.42826	1400.5476	16.227654
5160	123.99761	1398.3195	17.313252
5400	127.83217	1395.8917	18.444299
5640	131.95621	1393.2383	19.624281
5880	136.39681	1390.3285	20.856949
6120	141.18422	1387.1262	22.146339
6360	146.35221	1383.5885	23.496795
6600	151.9385	1379.6643	24.913002
6840	157.98519	1375.292	26.400006
7080	164.53914	1370.3972	27.963245
7320	171.65233	1364.8893	29.60858
7560	179.38196	1358.6569	31.342312
7800	187.79034	1351.562	33.171213
8040	196.94403	1343.4321	35.10253
8280	206.91203	1334.0497	37.143984
8520	217.76198	1323.1373	39.303731
8760	229.55318	1310.3377	41.590283
9000	242.32405	1295.1858	44.012335
9240	256.07005	1277.0692	46.573456
9480	270.70533	1255.1731	49.296513
9720	285.99652	1228.4025	52.172653
9960	301.44918	1195.2755	55.209417
10200	316.11541	1153.7801	58.402123
10440	328.27598	1101.2043	61.732089
10680	334.94214	1033.9865	65.150988
10920	331.16319	947.76831	68.546152
11160	309.33377	838.19009	71.645229
11400	259.29937	703.92296	73.70032
11640	171.11681	555.93236	71.985844
11880	42.411782	441.0031	45.33374

SPFFD RPM	STAT I2R	ROTOR I2R	FF
120	299150.52	139620.19	22.927332
360	298888.27	139492.07	23.063234
600	298612.85	139357.47	23.21482
840	298323.29	139215.88	23.367441
1080	298018.52	139066.78	23.526472
1320	297697.37	138909.59	23.692323
1560	297358.53	138743.66	23.865439
1800	297000.58	138568.27	24.046304
2040	296621.93	138382.63	24.235444
2280	296220.81	138185.83	24.433435
2520	295795.23	137977.03	24.640907
2760	295343.15	137755	24.85855
3000	294861.97	137518.56	25.087123
3240	294349.02	137266.35	25.327458
3480	293801.22	136996.84	25.580476
3720	293215.09	136708.29	25.847194
3960	292586.72	136398.73	26.128738
4200	291911.64	136065.93	26.426362
4440	291184.79	135707.36	26.741459
4680	290400.36	135320.1	27.075585
4920	289551.7	134900.82	27.430483
5160	288631.12	134445.65	27.808116
5400	287629.76	133950.16	28.210684
5640	286537.3	133409.14	28.640631
5880	285341.68	132816.53	29.100922
6120	284028.76	132165.21	29.594652
6360	282581.86	131446.78	30.125508
6600	280981.16	130651.23	30.697701
6840	279203.06	129766.66	31.31606
7080	277219.18	128778.72	31.986154
7320	274995.26	127670.09	32.71443
7560	272489.6	126419.64	33.508372
7800	269651.15	125001.51	34.376694
8040	266416.92	123383.72	35.329565
8280	262708.65	121526.5	36.378867
8520	258428.37	119380.01	37.538467
8760	253452.67	116881.33	38.8245
9000	247625.03	113950.59	40.255581
9240	240746.09	110485.8	41.852327
9480	232561.38	106356.5	43.639413
9720	222746.26	101396.17	45.639089
9960	210895.04	95394.451	47.872472
10200	196506.28	88092.464	50.348588
10440	179005.41	79189.673	53.046203
10680	157819.28	68381.951	55.872584
10920	132597.32	55471.744	58.5697
11160	103708.75	40619.843	60.486061
11400	73144.322	24806.878	59.952235
11640	45621.994	10408.992	52.368506
11880	28708.708	1287.2281	26.517547

MISC. OUTPUT BELOW

STATOR D SQ L= 1008
 ROTOR D SQ L= 411.8023
 ROTOR RISE DEG C/KW/SEC= 9.807933E-02
 STATOR DEG C/KW/SEC= 6.7220158E-02
 RATIO CU WT/FE WT= .16017961

STATOR AMPS/SQ IN AT EST CURRENT = 6699.5465

R1/R2 HOT STALL= 1.5183031

R2/X HOT STALL= .10556625

P.U. STATOR PITCH= .66666667

ROTOR D/L RATIO= .13696429

MOTOR SURFACE AREAS(INCHES SQ)

ROTOR	STOD	STID	STFND	STTOT
372.45339	640.8864	413.9058	32.945469	1087.7377

TOTAL MOTOR SURFACE AREA= 1460.2211

FORCE ON BAR (LBS)= 52.852457

FORCE ON TOOTH ROOT DUE TO TOOTH ONLY= 129.0456

TOOTH ROOT STRESS(PSI)= 1842.6363

END-----END-----END-----END-----END

>

IBN 2
THREE PHASE INDUCTION MOTOR,
ANALYSIS AND PERFORMANCE PROGRAM

ASSUMPTIONS

- 1-SINGLE STAR CONNECTION
- 2-ONE IN HAND WINDING
- 3-NO STATOR WIRE SKIN EFFECT
- 4-NO HARMONIC EFFECTS
- 5-PITCH FROM 0.33 TO 1.0P.U.
- 6-60 ELEC. DEG. PHASE BELTS

GENERAL DESCRIPTION

HP	RPM	VOLTS	FREQ	POLES
200	7500	250	250	4

OPERATING CONDITIONS

TEMP	WINDAGE	FRICTION
DEG C	WATTS	WATTS
150	14000	1000
POLE FACE WATTS=		1000
STRAY LOAD WATTS=		1000

INPUT DIMENSIONS

FRAME OD= 6.5
MOTOR TOTAL LENGTH= 42
GAP LENGTH= 2E-02
SLOTS SKEWED= 1
END TURN LENGTH= 3
ROTOR SLOT IS CLOSED BRIDGE TYP=.014
STATOR SLOT IS OPEN TRAPAZOID WITH OVERHANG

STATOR STEEL IS VANADIUM PERMENDUR

STACK	STACK	STEEL	SLOT	SLOT
FACT	LEN	LBS/IN	F	D
.95	28	.29	.11	3E-02
SLOT	SLOT	SLOT	SLOT	SLOT
C	B	A1	A2	R
2E-02	.6626	.235	.235	1E-02
KS1	T1/3	OD1	ID1	Y1
1.316	.14	6	3.875	.35
S1	T LAM	SSP	CLX	
36	1.4E-02	.3381	1	

STATOR WINDING DATA

SQUARE	URNS	SLOTS	KPKD	PERC
MILLS	COIL	PITCH	F	COND
39200	1	6	.831	66
SKEW	BELT	LBS/	OHMS/	SKFW
CSK	CST	1000	1000	0
.987	1.55	42.5	.314	6E-03

ROTOR MAGNETIC GEOMETRY OR PUNCHING DATA

STACK	ROTOR	STEEL	ROTOR	ROTOR
FACT	HI	LB/IN	F	D
.95	28	.29	5E-03	1.4E-02
ROTOR	ROTOR	ROTOR	ROTOR	ROTOR
C	R	A1	A2	R
8.5E-02	.7	.17	7.5E-02	3.75E-02
ROTOR MATERIAL IS VANADIUM PERMENDUR				
ROTOR				
KS2	T1/3	OD2	ID2	Y2
3.307	9.5E-02	3.835	1.625	.404
S2	RLAM	RSP		
44	1.4E-02	.2738		

AMORTISSEUR BAR AND END RING(S) DATA

ROTOR	BAR	BAR	BAR	BAR
SKEW	LONG	IN2	COND	COPR
.2738	30	7.5F-02	55	1
BAR	RING	RING	RING	RING
CDBX	OD	ID	AREA	COND
1	3.5	2	.375	60
K	BAR	RING	RING	
RING	LB/IN	LB/IN	LENG	
1.06	.11	.11	.5	

INPUT COMPLETE PER ABOVE

OUTPUT BELOW

TEMP	MLT	R1	R1	STATOR
FACT	FT	COLD	HOT	CUWT
1.5895	5.3126479	2.0018057F-02	3.1818702F-02	8.1283513
PHASE	BAR	RING	R2	R2
CKW	COLD	COLD	COLD	HOT
19.944	15.427735	.51579306	1.3184493F-02	
2.0956752E-02				

NOTE: DEEP BAR R2 FACTOR NOT INCLUDED
IN BAR COLD BUT INCLUDED IN R2 HOT AND COLD

BARS	RINGS	ST	SY	RT
LBS	LBS	LBS	LBS	LPS
10.89	.7127505	28.438834	48.228807	26.589238
RY	STAT	ROTOR	TOT	WIND
LBS	LBS	LBS	EMWT	FF
19.924232	84.795992	58.116221	142.91221	.50349686

MAGNETIC PARAMETERS BELOW

GUESS	CARTER	CARTER	GUESS	FLUX
AMPS	STAT	ROTOR	KPHI	KL
248.8	1.2054294	1.0008704	.98416701	2220.5934

FLUX DENSITIES IN KL/IN2

BY1	BT1	BY2	RT2	RG
119.25851	104.01056	99.185295	120.39347	39.475491
MAGNETIZING AMP TURNS				
SYOKE	ST	RYOKE	RT	GAP
423.18617	40.415787	28.4928	168.1835	298.14086
SATURATION FACTOR=		3.214652		
STATOR TEETH CORE LOSS WATTS=		92.920212		
STATOR YOKE CORE LOSS WATTS=		223.09927		

REACTANCE CALCULATIONS BELOW

CX	KS	KZZ	KM	KX
.75	3.7749773	5.4032522E-03	273.23085	
6.2480633E-03				
PERMEANCES				
SLOT	ZZ	END	BELT	SKEW
28.098414	.67135408	.9003165	1.4822774	1.5269102
PL	PM	PO	X	XO
32.679272	261.64242	277.98205	.20418216	1.7368495
X=S.C. REACT/PHASE, XO=O.C. REACT/PHASE				
KP	INL	RM	F3	F1
.93938335	143.93878	5.0843678F-03	4.4527037F-04	.20408902
F4	F5	F6	F7	
3.2416415E-02	.73183771	3.0164894	234.84584	

MOTOR PERFORMANCE DATA BELOW

SPEED RPM	TORQ LB-FT	INPUT AMPS	EFF
75	74.005371	1187.3818	.36860822
225	75.178919	1186.8085	1.1159501
375	76.410023	1186.2066	1.8775102
525	77.702117	1185.574	2.6541895
675	79.058913	1184.9084	3.4469368
825	80.484422	1184.2073	4.2567522
975	81.98299	1183.4677	5.0846903
1125	83.559328	1182.6867	5.9318642
1275	85.218556	1181.8607	6.7994495
1425	86.966239	1180.9859	7.6886884
1575	88.808444	1180.0581	8.6008952
1725	90.75179	1179.0726	9.5374607
1875	92.803513	1178.0239	10.499858
2025	94.971536	1176.9062	11.48965
2175	97.26455	1175.7127	12.508494
2325	99.692107	1174.4359	13.558148
2475	102.26472	1173.067	14.640485
2625	104.99398	1171.5964	15.757493
2775	107.89271	1170.013	16.91129
2925	110.97509	1168.3038	18.104133
3075	114.25684	1166.4543	19.33843
3225	117.75546	1164.4475	20.61675
3375	121.49038	1162.2636	21.941839
3525	125.4833	1159.8797	23.316632
3675	129.75842	1157.2689	24.744272
3825	134.3428	1154.3994	26.228126
3975	139.2667	1151.2335	27.771804
4125	144.56398	1147.7265	29.379179
4275	150.27251	1143.8243	31.05441
4425	156.43454	1139.4619	32.801966
4575	163.09711	1134.5597	34.626648
4725	170.31223	1129.0202	36.53362
4875	178.1369	1122.7225	38.528428
5025	186.63259	1115.5153	40.617031
5175	195.86388	1107.2077	42.805816
5325	205.89553	1097.556	45.101613
5475	216.78697	1086.2454	47.511689
5625	228.58207	1072.8651	50.043723
5775	241.29096	1056.8719	52.705721
5925	254.85798	1037.5386	55.505852
6075	269.10566	1013.8796	58.452115
6225	283.63719	984.54401	61.551707
6375	297.6685	947.66427	64.80978
6525	309.74431	900.64942	68.226913
6675	317.2784	839.93085	71.793645
6825	315.87834	760.73179	75.477447
6975	298.5751	657.12402	79.186996
7125	255.61969	523.14131	82.65044
7275	176.63449	357.23172	84.809802
7425	57.528041	183.84838	76.147763

SPEED RPM	STAT I2R	ROTOR I2R	PF
75	134581.23	78201.04	24.017908
225	134451.3	78124.943	24.189075
375	134314.96	78045.087	24.367167
525	134171.74	77961.197	24.552608
675	134021.13	77872.972	24.745861
825	133862.57	77780.079	24.947427
975	133695.42	77682.155	25.15785
1125	133519.01	77578.795	25.377722
1275	133332.58	77469.555	25.60769
1425	133135.28	77353.941	25.848458
1575	132926.18	77231.402	26.100801
1725	132704.24	77101.328	26.365564
1875	132468.3	76963.034	26.64368
2025	132217.04	76815.756	26.936173
2175	131949.02	76658.632	27.244177
2325	131662.57	76490.695	27.568943
2475	131355.84	76310.848	27.911863
2625	131026.7	76117.85	28.27448
2775	130672.76	75910.286	28.65852
2925	130291.27	75686.543	29.065908
3075	129879.08	75444.768	29.498807
3225	129432.56	75182.832	29.959649
3375	128947.52	74898.269	30.451177
3525	128419.1	74588.22	30.976501
3675	127841.62	74249.345	31.539152
3825	127208.42	73877.731	32.14316
3975	126511.66	73468.761	32.793138
4125	125742.05	73016.967	33.49439
4275	124888.48	72515.824	34.253039
4425	123937.67	71957.509	35.076183
4575	122873.56	71332.569	35.972086
4725	121676.63	70629.518	36.950414
4875	120322.98	69834.286	38.022519
5025	118783.14	68929.521	39.201792
5175	117020.5	67893.658	40.50409
5325	114989.2	66699.69	41.948251
5475	112631.43	65313.548	43.5567
5625	109873.75	63691.958	45.356134
5775	106622.4	61779.64	47.378247
5925	102757.2	59505.733	49.660333
6075	98124.277	56779.46	52.245463
6225	92528.172	53485.451	55.181484
6375	85726.032	49480.265	58.517276
6525	77431.07	44594.327	62.222885
6675	67342.74	38649.563	66.516326
6825	55241.676	31515.131	71.111495
6975	41219.09	23242.399	75.798858
7125	26124.124	14328.606	79.777618
7275	12181.583	6081.7786	80.33014
7425	3226.4379	761.36976	57.786338

MISC. OUTPUT BELOW

STATOR D SQ L= 1008
 ROTOR D SQ L= 411.8023
 ROTOR RISE DEG C/KW/SEC= 9.807933E-02
 STATOR DEG C/KW/SEC= 6.7220158E-02
 RATIO CU WT/FE WT= .16017961

STATOR AMPS/SQ IN AT EST CURRENT = 6346.9388

R1/R2 HOT STALL= 1.5183031

R2/X HOT STALL= .10263753

P.U. STATOR PITCH= .66666667

ROTOR D/L RATIO= .13696429

MOTOR SURFACE AREAS(INCHES SQ)

ROTOR	STOD	STID	STEND	STTOT
372.48339	640.8864	413.9053	32.945469	1087.7377

TOTAL MOTOR SURFACE AREA= 1460.2211

FORCE ON BAR (LBS)= 20.645491

FORCE ON TOOTH ROOT DUE TO TOOTH ONLY= 50.408437

TOOTH ROOT STRESS(PSI)= 719.77982

END-----END-----END-----END-----END

RUN 3
THREE PHASE INDUCTION MOTOR
ANALYSIS AND PERFORMANCE PROGRAM

ASSUMPTIONS

- 1-SINGLE STAR CONNECTION
- 2-ONE IN HAND WINDING
- 3-NO STATOR WIRE SKIN EFFECT
- 4-NO HARMONIC EFFECTS
- 5-PITCH FROM 0.33 TO 1.0P.U.
- 6-60 ELEC. DEG. PHASE BELTS

GENERAL DESCRIPTION

HP	RPM	V(LN)	FRFQ	POLES
160	6750	225	225	6

OPERATING CONDITIONS

TEMP	WINDAGE	FRICTION
DEG C	WATTS	WATTS
150	10000	1000
POLE FACE WATTS=		1000
STRAY LOAD WATTS=		1000

INPUT DIMENSIONS

FRAME OD= 6.5
MOTOR TOTAL LENGTH= 42
GAP LENGTH= 2E-02
SLOTS SKEWED= 1
END TURN LENGTH= 3
ROTOR SLOT IS CLOSED BRIDGE TWR=.014
STATOR SLOT IS OPEN TRAPAZOID WITH OVERHANG

STATOR STEEL IS VANADIUM PERMENDUR

STACK	STACK	STEEL	SLOT	SLOT
FACT	LEN	LRS/IN	E	D
.95	28	.29	.11	3E-02
SLOT	SLOT	SLOT	SLOT	SLOT
C	B	A1	A2	B
2E-02	.6626	.235	.235	1E-02
KS1	T1/3	OD1	ID1	Y1
1.316	.14	6	3.875	.35
S1	T LAM	SSP	CLX	
36	1.4E-02	.3381	1	

STATOR WINDING DATA

SQUARE	TURNS	SLOTS	PERC
MILLS	COIL	PITCH	COND
39200	1	6	.66
SKEW	BELT	LRS/	SKED
CSK	CST	1000	0
.987	1.55	42.5	6E-02

ROTOR MAGNETIC GEOMETRY OR PUNCHING DATA

STACK	ROTOR	STEEL	ROTOR	ROTOR
FACT	H1	LR/IN	E	D
.95	28	.29	5E-03	1.4E-02
ROTOR	ROTOR	ROTOR	ROTOR	ROTOR
C	B	A1	A2	B
8.5E-02	.7	.17	7.5E-02	2.75E-02
ROTOR MATERIAL IS VANADIUM PERMENDUR				
KS2	T1/3	OD2	ID2	Y2
3.307	9.5E-02	3.835	1.625	.404
S2	RLAM	RSP		
44	1.4E-02	.2738		

AMORTISSEUR BAR AND END RING(S) DATA

ROTOR	BAR	BAR	BAR	BAR
SKEW	LONG	IN2	COND	CDPR
.2738	30	7.5E-02	55	1
BAR	RING	RING	RING	RING
CDRX	CD	ID	AREA	COND
1	3.5	2	.375	60
K	BAR	RING	RING	
RING	LR/IN	LR/IN	LENG	
1.06	.11	.11	.5	

INPUT COMPLETE PER ABOVE

OUTPUT BELOW

TEMP	MLT	RI	RI	STATOR
FACT	FT	COLD	HOT	CURT
1.5895	5.3126479	2.0018057E-02	3.1818702E-02	8.1080012
PHASE	BAR	RING	R2	R2
CKW	COLD	COLD	COLD	HOT
19.944	15.427735	.51579306	1.3184493E-02	
2.0956752E-02				

NOTE:DEFP BAR R2 FACTOR NOT INCLUDED
IN BAR COLD BUT INCLUDED IN R2 HOT AND COLD

BARS	RINGS	ST	SY	RT
LBS	LBS	LBS	LBS	LBS
10.89	.7127505	28.438834	48.228807	26.589228
RY	STAT	ROTOR	TOT	WIND
LBS	LBS	LBS	FMWT	FF
19.924232	84.795992	58.116221	142.91221	.50349686

MAGNETIC PARAMETERS BELOW

GUESS	CARTER	CARTER	GUESS	FLUX
AMPS	STAT	ROTOR	KPHI	KL
221.15556	1.2054294	1.0008704	.98436248	2221.0048

FLUX DENSITIES IN KL/IN2

BY1	RT1	BY2	RT2	RG
119.2822	104.03122	99.204994	120.41738	39.483332

MAGNETIZING AMP TURNS

SYOKE	ST	RYOKE	RT	GAP
423.8431	40.484484	28.535965	168.69298	293.20007
SATURATION FACTOR=		3.2184989		
STATOR TEETH CORE LOSS WATTS=		92.959378		
STATOR YOKE CORE LOSS WATTS=		223.21351		

REACTANCE CALCULATIONS BELOW

CX	KS	KZZ	KM	KX
.75	3.7749773	5.4032522E-03	272.90427	
5.623257E-03				
PERMEANCES				
SLOT	ZZ	END	BFLT	SKEW
28.098414	.67135408	.9003165	1.4805057	1.8050851
PL	PM	PO	X	XO
32.675676	261.32969	277.66753	.18374372	1.5410959
X=S.C. REACT/PHASE, XO=O.C. REACT/PHASE				
KP	INL	RM	F3	F1
.93931936	144.10183	5.0753314E-03	4.9518454E-04	.18260029
F4	F5	F6	F7	
3.2415963E-02	.73136452	3.0199063	211.34636	

MOTOR PERFORMANCE DATA BELOW

SPEED RPM	TORQUE LB-FT	INPUT AMPS	EFF
67.5	81.136683	1179.2993	.36872605
202.5	82.484274	1178.6061	1.1173989
337.5	83.893357	1177.8786	1.8816736
472.5	85.367536	1177.1143	2.6624272
607.5	86.910697	1176.3103	3.4605729
742.5	88.527033	1175.4637	4.2770734
877.5	90.221079	1174.5712	5.1129438
1012.5	91.997738	1173.6289	5.9692554
1147.5	93.862328	1172.6329	6.8471397
1282.5	95.820617	1171.5736	7.7477927
1417.5	97.878876	1170.4609	8.6724791
1552.5	100.04393	1169.2742	9.622532
1687.5	102.32321	1168.0123	10.599388
1822.5	104.72483	1166.668	11.604532
1957.5	107.25768	1165.2336	12.639565
2092.5	109.93146	1163.6999	13.706183
2227.5	112.75682	1162.057	14.806185
2362.5	115.74546	1160.2934	15.941437
2497.5	118.91023	1158.3959	17.114128
2632.5	122.26529	1156.3497	18.326281
2767.5	125.82624	1154.1376	19.580262
2902.5	129.61032	1151.7398	20.878549
3037.5	133.63653	1149.1335	22.223781
3172.5	137.92591	1146.292	23.618788
3307.5	142.50172	1143.1841	25.066595
3442.5	147.38965	1139.7734	26.570444
3577.5	152.61808	1136.0166	28.133813
3712.5	158.2183	1131.8623	29.760431
3847.5	164.22465	1127.249	31.454304
3982.5	170.67467	1122.1029	33.219738
4117.5	177.60898	1116.3341	35.061358
4252.5	185.07101	1109.8332	36.984139
4387.5	193.10617	1102.4653	38.993427
4522.5	201.76035	1094.0627	41.094966
4657.5	211.0771	1084.4156	43.294914
4792.5	221.09279	1073.2586	45.599858
4927.5	231.82848	1060.2527	48.016813
5062.5	243.27624	1044.9606	50.553192
5197.5	255.37657	1026.8126	53.216735
5332.5	267.9811	1005.0586	56.015349
5467.5	280.79133	978.70284	58.956799
5602.5	293.25871	946.4132	62.048109
5737.5	304.42399	906.40187	65.294384
5872.5	312.66671	856.27762	68.696425
6007.5	315.33862	792.89434	72.245549
6142.5	308.29824	712.28303	75.911261
6277.5	285.52099	609.9123	79.607457
6412.5	239.34658	481.90596	83.077362
6547.5	162.5114	329.12601	85.322137
6682.5	53.059594	176.88822	77.405266

SPEED RPM	STAT I2R	ROTOR I2R	PF
67.5	132755.28	77125.361	26.503605
202.5	132599.26	77033.99	26.689646
337.5	132435.62	76938.146	26.883146
472.5	132263.79	76837.507	27.084559
607.5	132083.19	76731.718	27.294376
742.5	131893.14	76620.388	27.513129
877.5	131692.91	76503.089	27.741398
1012.5	131481.7	76379.35	27.979312
1147.5	131258.63	76248.647	28.229054
1282.5	131022.7	76110.404	28.489372
1417.5	130772.83	75963.978	28.763084
1552.5	130507.79	75808.656	29.049583
1687.5	130226.25	75643.642	29.350352
1822.5	129926.67	75468.047	29.666471
1957.5	129607.36	75280.871	29.999128
2092.5	129266.42	75080.993	30.349637
2227.5	128901.68	74867.146	30.719455
2362.5	128510.71	74637.898	31.110194
2497.5	128090.74	74391.621	31.52365
2632.5	127638.62	74126.464	31.961828
2767.5	127150.74	73840.306	32.426967
2902.5	126622.97	73530.715	32.92158
3037.5	126050.53	73194.888	33.448497
3172.5	125427.92	72829.582	34.010907
3307.5	124748.72	72431.027	34.612422
3442.5	124005.45	71994.819	35.257147
3577.5	123189.32	71515.792	35.949756
3712.5	122289.98	70987.853	36.695597
3847.5	121295.15	70403.778	37.500806
3982.5	120190.2	69754.954	38.372452
4117.5	118957.58	69031.052	39.318701
4252.5	117576.13	68219.616	40.349024
4387.5	116020.18	67305.53	41.474439
4522.5	114258.4	66270.337	42.707793
4657.5	112252.3	65091.369	44.064099
4792.5	109954.37	63740.629	45.560909
4927.5	107305.63	62183.356	47.218725
5062.5	104232.6	60376.229	49.061382
5197.5	100643.58	58265.164	51.116336
5332.5	96424.298	55782.743	53.414623
5467.5	91433.513	52845.583	55.990109
5602.5	85499.838	49352.437	58.877183
5737.5	78423.334	45185.07	62.10527
5872.5	69989.502	40216.406	65.687011
6007.5	60011.482	34335.27	69.593407
6142.5	48429.38	27504.761	73.70229
6277.5	35509.004	19879.263	77.683215
6412.5	22168.092	11996.857	80.673922
6547.5	10340.181	4994.6111	79.736831
6682.5	2986.7682	617.63901	54.495049

MISC. OUTPUT BELOW

STATOR D SQ L= 1008
 ROTOR D SQ L= 411.8023
 ROTOR RISE DEG C/KW/SEC= 9.807933E-02
 STATOR DEG C/KW/SEC= 6.7220158E-02
 RATIO CU WT/FE WT= .16017961

STATOR AMPS/SQ IN AT EST CURRENT = 5641.7234

R1/R2 HOT STALL= 1.5183031

R2/X HOT STALL= .11405425

P.U. STATOR PITCH= .66666667

ROTOR D/L RATIO= .13696429

MOTOR SURFACE AREAS(INCHES SQ)

ROTOR	STOD	STID	STEND	STTOT
372.48339	640.7864	413.9058	32.945469	1087.7377

TOTAL MOTOR SURFACE AREA= 1460.2211

FORCE ON BAR (LBS)= 16.722848

FORCE ON TOOTH ROOT DUE TO TOOTH ONLY= 40.830834

TOOTH ROOT STRESS(PSI)= 583.02165

END-----END-----END-----END-----END

THREE PHASE INDUCTION MOTOR
 ANALYSIS AND PERFORMANCE PROGRAM

ASSUMPTIONS

- 1-SINGLE STAR CONNECTION
- 2-ONE IN HAND WINDING
- 3-NO STATOR WIRE SKIN EFFECT
- 4-NO HARMONIC EFFECTS
- 5-PITCH FROM 0.33 TO 1.00 IN.
- 6-60 FREQ. DEG. PHASE BELTS

GENERAL DESCRIPTION

HP	RPM	V(LN)	FREQ	POLES
140	6000	200	200	4

OPERATING CONDITIONS

TEMP	WINDAGE	FRICTION
DEG C	WATTS	WATTS
150	7000	1000
POLF FACE WATTS=		1000
STRAY LOAD WATTS=		1000

INPUT DIMENSIONS

FRAME OD= 6.5
 MOTOR TOTAL LENGTH= 42
 GAP LENGTH= 2E-02
 SLOTS SKEWED= 1
 END TURN LENGTH= 3
 ROTOR SLOT IS CLOSED BRIDGE TYP=.014
 STATOR SLOT IS OPEN TRAPAZOID WITH OVERHANG

STATOR STEEL IS VANADIUM PERMENDUR

STACK	STACK	STEEL	SLOT	SLOT
FACT	LEN	LPS/IN	F	D
.95	.28	.29	.11	3E-02
SLOT	SLOT	SLOT	SLOT	SLOT
C	P	A1	A2	R
2E-02	.6626	.235	.235	1E-02
KS1	T1/3	OD1	ID1	Y1
1.316	.14	6	3.875	.35
S1	T LAM	SSP	CLX	
36	1.4E-02	.3381	1	

STATOR WINDING DATA

SQUARE	URNS	SLOTS		FREQ
MILLS	COIL	PITCH	KPKD	COND
39200	1	6	.831	66
SKEW	RELT	LPS/	OHVS/	SKEW
CSK	CST	1000	1000	C
.987	1.55	42.5	.310	4E-02

ROTOR MAGNETIC GEOMETRY OR PUNCHING DATA

STACK	ROTOR	STEEL	ROTOR	ROTOR
FACT	HI	LR/IN	E	D
.95	.28	.29	5E-03	1.4E-02
ROTOR	ROTOR	ROTOR	ROTOR	ROTOR
C	R	A1	A2	R
8.5E-02	.7	.17	7.5E-02	3.75E-02

ROTOR MATERIAL IS VANADIUM PERMENDUR

ROTOR				
KS2	T1/3	OP2	ID2	Y2
3.307	9.5E-02	3.835	1.625	.405
S2	RLAM	RSP		
44	1.4E-02	.2738		

AMORTISSEUR BAR AND END RING(S) DATA

ROTOR	BAR	BAR	BAR	BAR
SKFW	LONG	IN2	COND	CDRX
.2738	30	7.5E-02	55	1
BAR	RING	RING	RING	PING
CDRX	OD	LD	AREA	COND
1	3.5	2	.375	60
K	BAR	RING	RING	
RING	LR/IN	LR/IN	LENG	
1.06	.11	.11	.5	

INPUT COMPLETE PER ABOVE

OUTPUT BELOW

TEMP	MLT	R1	R1	STATOR
FACT	FT	COLD	HOT	CVT
1.5895	5.3126479	2.0018057E-02	3.1813702E-02	8.1222512
PHASE	BAR	RING	R2	R2
CKW	COLD	COLD	COLD	HOT
19.944	15.427735	.51579306	1.3184493E-02	
2.0956752E-02				

NOTE:DEFP BAR R2 FACTOR NOT INCLUDED
IN BAR COLD BUT INCLUDED IN R2 HOT AND COLD

BAR	RINGS	ST	SY	RT
LRS	LRS	LPS	LPS	LPS
10.89	.7127505	28.438834	28.228807	26.582238
RY	STAT	ROTOR	TOT	WIND
LRS	LRS	LPS	FMVT	FF
19.924232	84.795992	58.116221	142.91221	.50349686

MAGNETIC PARAMETERS BELOW

GUESS	CARTER	CARTER	GUESS	FLUX
AMPS	STAT	ROTOR	KPHI	KL
217.7	1.2054294	1.0008704	.98268267	2217.2443

FLUX DENSITIES IN KL/IN2

RY1	RT1	RY2	RT2	RG
119.07864	103.85369	99.035701	120.21189	39.415952

MAGNETIZING AMP TURNS

SYOKE	ST	RYOKE	RT	GAP
418.19763	39.894118	28.165015	164.31464	297.6912
SATURATION FACTOR=		3.1853901		
STATOR TEETH CORE LOSS WATTS=		92.622797		
STATOR YOKE CORE LOSS WATTS=		222.23179		

REACTANCE CALCULATIONS BELOW

CX	KS	KZZ	KM	KY
.75	3.7749773	5.4032522E-03	275.74083	
4.9984507E-03				
PERMEANCES				
SLOT	ZZ	END	PFLT	SKFW
28.098414	.67135408	.9003165	1.4958294	1.5609368
PL	PM	PO	X	XO
32.706916	264.04594	280.3994	.1634839	1.4015626
X=S.C. REACT/PHASE, XO=O.C. REACT/PHASE				
KP	INL	RM	F3	F1
.93987019	142.69787	5.1541109E-03	5.5283303E-04	.16226689
F4	F5	F6	F7	
3.2419898E-02	.73548067	2.990484	187.97404	

MOTOR PERFORMANCE DATA BELOW

SPEED RPM	TORQUE LB-FT	INPUT AMPS	EFF
60	89.525193	1167.06	.36911787
180	91.050911	1166.2093	1.1193426
300	92.642143	1165.317	1.8862267
420	94.302634	1164.3798	2.6706087
540	96.03641	1163.3947	3.4733761
660	97.847803	1162.3578	4.2954633
780	99.741487	1161.2651	5.1378554
900	101.7225	1160.1123	6.0015924
1020	103.7963	1158.8945	6.8877722
1140	105.96876	1157.6061	7.797556
1260	108.24626	1156.2413	8.7321709
1380	110.63573	1154.7933	9.6929164
1500	113.14467	1153.2546	10.681169
1620	115.78123	1151.6168	11.698388
1740	118.55428	1149.8706	12.746121
1860	121.47348	1148.0054	13.826012
1980	124.54936	1146.0093	14.939308
2100	127.79341	1143.8686	16.089368
2220	131.21816	1141.5681	17.276671
2340	134.83731	1139.0903	18.503823
2460	138.66584	1136.415	19.773075
2580	142.72009	1133.5191	21.086825
2700	147.01793	1130.3762	22.447638
2820	151.57885	1126.9552	23.858257
2940	156.42412	1123.2202	25.321616
3060	161.57679	1119.1292	26.840861
3180	167.06185	1114.6326	28.419362
3300	172.90616	1109.6718	30.060739
3420	179.13834	1104.1772	31.768875
3540	185.78848	1098.0652	33.547944
3660	192.8876	1091.2355	35.402433
3780	200.46659	1083.566	37.337162
3900	208.55459	1074.9079	39.357316
4020	217.1763	1065.0779	41.46846
4140	226.34763	1053.8488	43.676561
4260	236.06898	1040.9365	45.988004
4380	246.31461	1025.983	48.409582
4500	257.01609	1008.5336	50.948477
4620	268.03649	988.00628	53.612173
4740	279.13037	963.65068	56.403336
4860	289.88202	934.49457	59.344459
4980	299.61133	899.27491	62.427322
5100	307.2339	856.35482	65.661834
5220	311.06247	803.63629	69.048698
5340	308.55077	738.50124	72.579391
5460	296.02958	657.86685	76.224176
5580	268.60687	558.55847	79.899289
5700	220.63131	438.49179	83.355352
5820	147.34826	300.31056	85.624585
5940	48.113755	169.12375	78.112438

SPEED RPM	STAT 12R	ROTOR 12R	PF
60	130013.98	75616.082	29.519865
180	129824.52	75505.002	29.723021
300	129625.92	75388.554	29.934223
420	129417.52	75266.354	30.153954
540	129198.61	75137.984	30.382736
660	128968.41	75002.982	30.621135
780	128726.06	74860.846	30.869762
900	128470.61	74711.018	31.129282
1020	128201.02	74552.884	31.400419
1140	127916.14	74385.768	31.68396
1260	127614.69	74208.918	31.980764
1380	127295.26	74021.5	32.291772
1500	126956.25	73822.587	32.618011
1620	126595.92	73611.143	32.96061
1740	126212.3	73386.01	33.320811
1860	125803.17	73145.888	33.69998
1980	125366.06	72889.316	34.099628
2100	124898.15	72614.644	34.521424
2220	124396.28	72320.005	34.967221
2340	123856.84	72003.281	35.439079
2460	123275.73	71662.055	35.939293
2580	122648.27	71293.569	36.470427
2700	121969.07	70894.653	37.035354
2820	121231.93	70461.658	37.6373
2940	120429.69	69990.364	38.2799
3060	119554.02	69475.871	38.967256
3180	118595.22	68912.462	39.704015
3300	117541.93	68293.441	40.495455
3420	116380.77	67610.929	41.347584
3540	115095.94	66855.608	42.26726
3660	113668.64	66016.408	43.26233
3780	112076.47	65080.116	44.34179
3900	110292.56	64030.888	45.515963
4020	108284.54	62849.634	46.796707
4140	106013.29	61513.273	48.197626
4260	103431.34	59993.795	49.73423
4380	100481.02	58257.151	51.424358
4500	97092.229	56261.951	53.287744
4620	93180.09	53958.044	55.346331
4740	88642.701	51285.193	57.623363
4860	83359.919	48172.322	60.141835
4980	77194.911	44538.396	62.921124
5100	70002.123	40297.061	65.970328
5220	61648.54	35369.107	69.27542
5340	52060.24	29709.835	72.774535
5460	41312.332	23362.015	76.308534
5580	29781.118	16545.642	79.50892
5700	18353.828	9781.9022	81.456001
5820	8608.8459	4000.2271	78.954157
5940	2730.316	489.26041	51.216158

MISC. OUTPUT BELOW

STATOR D SC L= 1008

ROTOR D SC L= 411.8023

ROTOR RISE DEG C/KW/SEC= 9.807933E-02

STATOR DEG C/KW/SEC= 6.7220158E-02

RATIO CU WT/FE WT= .16017961

STATOR AMPS/SC IN AT FST CURRENT = 5553.5714

R1/R2 HOT STALL= 1.5183031

R2/X HOT STALL= .12818847

P.U. STATOR PITCH= .66666667

ROTOR D/L RATIO= .13696429

MOTOR SURFACE AREAS(INCHES SQ)

ROTOR	STOD	SIID	STENP	STTOT
372.48339	640.8864	413.9058	32.945469	1087.7377

TOTAL MOTOR SURFACE AREA= 1460.2211

FORCE ON BAR (LBS)= 13.213114

FORCE ON TOOTH ROOT DUE TO TOOTH ONLY= 32.2614

TOOTH ROOT STRESS(PSI)= 460.65908

END-----END-----END-----END-----END

The computer program runs and related test data are outlined below.

Run No.	Page	Input Volts	Input Freq.	Current Calc. Near Rated/T	Current Meas. Near Rated/T	PF Calc. Near Rated/T	PF Meas. Near Rated/T	EFF Calc. Near Rated/T	EFF Meas. Near Rated/T
1	C37 - C41	450	400	- Example run only - no comparable test data					
2	C42 - C46	250	250	357/176 183/57	300/176 150/57	80/176 58/57	85/176 70/57	85/176 76/57	80/176 70/57
3	C47 - C51	225	225	329/162 176/53	280/162 118/53	80/162 55/53	85/162 77/53	85/162 77/53	85/162 67/53
4	C52 - C56	200	200	300/147 169/48	260/147 110/48	79/147 51/48	81/147 79/48	86/147 78/48	88/147 66/48

A comparison of the test and calculated data shows that the motor "likes" to operate at slightly higher volts per cycle than anticipated. When operated on the calculated volts/cycle, efficiencies and power factor are nearly correct at rated torque with efficiency varying from 5% below calculated to 2% above calculated. At reduced load, the measured efficiencies are lower than calculated (up to 12%), however, the power factor is up to 22% higher.

When operated at higher volts/cycle, the efficiency is 2% to 5% higher than originally predicted and the power factor about 5% higher than calculated.

All of this data suggests that the saturation characteristics of the vanadium permendur are better than predicted, with only moderate mmf required for magnetizing near 150 kI/in^2 .

The reduced magnetizing current combined with operation at higher than predicted volts/cycle reduces the required current to 10%-15% below the values calculated.

Peak torques could not be accurately measured due to test limitations, however there is an indication they were below calculated, suggesting higher than calculated leakage reactance. Stall tests would have been of great value in determining leakage reactance, however the motor's stall torque, etc., could not be measured since the rotor and stator appeared to stick or rub at stall. Slight recalibration of the computer program may be recommended based on test results.