DOE/NASA/0123-2
NASA CR-165382
ERC TR-80169

Straight and Chopped DC Performance Data for a Prestolite MTC-4001 Motor and a General Electric EV-1 Controller

Paul C. Edie
Eaton Corporation
Engineering & Research Center

April 1981

Prepared for
National Aeronautics and Space Administration
Lewis Research Center
Under Contract DEN 3-123

for
U.S. DEPARTMENT OF ENERGY
Conservation and Renewable Energy
Office of Transportation Programs

NOTICE

DOE/NASA/0123-2
NASA CR-165382
ERC TR-80169

Straight and Chopped DC Performance Data for a Prestolite MTC-4001 Motor and a General Electric EV-1 Controller

Paul C. Edie
Eaton Corporation
Engineering & Research Center
Southfield, Michigan 48037

April 1981

Prepared for
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135
Under Contract DEN 3-124

for
U.S. DEPARTMENT OF ENERGY
Conservation and Renewable Energy
Office of Transportation Programs
Washington, D.C. 20585
Under Interagency Agreement DE-AI01-77CS51044

N81-29346#

TABLE OF CONTENTS

PAGE

LIST OF TABLES

SUMMARY

This report is intended to supply the electric vehicle manufacturer with performance data on the Prestolite MTC-4001 series wound DC motor and General Electric EV-1 Chopper Controller. Data is provided for both straight and chopped DC input to the motor, at 2 motor temperature levels. Testing was done at 6 voltage increments to the motor, and 2 voltage increments to the controller. Data results are presented in both tabular and graphical forms. Tabular information includes motor voltage and current input data, motor speed and torque output data, power data and temperature data. Graphical information includes torque-speed, motor power output-speed, torque-current, and efficiency-speed plots under the various operating conditions.

The data resulting from this testing shows the speed-torque plots to have the most variance with operating temperature. The maximum motor efficiency is between 76% and 82%, regardless of temperature or mode of operation. When the chopper is utilized, maximum motor efficiency occurs when the chopper duty cycle approaches 100%. At low duty cycles the motor efficiency may be considerably less than the efficiency for straight DC. Chopper efficiency may be assummed to be 95% under all operating conditions. For equal speeds at a given voltage level, the motor operated in the chopped mode develops slightly more torque than it does in the straight DC mode. System block diagrams are included, along with test setup and procedure information.

Page Missing in
Original Document

INTRODUCTION

Today about one-half of the petroleum consumed in the United States is used for transportation. The introduction of electric vehicles could significantly shift the transportation energy base to other sources such as coal, nuclear, and solar.

In 1976 the Electric and Hybrid Vehicle Program was initiated within the Energy Research and Development Administration (ERDA), now the Department of Energy (DOE). In September of that same year, the Congress passed the Electric and Hybrid Vehicle Research, Development, and Demonstration Act of 1976 (Public Law 94-413). This Act is intended to accelerate the integration of electric and hybrid vehicles into our transportation system and to stimulate growth in the electric vehicle industry.

Part of the Electric and Hybrid Vehicle Program is focused upon assisting electric vehicle manufacturers with general technical problems relating to the design of near-term vehicles. For the most part, these manufacturers are small companies which often lack resources for testing, research, or development.

This report is intended to provide these manufacturers with performance data on an electric motor and chopper controller which may be used on this type of vehicle.

Due to the limited power and energy capability of batteries, high efficiency is a very desirable attribute of motors and controllers used in electric vehicles.

Although there is a great deal of electric motor and controller developmental work ongoing in both private industry and government research centers, the data supplied by the manufacturers of motors usually consists of limited information for straight DC operation only, and does not cover the motor's performance when used in conjunction with a chopper/controller.

The testing done under this contract and the resulting data formats were specified by the NASA Lewis Research Center. This report summarizes data on a Prestolite MTC-4001 series wound motor and a General Electric model EV-1 controller. Other motor/controller combinations have also been tested, and appear as separate reports under the same contract number. To assure consistent test results under severe load, the batteries used for these tests had much higher capacity than those typically available in an electric vehicle. If smaller, more portable power sources are used, the resulting motor torque and speed would be limited by the output capacity of the source.

All tests were made at two motor operating temperatures, as outlined in the "Test Procedure" section. The data from these tests should characterize the motor performance under typical "hot" and "cold" conditions. It should be noted that these are only representative temperature levels.

The data contained in these results is all of a steady-state nature, and does not show motor or controller efficiency during acceleration, deceleration or regenerative operation. To provide a complete range of data, motor nameplate ratings were exceeded in some instances for short periods of time. At no time were the motors exposed to severe abuse, physical shock or contaminated environments.

The test data presented here is not intended to represent the absolute maximum power available from any motor or controller. Under certain conditions, the motor or controller may be capable of exceeding the input and output power levels shown in the data and still remain undamaged. However, since this represents the extreme conditions of motor/controller operation and is useful only in limited circumstances, such data is not presented here.

Data is presented in graphical and tabular forms. Tests were run as detailed in the section titled "Test Procedure." Tabular data represents the arithmetic average of all test runs, and is intended to reduce data scatter as well as the volume of total data recorded. Tabular data will supply the user with performance information at a specific desired test point.

Graphical data presents the averaged results plotted and extrapolated, such that information for any given point within the testing range may be found.

EQUIPMENT TESTED

Description of Motor

The motor tested in this report is a Prestolite model MTC-4001 series wound DC motor. This motor is shown in Figure 1, with a print detailing critical dimensions in Figure 2. Weight of this motor is 45.5 Kg (100.6 lbs.) with all mounting hardware attached. The following nameplate data appears on the motor:

Part No.	MTC-4001 0170
Volts DC	96
Class	H
Ser.	L11

During inspection, prior to testing, no signs of abuse or wear were noted.

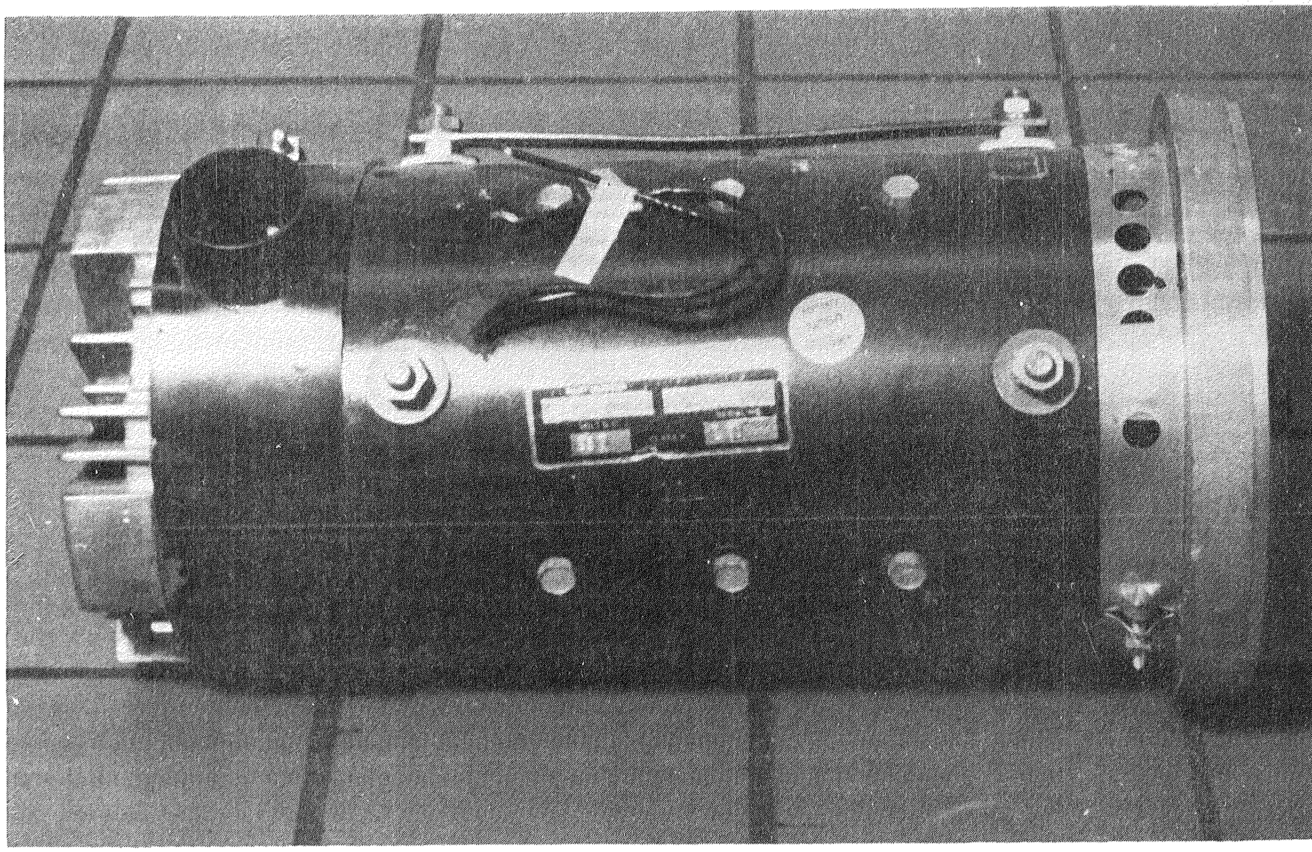


Figure 1 Prestolite MTC-4001 Motor

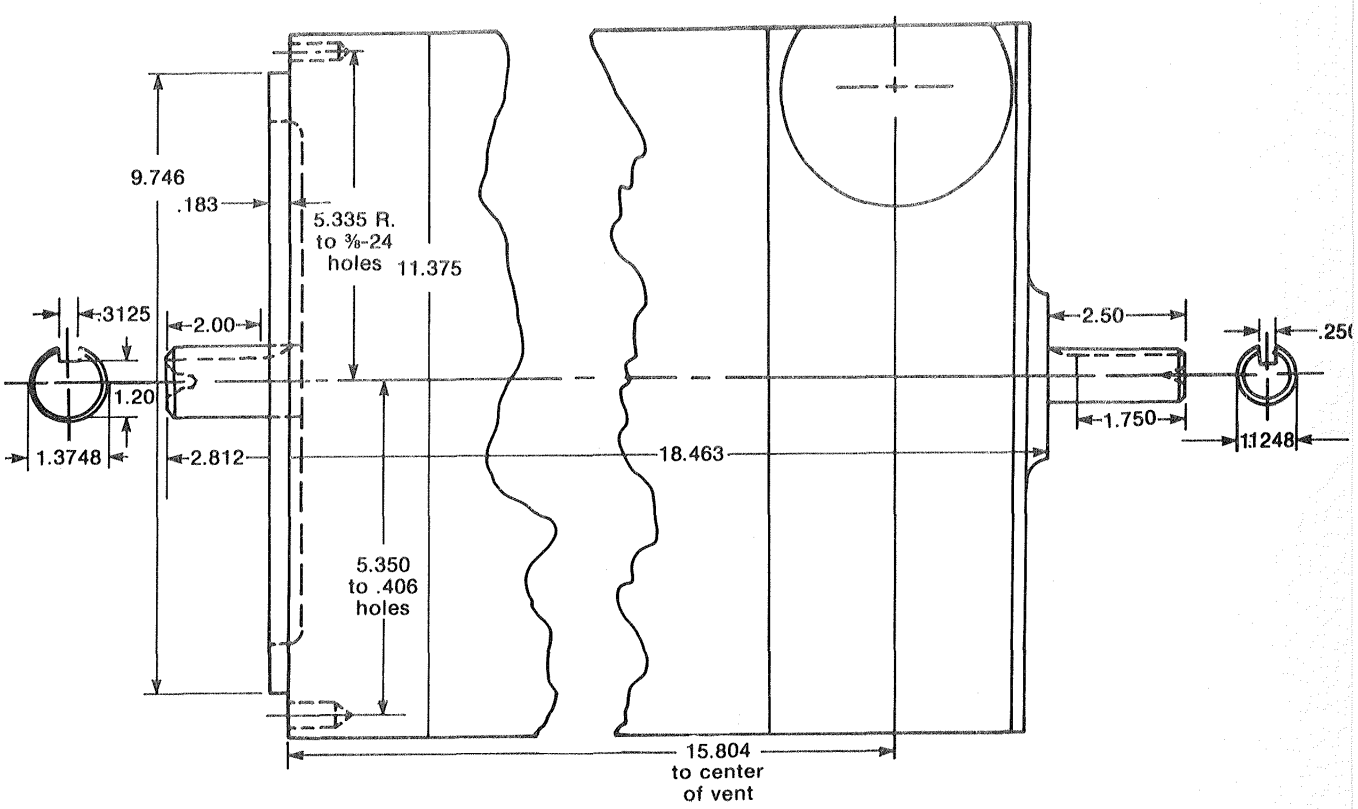


Figure 2 Outline Drawing of Prestolite MTC-4001 Motor

Description of Controller

The chopper/controller testing in conjunction with the Prestolite motor was a General Electric model EV-1. This unit is a conventional SCR controller. The controller is shown in Figure 3, with a print detailing critical mounting dimensions in Figure 4. Weight of the controller is 24.3 Kg (53.7 lbs.). The only nameplate data on the controller is a 144 volt DC rating. During inspection, prior to testing, it was found that the plastic mounts holding the oscillator card to the base were cracked, probably caused by mishandling when the unit was shipped. Several wires had been pulled off the card, apparently due to the shipping abuse. Once these were repaired, the unit functioned properly.

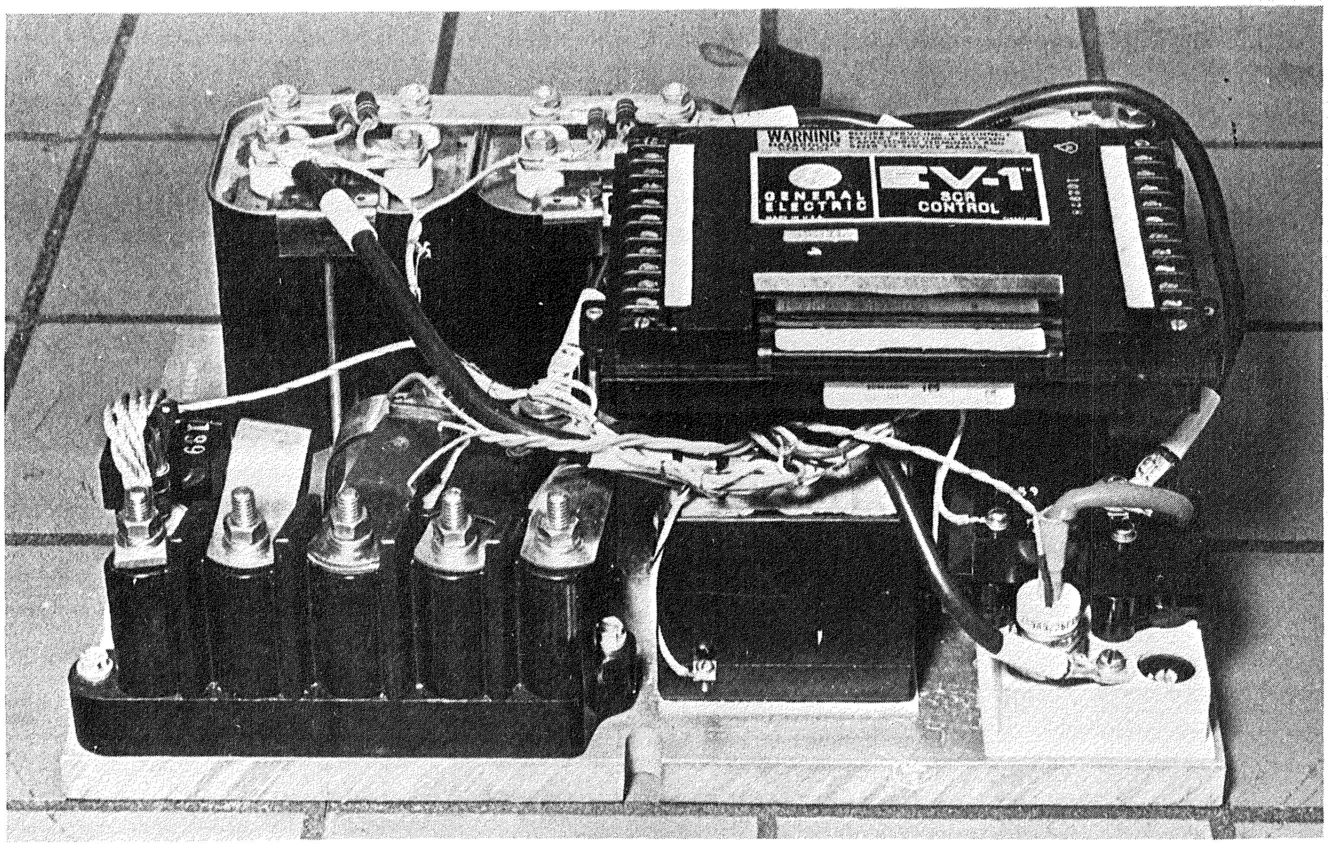


Figure 3 General Electric Model EV-1 Controller

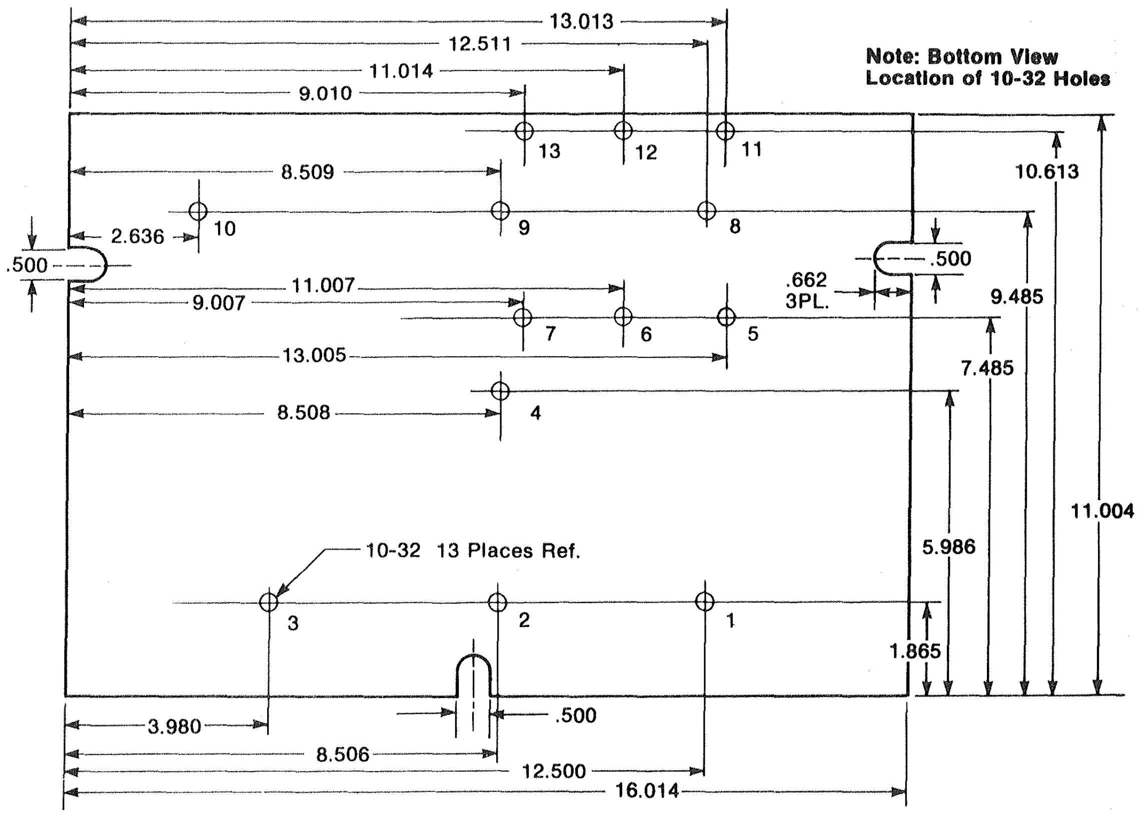


Figure 4 Drawing of General Electric EV-1 Controller Base Plate

TEST FACILITY

1. Dynamometer

The motor controller combination was mounted as shown in Figures 5-6. A conventional T-slot bedplate served as the mounting base. To absorb the motor output power, a General Electric DC dynamometer rated at 100 hp @ 6000 rpm was used. The dynamometer used a motor generator set as its source of DC power, and was controlled by a console located outside the test cell (Figure 7). The control console consisted of necessary dynamometer power and speed controls, along with a safety annunciator system to shut down the entire test cell should an overspeed, overcurrent or overtemperature condition occur. An automatic halogen fire extinguishing system was used to protect the entire testing area.

2. Power Source

To power the motor and controller, lead acid type batteries were used (Figure 8). Four 36 volt, 1100 amp hour batteries were wired in series using 4/0 copper stranded wire. Taps were wired at 6 volts increments from 0 to 144 volts. The batteries were charged using a Barrett current regulated industrial charger, rated at a capacity of 300 amps. Room air and hydrogen from the batteries were exhausted directly to the outside via overhead blowers.

3. Motor & Controller Installation

Figure 9 shows the motor mounting and transducer configuration. The motor was mounted directly on a small I-beam, which was in turn mounted on the bedplate. The motor was coupled to the telemetry transmitter (which is discussed in the Instrumentation section) by special machined slip fit couplings, held by a keyway. The transmitter assembly was coupled to the torque speed transducer (also discussed in the Instrumentation section) with Waldron Flex-Align couplings, which compensate for small alignment or balance errors. The opposite end of the torque/speed transducer was coupled to the dynamometer using another Waldron coupling.

All alignments between shafts were held to within 0.20 mm (0.008 in.) during setup.

The controller was mounted on a bench located directly over the motor to keep wire lengths as short as possible. All power wiring was accomplished using rubber insulated 4/0 stranded copper welding cable. Connections were made to the motor and controller via copper crimp type lugs.

The motor was cooled, when necessary to maintain temperature within the specified limits, by a squirrel cage blower motor forcing air through the motor's cooling duct. Room air was

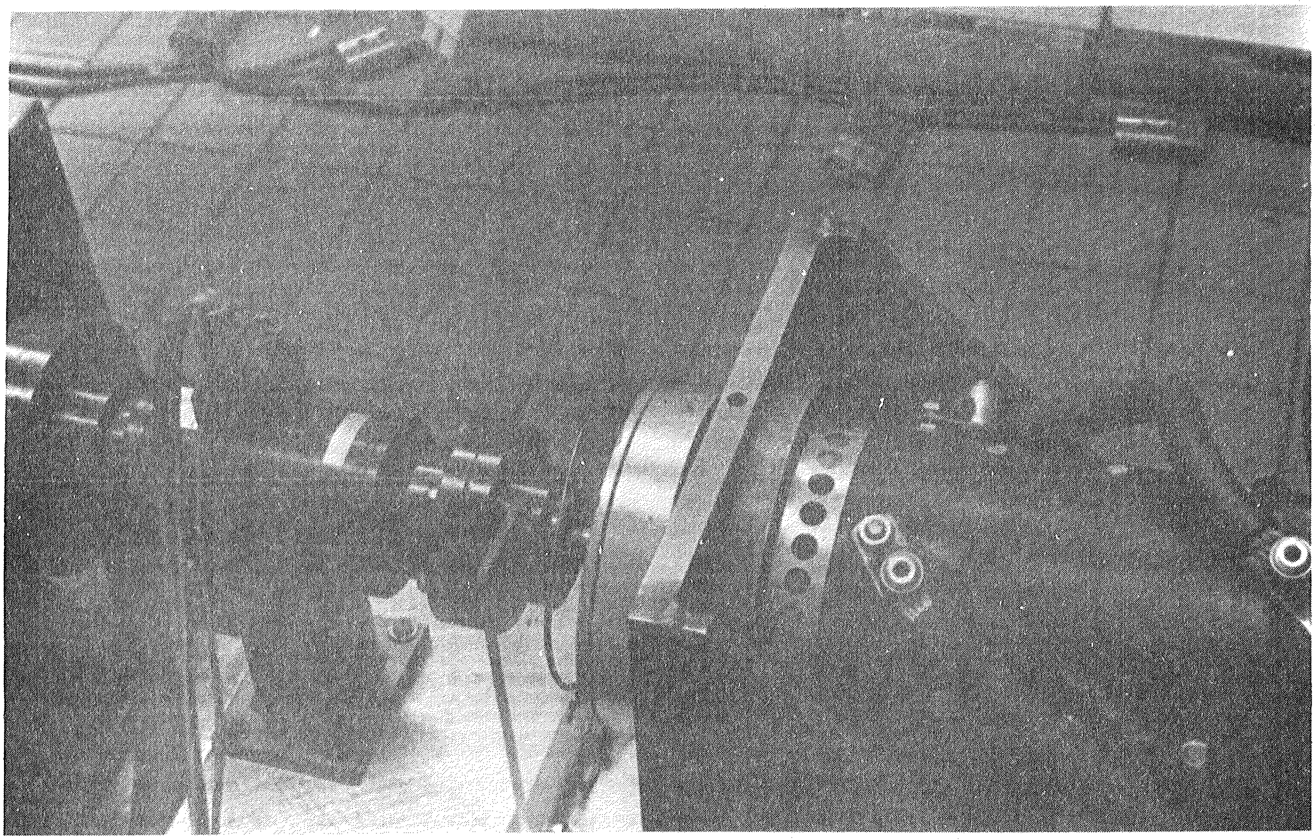


Figure 5 Mounting of Motor and Torque Transducer

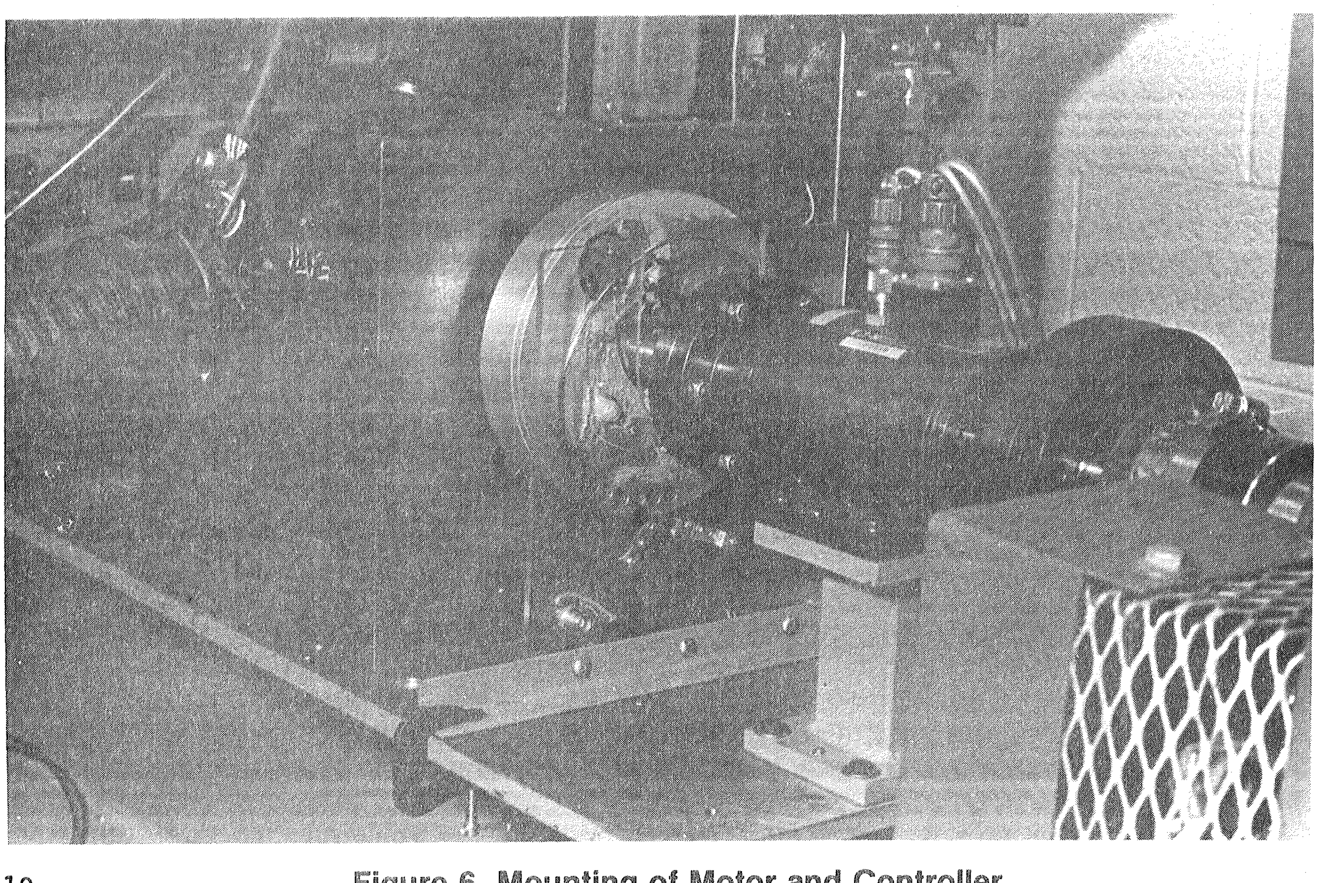


Figure 6 Mounting of Motor and Controller

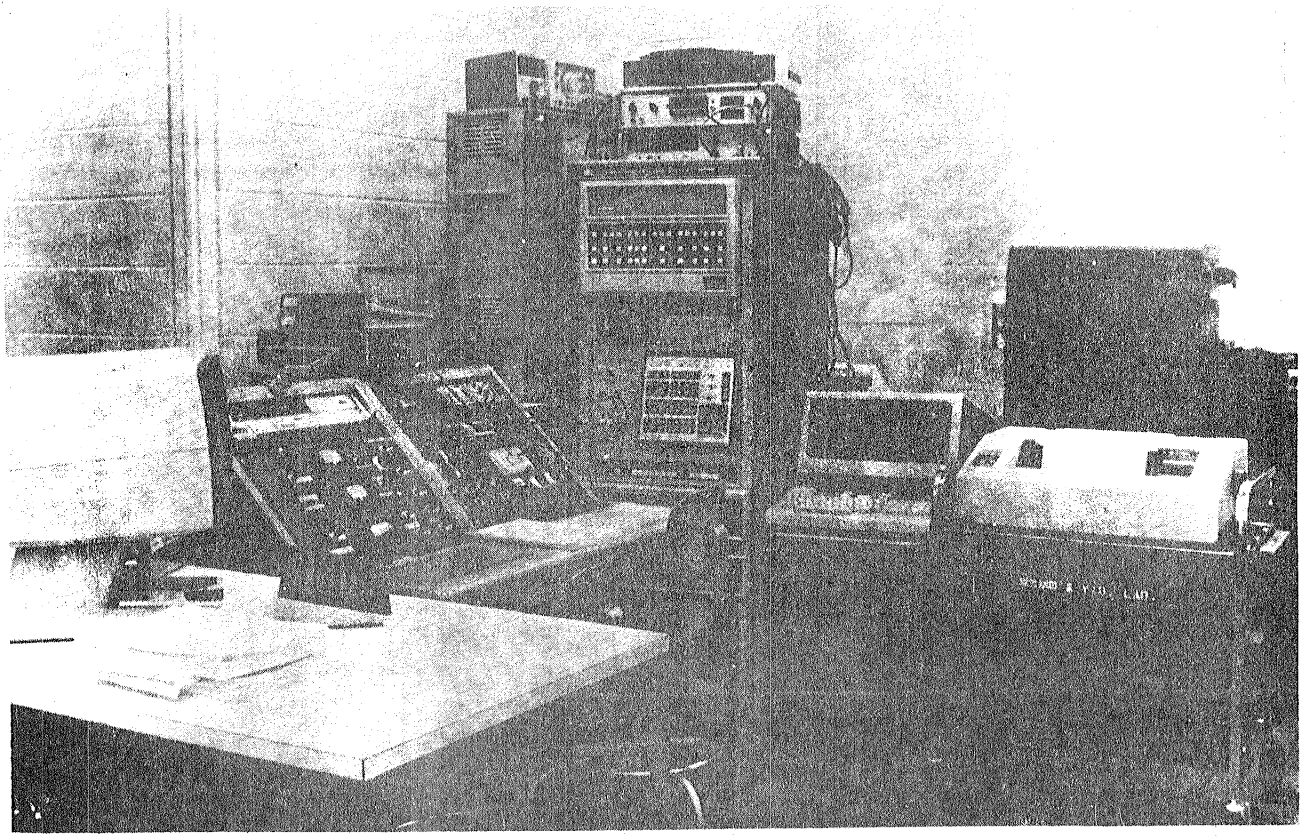


Figure 7 Control and Instrumentation Consoles

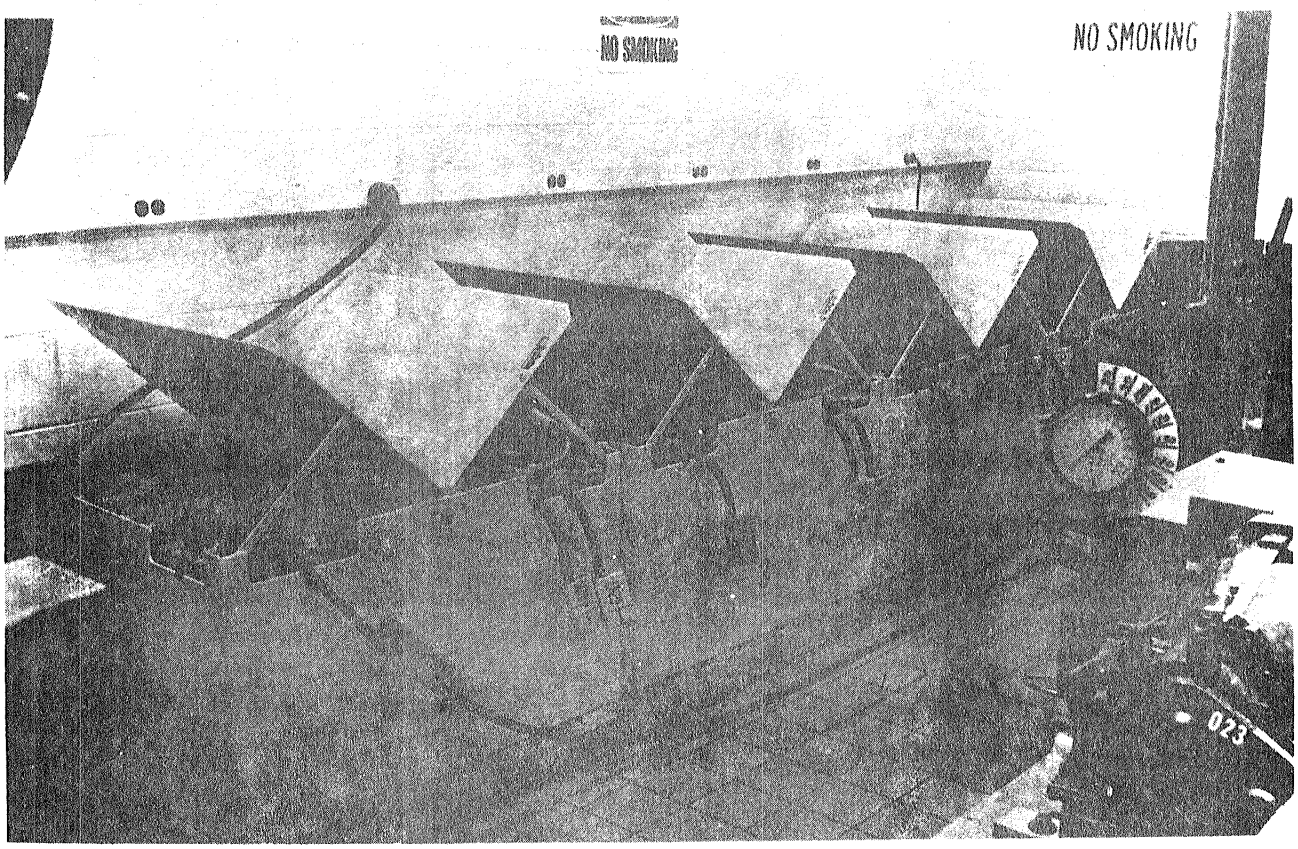
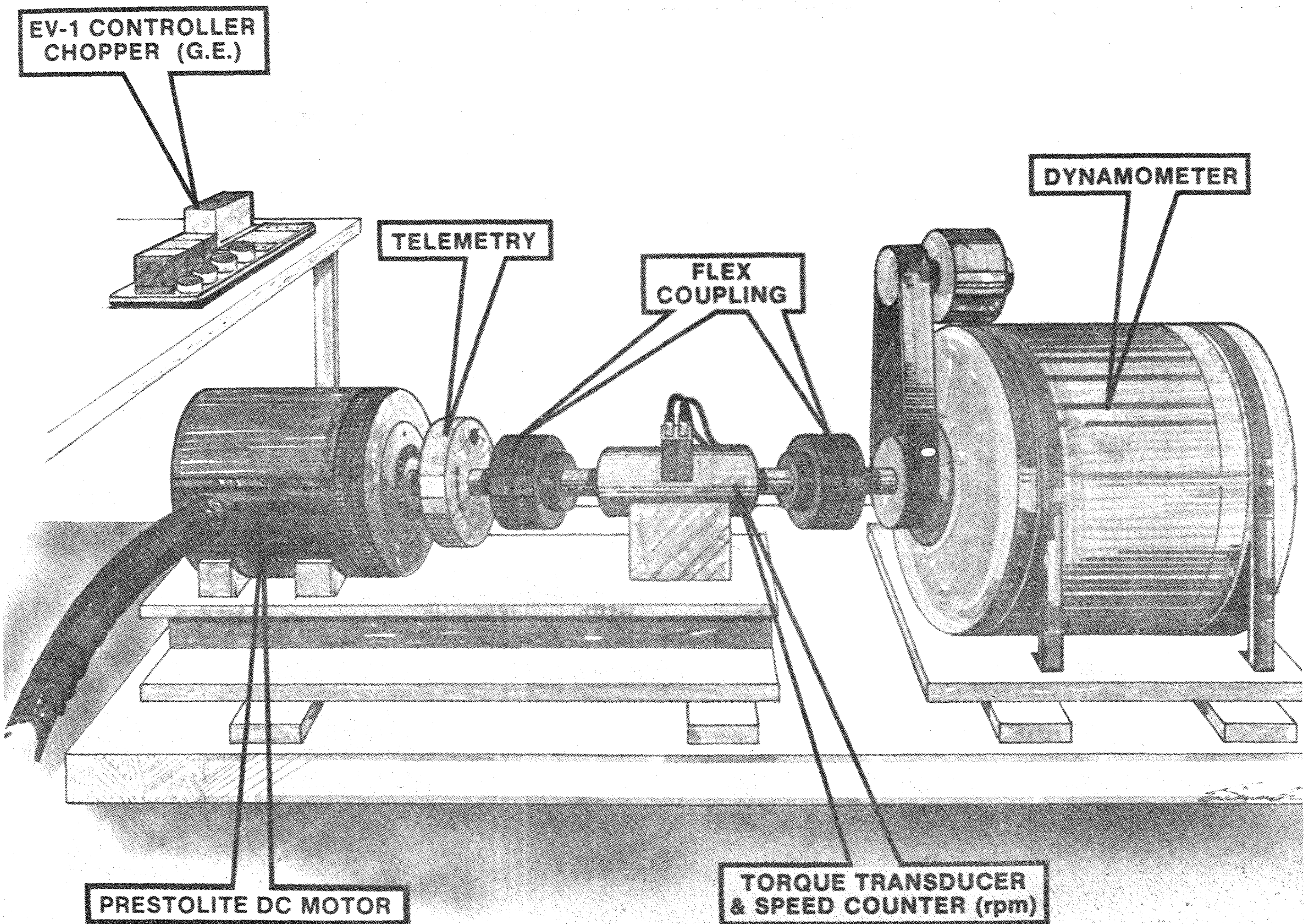


Figure 8 Battery Power Supply


EV-1 CONTROLLER
CHOPPER (G.E.)
TELEMETRY
FLEX
COUPLING
DYNAMOMETER
PRESTOLITE DC MOTOR
TORQUE TRANSDUCER
& SPEED COUNTER (rpm)

also forced over the motor housing using a conventional fan. Motor and controller operator controls were located on the dynamometer console. These included motor power and controller power switches and controller acceleration potentiometer. Safety systems for the dynamometer also served to shut off the motor/controller in event of an unsafe condition. A 300 amp DC contactor, controlled at the console, switched battery power to the motor. When data was taken for chopped DC operation, power was routed through a resistive load in series with the battery to simulate a more realistic source impedance, as would be found in a typical electric vehicle. This resistance had a value of 0.059 OHM, and was capable of dissipating approximately 5200 watts.

4. Instrumentation

Connection between the motor and dynamometer was made via a Lebow type 1604-2K torque-speed transducer. The torque transducer was of the rotary transformer type; the speed transducer was of the magnetic pickup type. Full-scale ranges were 225 N-m (2000 in-lbs) for the torque and 15,000 rpm for the speed pickup.

Also coupled directly to the motor was an Inmet Model 201A temperature telemeter. Two type T thermocouples were mounted on the motor armature laminations, 180 degrees apart. Thermocouple wire was run underneath the motor bearings, through the shaft keyway (which was extended for this purpose) and directly to the telemeter module. The module and its 9 volt power source were mounted in an aluminum disc 19.0 cm (7.5 inches) in diameter and rotationally balanced to 6000 rpm. A loop antenna was mounted on the small support I-beam to receive the FM transmission. A receiver was located on the control console and calibrated to readout directly in degrees centigrade.

Other temperature measurements were made directly on the field windings, with type K thermocouples. Thermocouple wire was run directly to the control console for readout.

Torque, speed and temperature readout were accomplished using a Daytronics 9000 series modular signal conditioning rack. Readout was directly in SI units. A readout was also provided to calculate motor output horsepower from the speed and torque signals.

Current measurements were made using T&M Research Type F coaxial shunts located on the bench, directly over the motor. These shunts were rated for a 100 mV drop at 200 amps and frequency response of over 0.5 MHz at rated current. Voltage measurements were taken directly from the motor and controller terminals via coaxial cable.

For the straight DC tests, current and voltage measurements were made directly on Fluke Model 8350A digital voltmeters.

For the chopped tests, both the current and voltage signals were fed into Phillips type PM-8940 optical isolators. These units have a frequency response of DC to 1.5 MHz ± 3 dB, with a phase shift of less than 2 degrees at 15 kHz. The isolators serve to amplify (for current measurements) or attenuate (for voltage measurements) the input signal as well as to "float" the inputs, allowing the output signal "commons" to be tied together. The isolator's "front end" is battery powered, completely eliminating any chance for ground loops to be created on the signal lines.

Since it was necessary to measure average and RMS voltages and currents, as well as average wideband power for the chopped DC tests, a Hewlett-Packard 5451B Signature Analysis System was utilized.

Output signals from the isolators were fed directly into the Hewlett Packard system. Analog-to-digital converters sampled the data at 20,000 points/sec., and digitally performed the calculations for average, RMS and power measurements.

The analyzer was programmed to print out all data required for each test point automatically. To assure waveform integrity, data from each channel was constantly monitored on an oscilloscope while being input to the analyzer.

TEST PROCEDURES

1. <u>Test Sequence</u>

A typical test run consisted of initially assuring the motor to be at the correct test temperature. Two temperature ranges were tested, 25°-45°C and 130°-150°C. For the high temperature runs, this was accomplished by wrapping the frame with layers of fiberglass insulation. Once the desired temperature range had been reached, the motor was driven to its maximum rated speed by the dynamometer. When speed had stabilized, the motor was powered at a specific input voltage and data was recorded. Once completed, the dynamometer speed was reduced 600 RPM for a second data point. This procedure continued until the torque transducer limit was reached. When the motor heated above its testing temperature range, forced air blowers were turned on, allowing it to cool. Once the maximum torque point had been taken, the motor was brought back to maximum speed at 500 RPM increments to record motor hysteresis. When completed, the next voltage tap was selected, and tested as before. Six motor input voltage levels were selected: 16, 24, 36, 64, 80, and 96 volts. When all required input voltages were tested, the entire procedure was repeated a total of 3 times. The procedure was followed for both ripple-free and chopped testing, the only difference being that for the chopped data, motor input voltage was controlled by adjusting the chopper acceleration potentiometer to achieve the proper level. Chopped data was taken at 80 and 96 volt input levels to the chopper, and the above test sequences were followed for both chopper input voltages. Battery condition was constantly monitored to assure that excessive "droop" was not occurring due to lack of charge level. For the resulting data, "droop" in input voltage level is primarily due to interconnecting cable IR drop, inter-battery connection IR drop, and for chopped data only, the IR drop due to the series 0.059 OHM added resistance.

2. <u>Data Acquisition</u>

Data which was directly read from instruments and the Hewlett Packard analyzer printout was typed into a portable CRT screen located on the control console. The CRT was tied into the Eaton VAX 11/780 computer, pre-programmed with a "form" format, so that all data was typed under correct headings. This allowed an orderly method of data acquisition, and made it possible to "call up" data from previous runs to compare data points for hysteresis and to assure that there was no substantial data shift from identical earlier tests.

Once in the VAX system, all data from the tests was averaged for each unique test point. This included all three test runs as well as hysteresis points. Averaging was done arithmetically, and was available on hard copy as final test results.

The following parameters have been measured for the motor at each test point:

1. Motor speed - measured at the motor shaft in units of revs./min. (Accuracy, ±1% of 6000 RPM full scale.)

2. Motor torque - measured at the motor shaft in units of Newton-meters. (Accuracy, ±1% of 225 Nm full scale.)

3. Motor temperatures - measured at various points internal to the motor (see section titled "Instrumentation" for details) in units of degrees centigrade. (Accuracy, ±0.4°C for field measurements, ±2°C for armature measurements.)

4. Motor input voltage - measured at the input terminals of the motor in units of volts. (Accuracy, ±0.01% of 199 volt full scale.)

5. Motor input current - measured at the input terminals of the motor in units of amperes. (Accuracy, ±0.50% of 400 ampere full scale.)

6. Controller input voltage - measured at the input terminals to the controller in units of volts. (Accuracy, ±1% of 200 volt full scale.)

7. Controller input current - measured at the input terminals to the controller in units of amperes. (Accuracy, ±1% of 400 ampere full scale.)

8. Controller input power - measured at the input terminals to the controller in units of watts. (Accuracy, ±2% of 80,000 watt full scale.)

9. Controller output voltage - measured at the output terminals of the controller in units of volts. (Accuracy, ±1% of 200 volt full scale.)

10. Controller output current - measured at the output terminals of the controller in units of amperes. (Accuracy, ±1% of 400 ampere full scale.)

11. Controller output power - measured at the output terminals of the controller in units of watts. (Accuracy, ±2% of 80,000 watt full scale.)

(Measurements #1-#3 were made for all tests, measurements #4 and #5 for straight DC tests, and measurements #6-#11 for chopped DC tests.)

TEST RESULTS

The test results are tabulated in Tables 1 through 6 and depicted graphically in Figures 10 through 19. As indicated in the "Test Procedures" Section of this report, three separate test runs were made at each test condition. Each run started at maximum speed. The motor was gradually loaded, and data was taken at the speeds indicated in the tables until maximum load was achieved. The load was then gradually removed, and data was again taken at the same speeds. Consequently, the original test data consists of six data points at each speed and each test condition. This data was averaged and reduced to decrease the data scatter and the volume of test data to be reported.

1. Data Reduction

The original intent of running three test points with speed decreasing and three test points with speed increasing was to show the effect of hysteresis on the motor performance. However, the hysteresis effects were found to be negligible, so all six data points were averaged together.

For tests of a motor that will be used with a specified power source, the input voltage is usually varied in accordance with the power supply characteristics. Where the power source is not specified, the input voltage is usually held constant.

For the straight DC tests, constant voltage data was desired. Since the input voltage varied somewhat, a correction factor was applied to the speed data. This compensation factor considered the internal copper $I_A R_A$ drop of the motor but did not include an allowance for brush drop. The following compensation equation was used:

$$\text{compensated speed} = \text{test speed} \; \frac{V_{IDEAL} - R_A I_A}{V_{TEST} - R_A I_A}$$

0.00624 ohms was used for the value of R_A. The new compensated speed was used in all subsequent calculations such as motor output, power, and efficiency. The curves were also plotted using the compensated speed or the compensated power output as a parameter.

For the chopped DC tests, it appeared to be more appropriate to try to simulate the voltage "droop" characteristics of presently available electric vehicle batteries. At each test point, the controller was adjusted to maintain a nearly constant value of average motor voltage; thus, speed conpensation is not necessary.

Once the data was averaged, a best fit plotting routine was utilized on the VAX to produce the following plots:

1. Torque - speed (for each voltage level)
2. Power - speed (for each voltage level)
3. Torque - current (for all voltage levels)

At this time, plots of efficiency-speed were derived by the following process: (for straight DC)

1. Lines of constant power were drawn on the power-speed curves.

2. From these lines, values of speed at each power level for every voltage were extrapolated.

3. Knowing speed and power, torque was calculated for every point.

4. Current was extrapolated for every torque value using the torque current curves.

5. Efficiency for each point was calculated as

$$n = \frac{\text{power out}}{V x I} .$$

6. For each line of constant power, the efficiency was plotted against speed using a best fit program.

For the chopped DC data a similar method was used with the following exceptions:

1. Once torque was known for each intersection point, input power to the motor was extrapolated using a torque vs. input power plot (derived for each voltage level from the averaged data).

2. Once derived, efficiency was calculated as

   $n = \frac{\text{power out}}{\text{power in}}$ and plotted against speed for each

   power level using a best fit program.

The final plot of chopper efficiency versus volts was derived using the following routine.

1. Equations were calculated for controller efficiency

   $\frac{\text{power out}}{\text{power in}}$ versus controller output power for each

   motor input voltage level using each averaged data point.

2. For fixed levels of controller output power, the value of controller efficiency and voltage were stored.

3. Plots were made of controller efficiency-controller output voltage for each power level.

4. Since these plots were overlapping within a very small range of efficiency (approximately 95%), plots were replaced with a band showing the maximum and minimum extremes of controller efficiency within the power levels indicated.

2. Straight DC Results

The straight DC data for two ranges of temperatures are presented in Tables 1 and 2. The voltage, current, torque, and speed variables are tabulated in the conventional manner. The compensated speed and the compensated power output were calculated as discussed in the Data Reduction Section of this report. The calculated efficiency is the ratio of the compensated power output to the product of the nominal voltage and current.

The temperature tabulations illustrate one of the difficulties in performing this type of testing. Not only does the temperature vary from one point to another in the machine, but the temperature difference also varies.

The tabulated data is depicted graphically in Figures 10 through 17. These curves all have the expected shape.

The data was recorded for two temperature ranges in order to allow an evaluation of temperature effects. The most discernable temperature effects appear in the torque-speed curves. The high temperature curves (Figure 11) are shifted downward or to the right of the corresponding low temperature curves (Figure 10).

The shift in the torque-speed curves is primarily due to the increase of armature resistance with increased temperature. Since the torque-current curves are in close agreement, a given torque will produce a greater $I_A R_A$ voltage drop at the higher temperature. Consequently, the counter electromotive force and the speed will decrease.

Temperature appears to have very little effect on motor efficiency. For both temperature ranges, the peak efficiencies are between 76% and 82%. These peak efficiencies all appear at moderate loads, reasonably high speeds and near maximum voltage. The efficiency drops below 75% only at light loads or low voltage.

3. Chopped DC Results

The chopped DC data are tabulated in four categories as follows:

Table 3	25-45°C	96 Volt Input
Table 4	25-45°C	80 Volt Input
Table 5	130-150°C	96 Volt Input
Table 6	130-150°C	80 Volt Input

This data is also depicted graphically in Figures 10 through 19.

The voltages refer to the nominal input voltages to the chopper. Two voltage ranges were used to allow an evaluation of the effects of the batteries' state of charge. The 96 volt tests were intended to represent a fully charged battery. The 80 volt tests were intended to represent a partially discharged battery.

Both the average and the root mean square (RMS) values of all the voltages and currents were recorded. Only the average values of the variables were used to generate the curves depicted in Figures 10 through 19. The RMS values were recorded to give an indication of the form factor of each variable and to aid in future modeling work. The duty cycle of the controller may roughly be considered to be the ratio of the average value of the chopper output voltage to the average value of the chopper input voltage.

A comparison of the chopper input power wattmeter reading with the product of the average input voltage and current value will indicate that sizeable errors may result by using the volt-amp product as a measure of power. For the low voltage tests, the product of the average values of voltage and current is greater than the wattmeter reading. However, at high values of test voltage the volt-amp product is less than the wattmeter reading. (The deviation at high test voltage is approximately 3%, and may be attributed to instrumentation error.) The same results are found when the product of the RMS values are compared to the wattmeter readings.

On the output side of the chopper a similar comparison may be made. Here the product of the average values of voltage and current are less than the wattmeter reading for low values of motor voltage and are higher than the wattmeter reading for high values of motor voltage. (Again, a 3% deviation is typical at high voltage, and may be attributed to instrumentation error.) These results are the opposite of those found on the input side of the chopper. The product of the RMS values of voltage and current are always greater than the wattmeter reading.

The maximum values of motor efficiency for the chopped DC case are approximately the same as the maximum values for the straight DC case. These maximum efficiency values all occur at or near maximum voltage and correspond to duty cycles near 100%. Consequently, they should be expected to approach the straight DC values. At low duty cycles the efficiency may be considerably less than the efficiency for straight DC.

The measured chopper efficiency is about 95% throughout the test range. Small errors in either chopper input or output power measurement result in variations in the calculated chopper efficiency. Consequently, the variations observed at individual test points are not significant.

A comparison of the chopped DC torque versus speed curves with the corresponding straight DC curves shows that the chopped DC curves are shifted slightly upward and to the right. For equal speeds, the additional torque produced in the chopped mode is due to the AC component in both the current and flux waves.

The torque-speed curves for the chopped mode of operation (Figures 12, 14, 16 and 18) show that the curve for maximum voltage coincides with the next lower voltage curve for high values of torque. This phenomenon is caused by the impedance of the power source. The corresponding tabulated data shows that for the highest voltage curve in each category, the chopper duty cycle is nearly 100% and that a constant voltage cannot be maintained at the chopper output terminals as torque is increased. In the region of coincidence, the chopper duty cycle is also 100% for the second highest voltage curve.

CONCLUSIONS

A fairly elaborate setup is required to perform the tests described in this report.

1. Power Supply Requirements

   Ideally the motor should be tested with the specific power supply with which it will be used. In the case of battery powered vehicles, the variations of battery characteristics and its limited energy capacity make actual vehicle batteries impractical. Some compromises must be made. In the straight DC mode of operation, a constant voltage source appears to be most desirable. In the chopped mode, the internal impedance of the source substantially affects wave shapes.

2. Temperature Control

   The temperature of the motor windings can change very rapidly. To expedite testing, the winding temperatures should be monitored and some method of heating and cooling the motor is desirable.

3. Instrumentation

   For the chopped mode of operation, the instrumentation must be carefully considered. Significant errors can result from using the product of voltage and current as an indicator of power. Suitable wattmeters must be used. Many readings will be a small fraction of full scale and accuracy may be less than expected.

4. Test Results

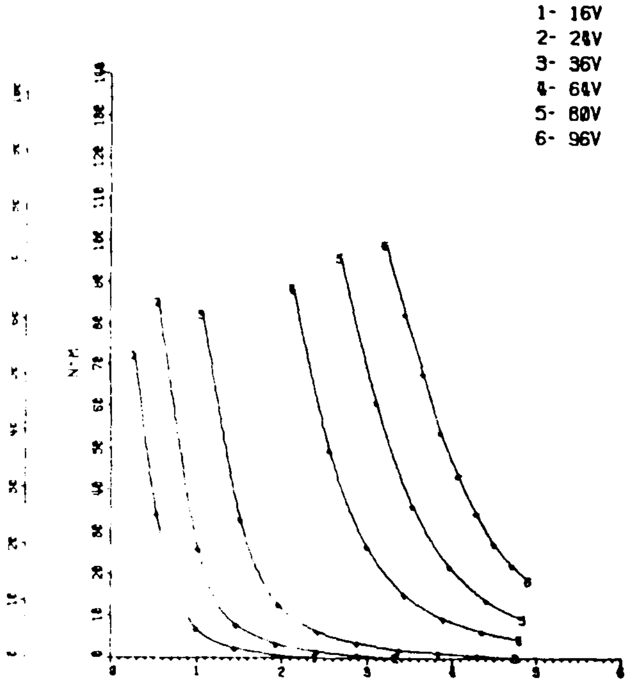
   a. The controller efficiency may be assumed to be about 95% throughout the test range.

   b. The maximum efficiency of the motor was between 76% and 82% regardless of the motor temperature or the mode of operation. However, at low chopper duty cycles the motor efficiency may be considerably less than it is on straight DC.

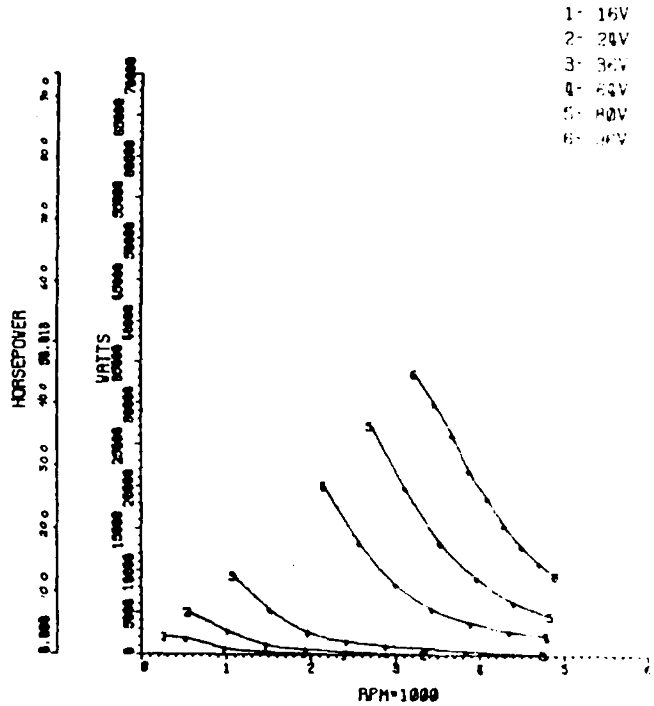
   c. Most of the variations caused by changing test conditions are discernable on conventional torque-speed curves. For equal torque, a motor at high temperature will run somewhat slower than the same motor at a lower temperature. For equal speeds, a motor operated in the chopped mode develops slightly more torque than it does in the straight DC mode.

   d. The hysteresis effects of the motor alone, as well as the motor-controller combination, are negligible and can be ignored.

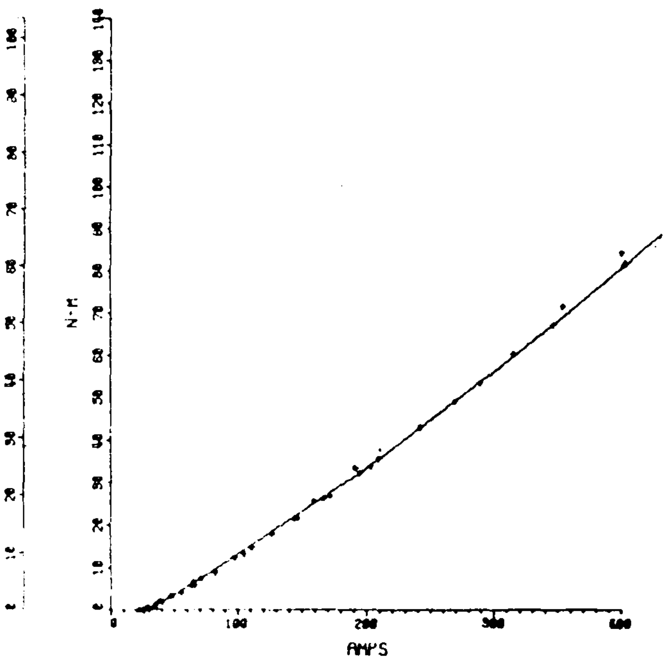
Page Missing in Original Document



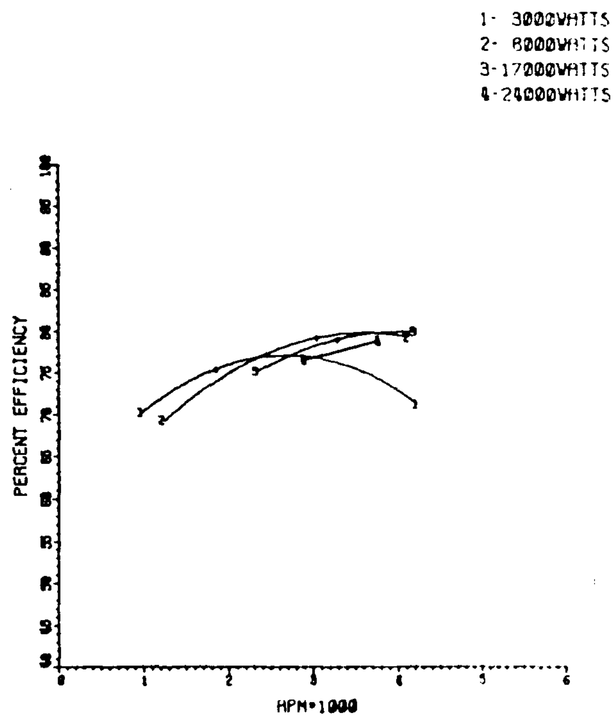
A. Speed-Torque Characteristics



B. Output Power-Speed Characteristic

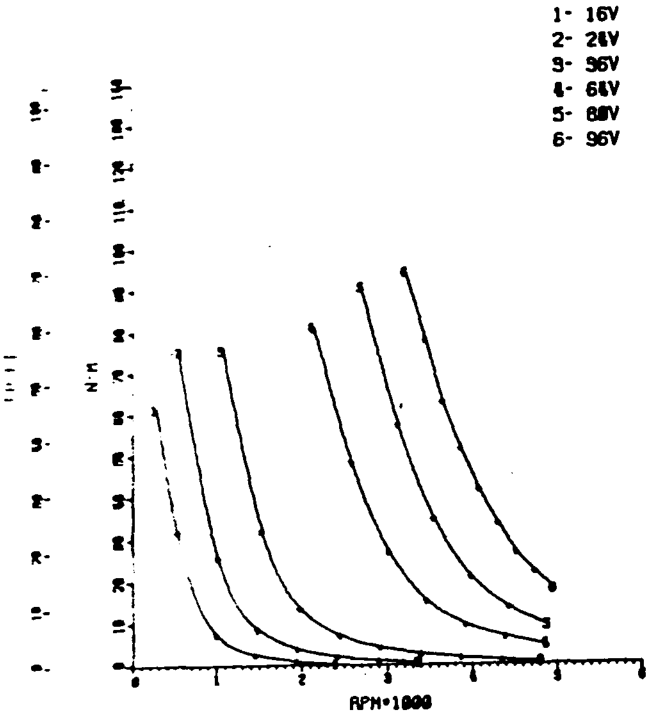


C. Torque-Current Characteristics

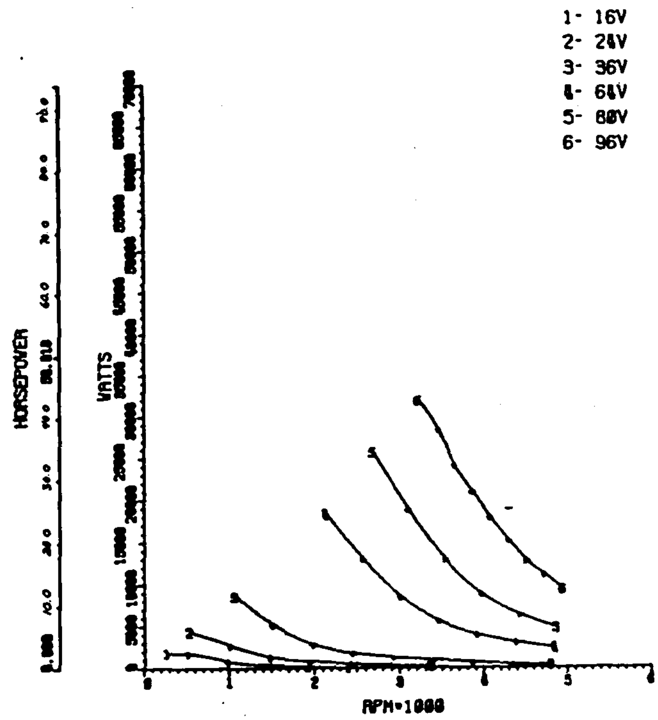


D. Efficiency-Speed-Power Relationsh

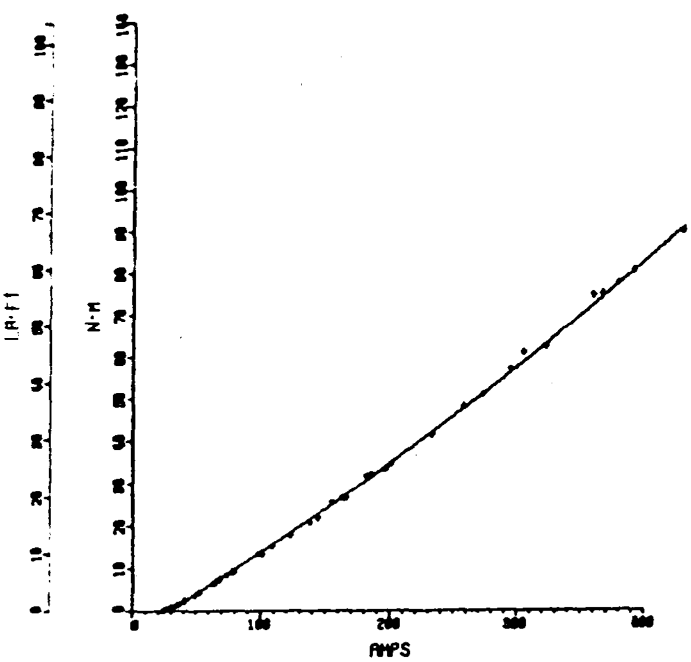
Figure 10 Low Temperature-Straight DC



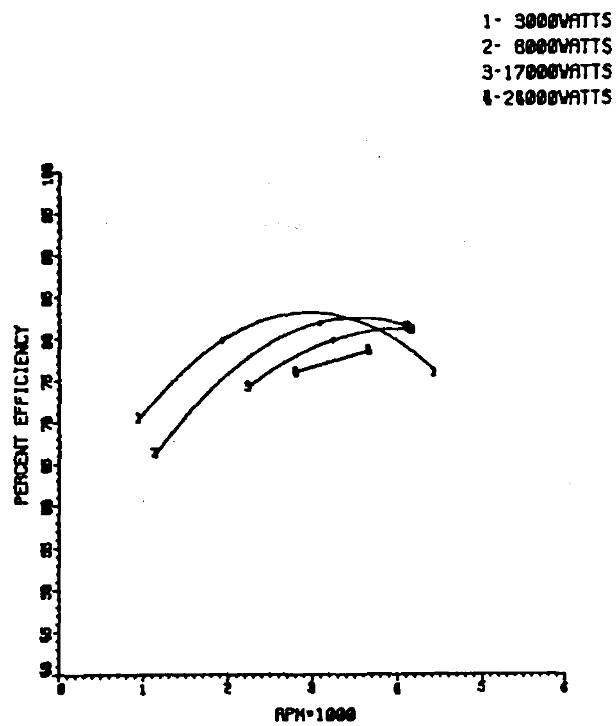
A. Speed-Torque Characteristics



B. Output Power-Speed Characteristic

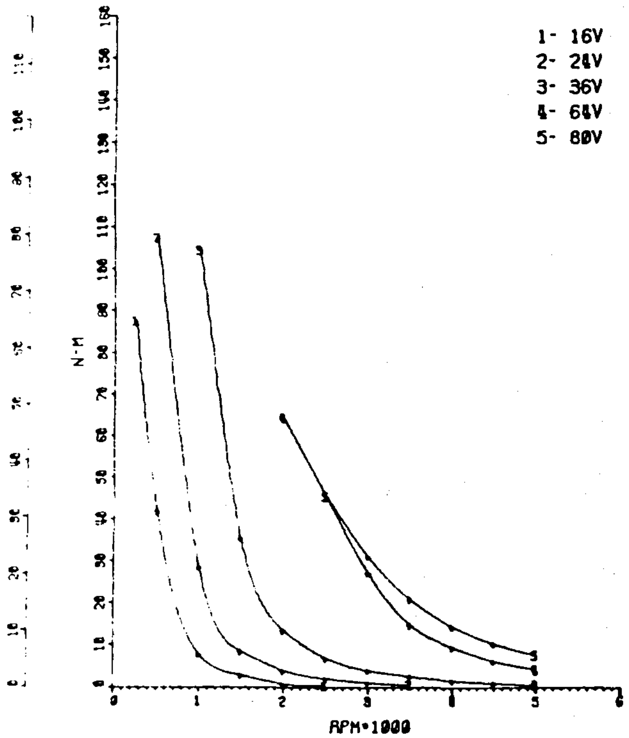


C. Torque-Current Characteristics

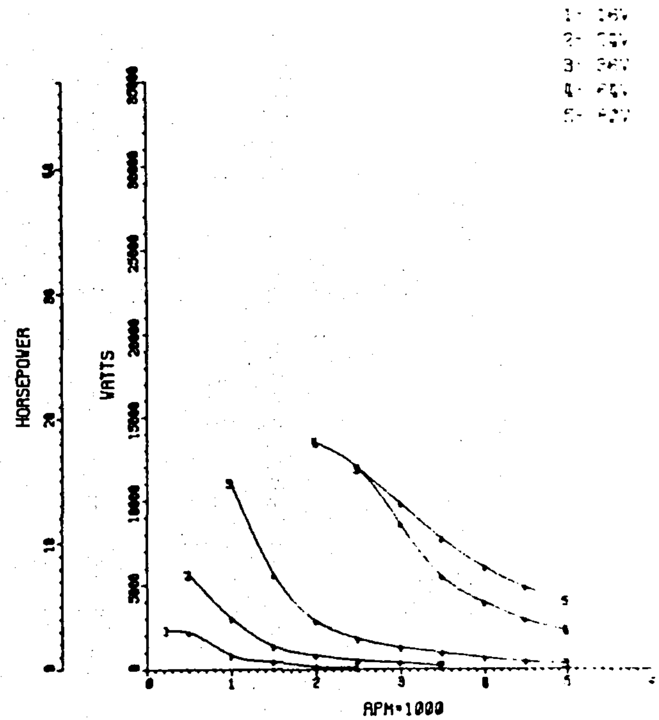


D. Efficiency-Speed-Power Relationsh

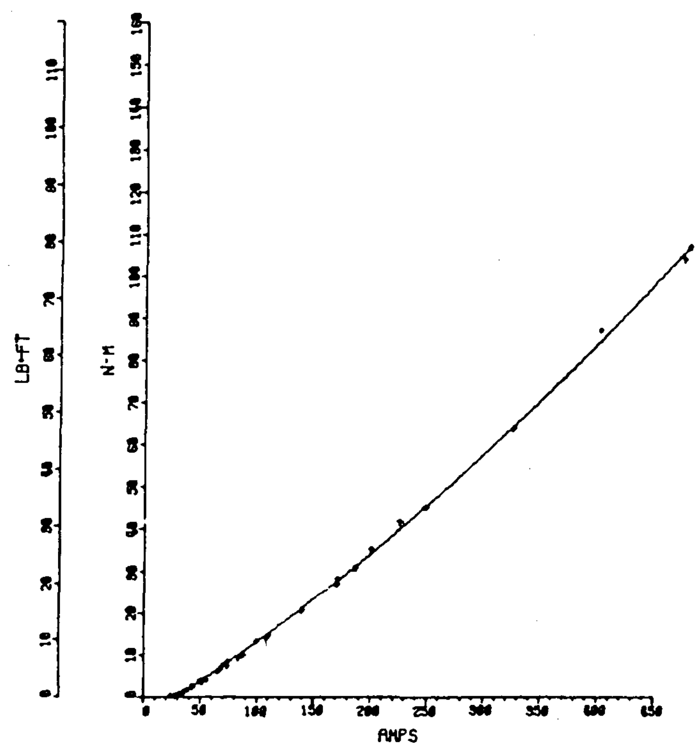
Figure 11 High Temperature-Straight DC



A. Speed-Torque Characteristics

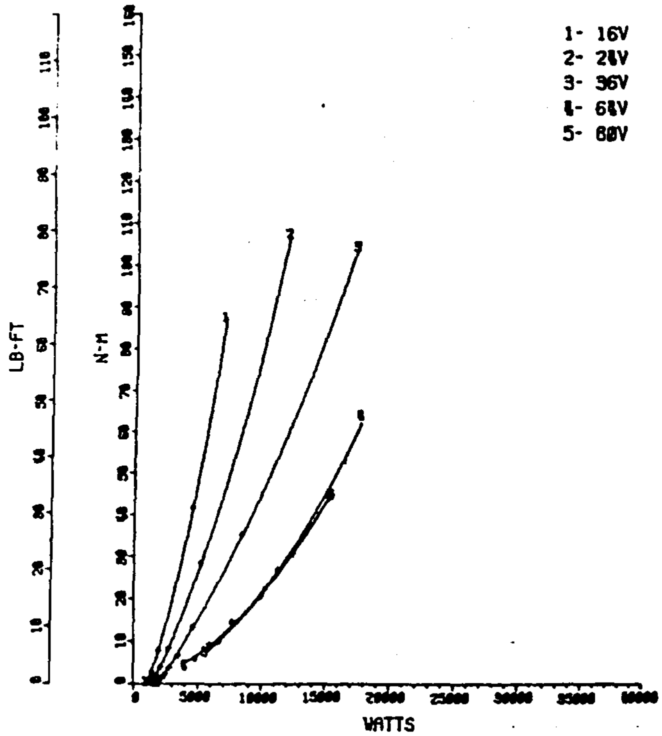


B. Output Power-Speed Characteristics

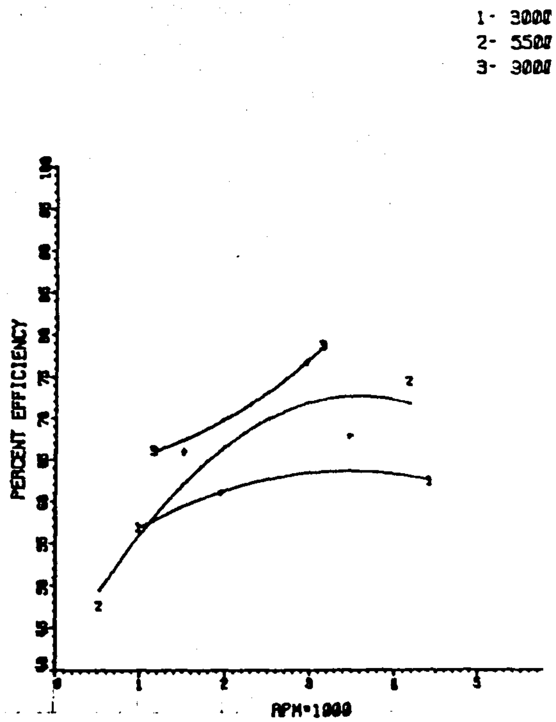


C. Torque-Current Characteristics

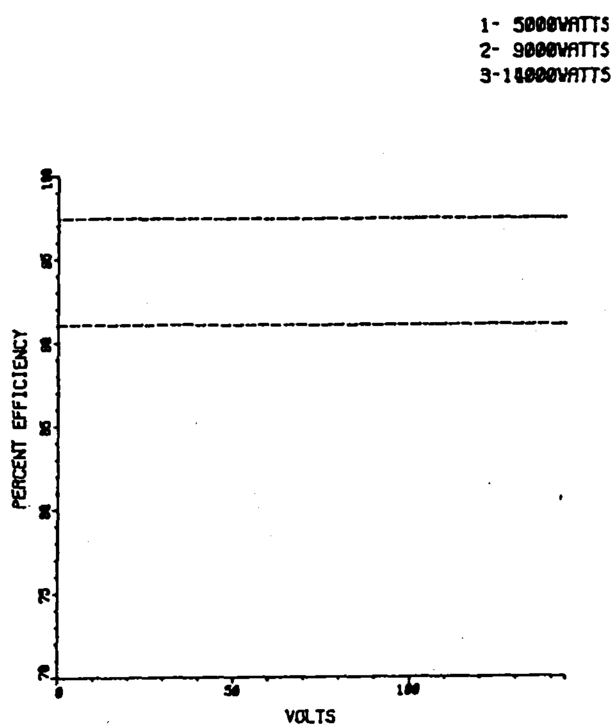
Figure 12 Low Temperature-Chopped DC-120 Volt Input



A. Torque-Power-Voltage Relationships

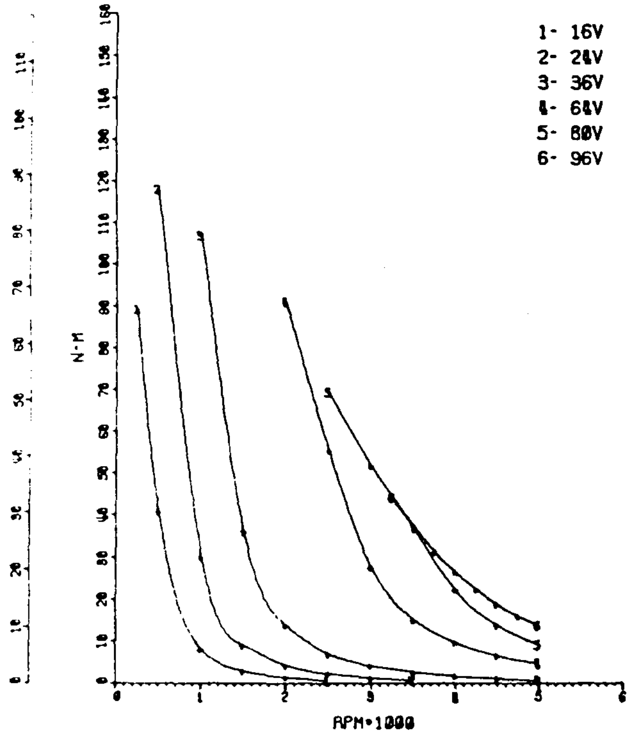


B. Motor Efficiency-Speed-Pow Relationships

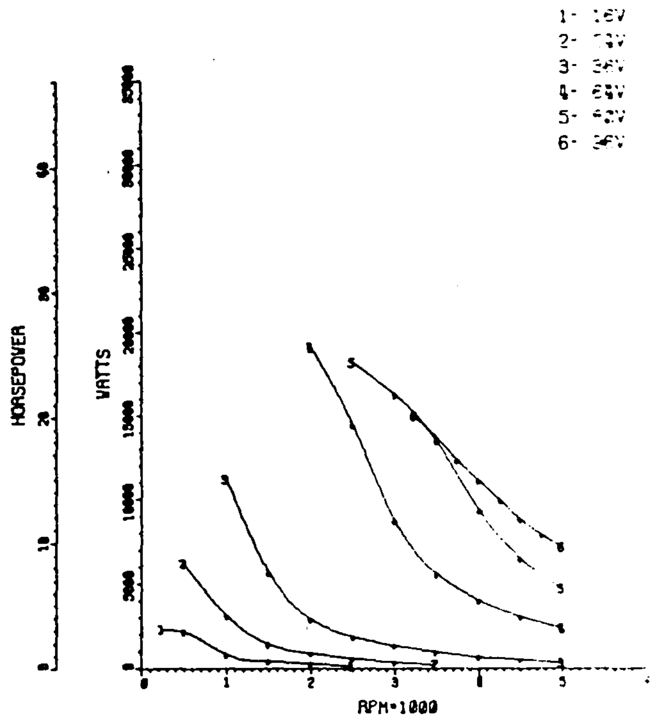


C. Controller Efficiency

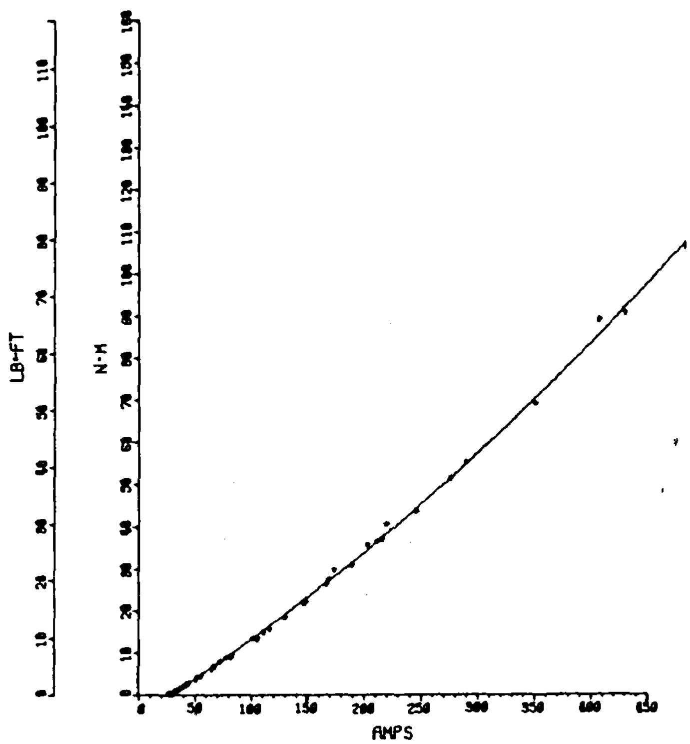
Figure 13 Low Temperature-Chopped DC-120 Volt Input



A. Speed-Torque Characteristics

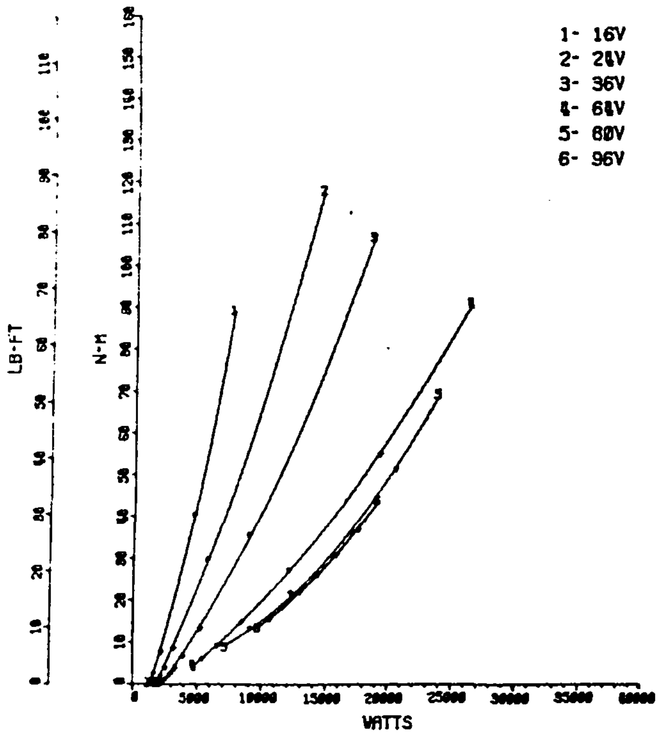


B. Output Power-Speed Characteristics

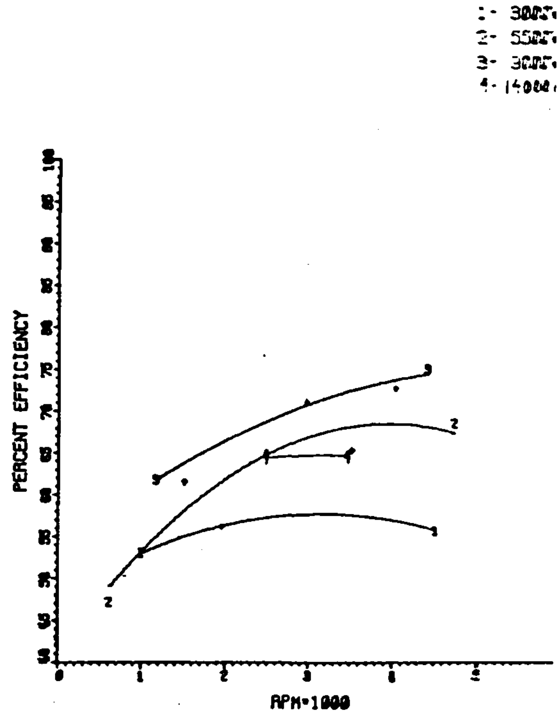


C. Torque-Current Characteristics

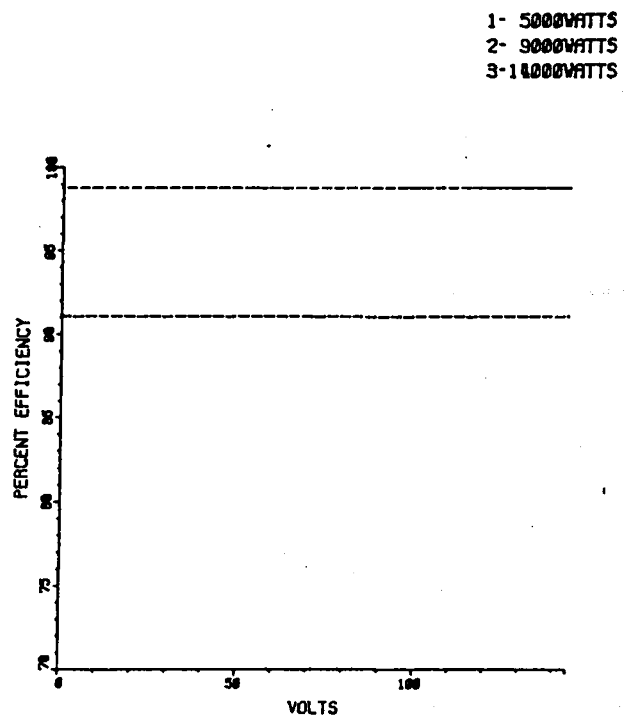
Figure 14 Low Temperature-Chopped DC-144 Volt Input



A. Torque-Power-Voltage Relationships

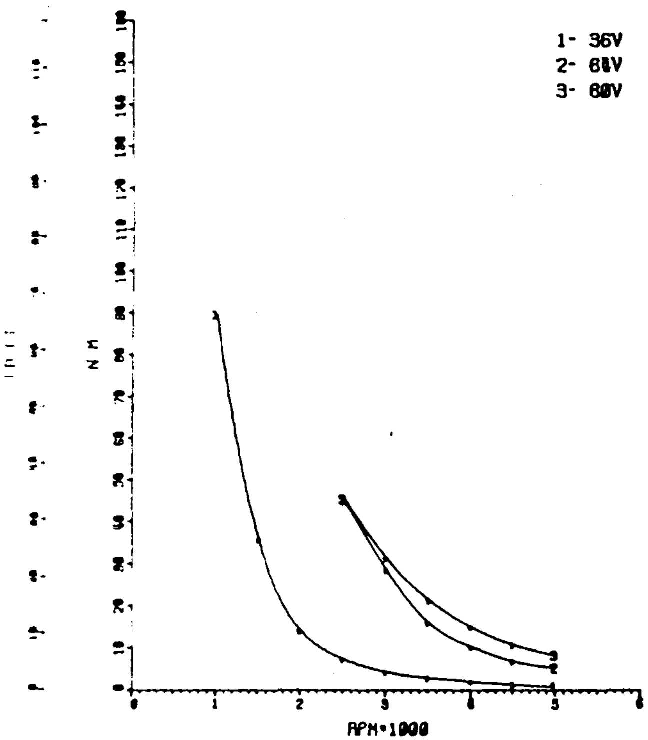


B. Motor Efficiency-Speed-Pow Relationships

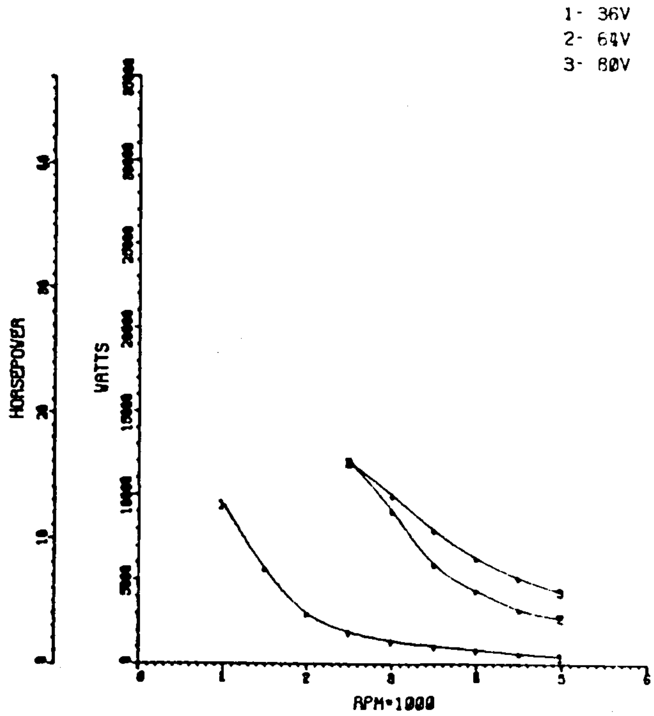


C. Controller Efficiency

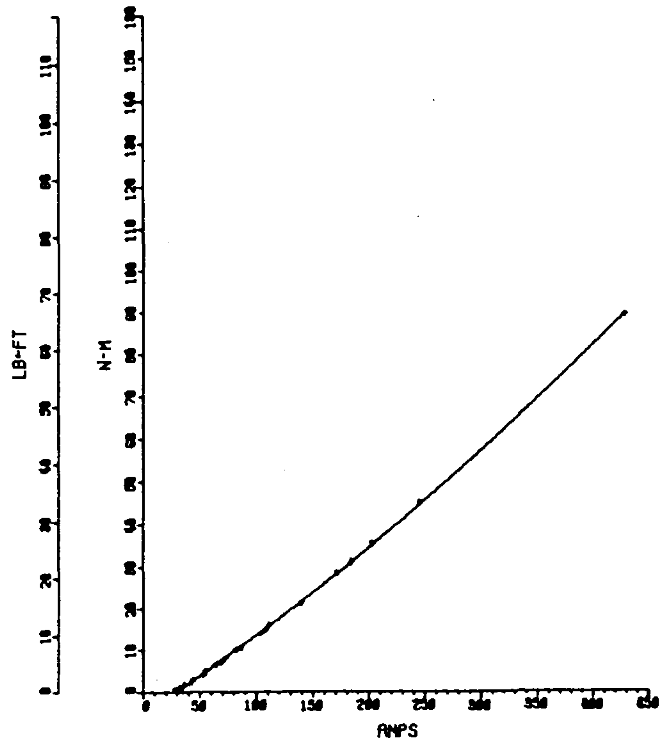
Figure 15 Low Temperature-Chopped DC-144 Volt Input



A. Speed-Torque Characteristics

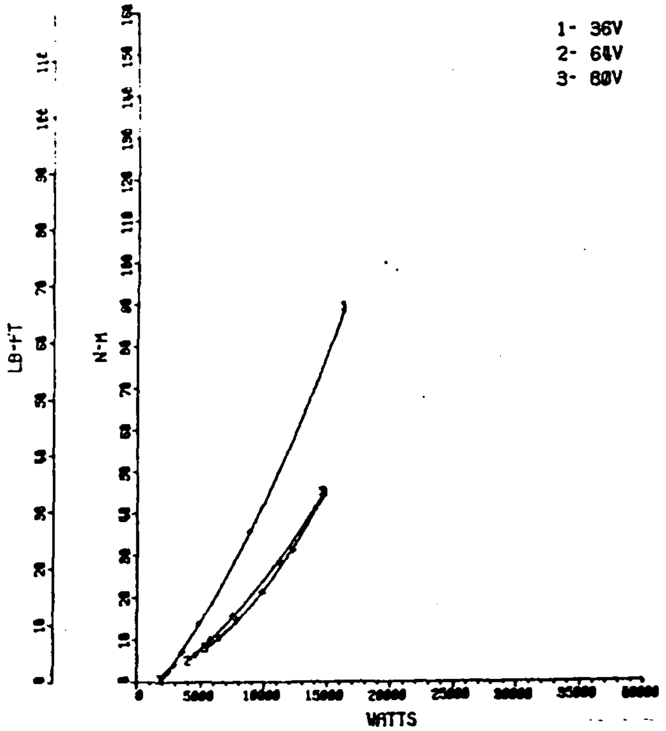


B. Output Power-Speed Characteristics

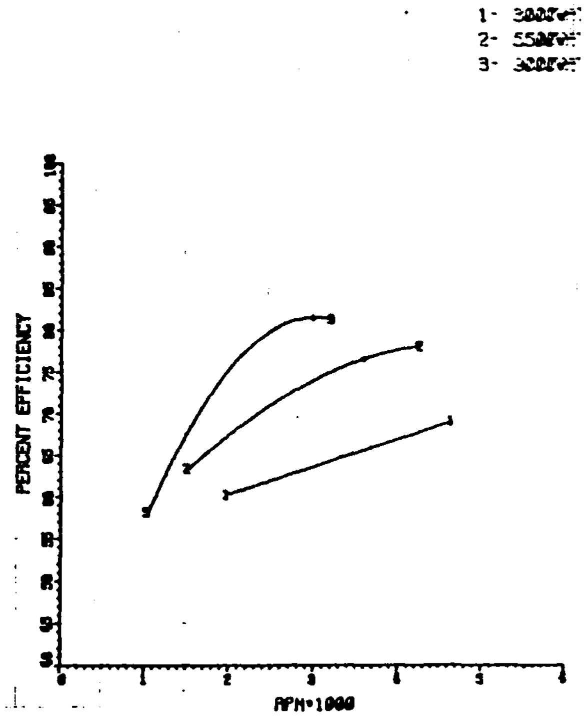


C. Torque-Current Characteristics

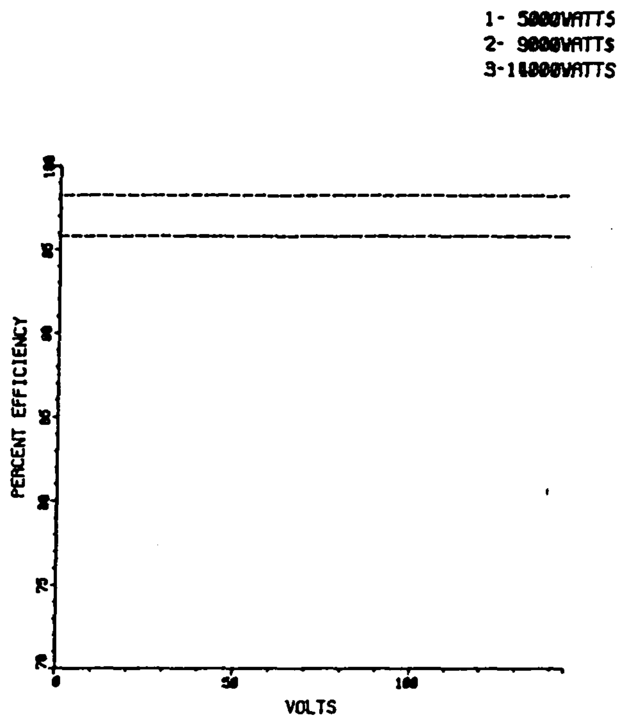
Figure 16 High Temperature-Chopped DC-120 Volt Input



A. Torque-Power-Voltage Relationships

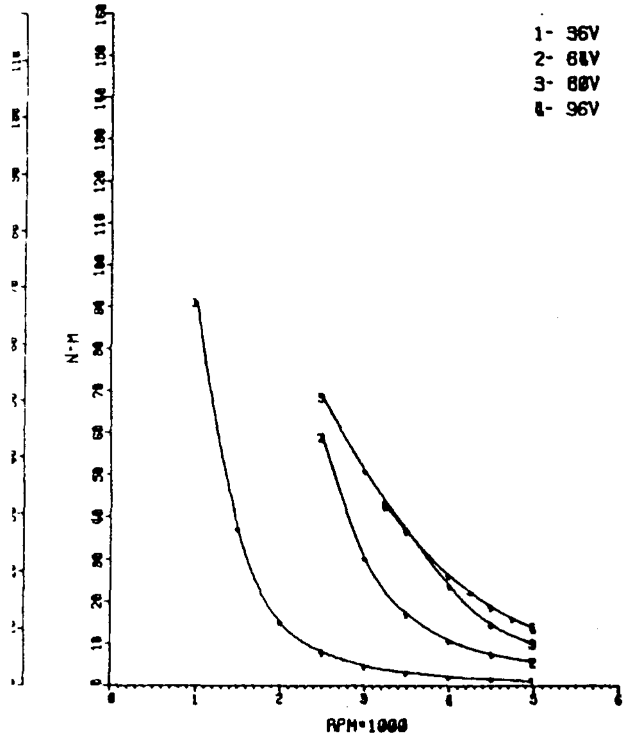


B. Motor Efficiency-Speed-Powe Relationships

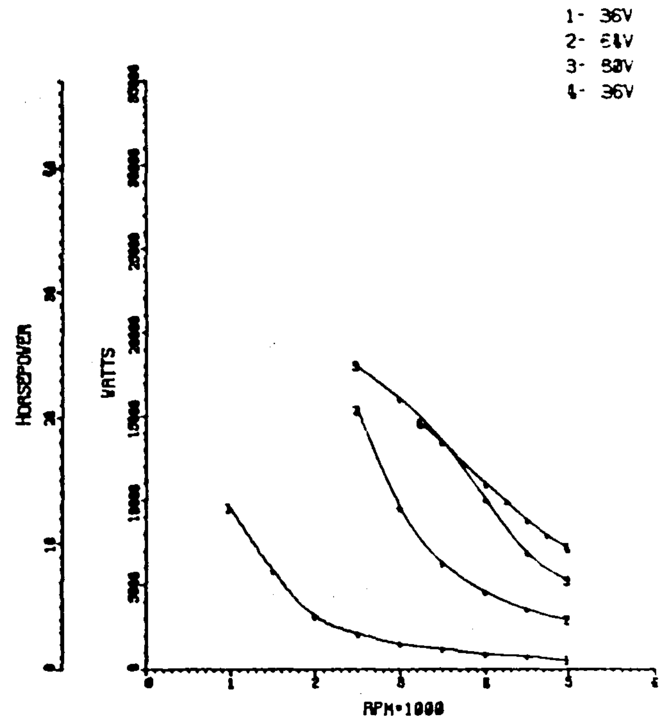


C. Controller Efficiency

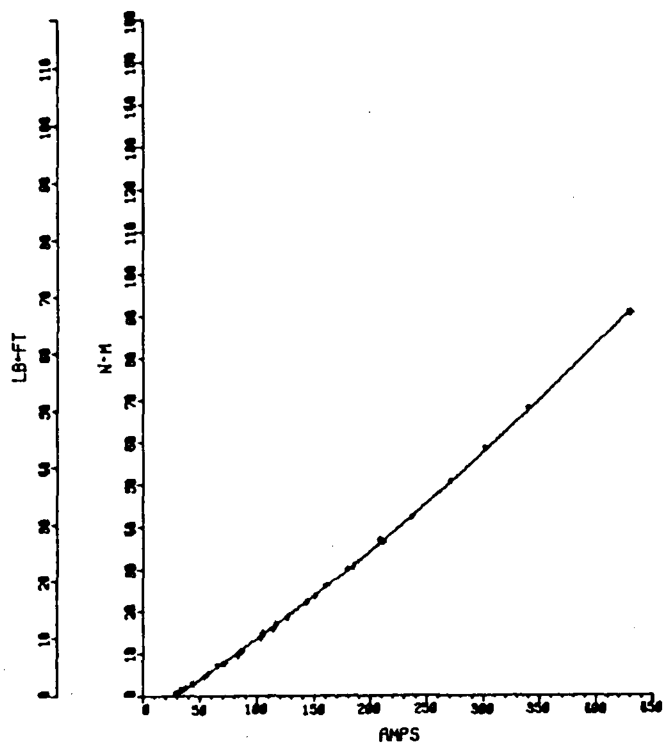
Figure 17 High Temperature-Chopped DC-120 Volt Input



A. Speed-Torque Characteristics

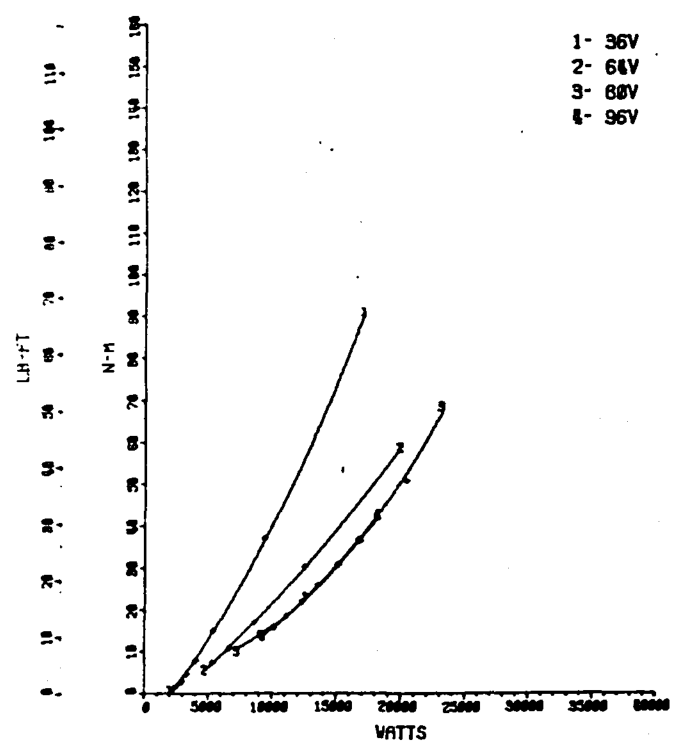


B. Output Power-Speed Characteristics

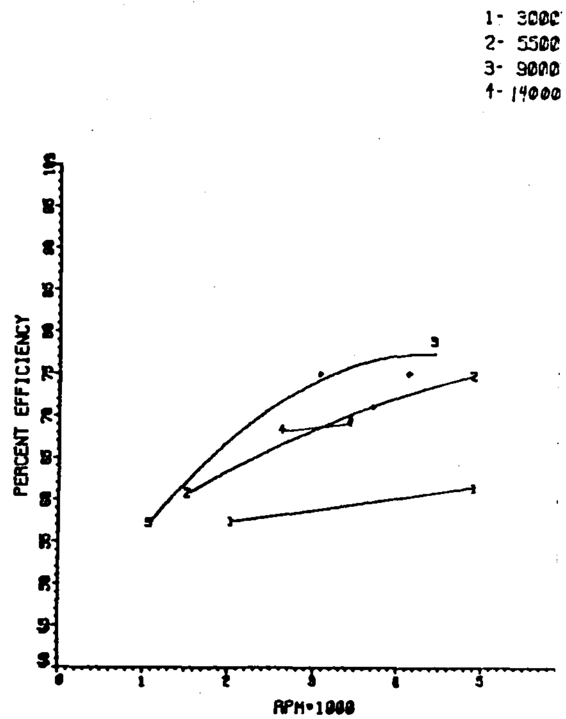


C. Torque-Current Characteristics

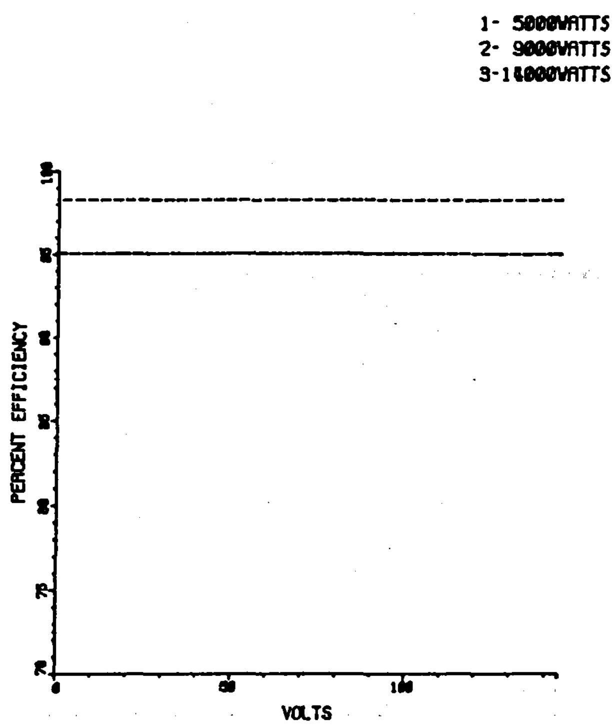
Figure 18 High Temperature-Chopped DC-144 Volt Input



A. Torque-Power-Voltage Relationships



B. Motor Efficiency-Speed-Power Relationships



C. Controller Efficiency

Figure 19 High Temperature-Chopped DC-144 Volt Input

T A B U L A R   D A T A

Table 1

PRESTOLITE MODEL MTC-4001 DC MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER

PRESTOLITE STRAIGHT DC TESTS, 25-45°C TEMPERATURE RANGE

BATTERY TAP (VOLTS)	MOTOR FIELD TEMP (°C) #1	MOTOR FIELD TEMP (°C) #2	MOTOR ARMATURE TEMP (°C)	INPUT VOLTAGE (VOLTS)	INPUT CURRENT (AMPS)	OUTPUT TORQUE (Nm)	OUTPUT SPEED (RPM)	COMPENSATED OUTPUT SPEED (RPM)	COMPENSATED OUTPUT POWER (WATTS)	EFFICIENCY (%)
16	39	39	54	16.6	22.8	0.1	2500	2413.7	25.3	6.9
	39	39	53	16.6	28.7	0.7	2000	1932.8	141.7	30.9
	38	38	53	16.4	39.4	2.3	1500	1462.9	352.5	55.9
	38	37	55	16.2	65.0	6.9	1000	988.4	714.5	68.7
	37	37	55	15.2	191.3	34.1	500	527.9	1885.9	61.6
	38	38	54	14.3	354.2	72.3	250	285.9	2165.5	38.2
24	35	35	57	25.0	25.4	0.1	3500	3354.6	35.1	5.8
	35	35	58	25.0	29.9	0.6	3000	2884.9	181.3	25.3
	35	35	59	24.8	36.2	1.5	2500	2417.0	379.8	43.7
	36	36	59	24.7	47.2	3.3	2000	1941.3	671.1	59.2
	36	36	60	24.4	70.8	7.7	1500	1472.9	1188.2	70.0
	35	35	62	23.6	159.6	26.0	1000	1016.9	2769.9	72.3
	33	33	59	21.7	400.4	85.1	500	559.9	4991.7	52.0
36	39	39	63	37.7	26.6	0.0	5000	4771.4	0.0	0.0
	40	40	62	37.6	30.7	0.5	4500	4311.4	225.8	20.4
	40	40	59	37.5	35.0	1.2	4000	3842.5	483.1	38.3
	40	40	60	37.3	41.0	2.0	3500	3377.2	707.6	47.9
	40	40	60	37.4	49.4	3.5	3000	2886.8	1058.5	59.5
	40	40	60	37.1	63.5	6.1	2500	2422.9	1548.4	67.7
	39	39	61	36.6	98.2	12.7	2000	1967.6	2617.9	74.1
	39	38	64	35.4	195.1	33.0	1500	1524.8	5271.5	75.1
	44	44	80	33.3	402.6	82.1	1000	1086.5	9345.1	64.5

Table 1 Cont'd.

PRESTOLITE MODEL MTC-4001 DC MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER

PRESTOLITE STRAIGHT DC TESTS, 25-45°C TEMPERATURE RANGE

BATTERY TAP (VOLTS)	MOTOR FIELD TEMP (°C) #1	MOTOR FIELD TEMP (°C) #2	MOTOR ARMATURE TEMP (°C)	INPUT VOLTAGE (VOLTS)	INPUT CURRENT (AMPS)	OUTPUT TORQUE (Nm)	OUTPUT SPEED (RPM)	COMPENSATED OUTPUT SPEED (RPM)	COMPENSATED OUTPUT POWER (WATTS)	EFFICIENCY (%)
64	42	42	58	66.5	55.8	4.2	5000	4814.7	2118.5	59.3
	43	43	56	66.1	66.2	6.1	4500	5356.1	2783.8	65.7
	43	43	59	65.7	83.0	9.4	4000	3897.7	3838.4	72.3
	44	44	58	65.0	111.3	15.1	3500	3443.8	5447.9	76.5
	43	43	60	64.0	167.3	26.7	3000	3000.8	8393.8	78.4
	42	42	60	62.3	270.0	49.5	2500	2570.8	13331.7	77.2
	44	44	70	59.5	434.2	88.3	2000	2158.5	19967.5	71.9
80	39	39	45	82.4	82.5	9.1	5000	4852.5	4626.1	70.1
	41	41	43	81.6	105.3	13.6	4500	4411.0	6284.7	74.6
	41	41	45	80.5	144.0	21.9	4000	3973.2	9115.8	79.1
	41	41	47	79.1	209.7	36.3	3500	3539.7	13461.2	80.2
	39	38	44	77.1	315.5	61.0	3000	3117.9	19925.2	78.9
	45	45	55	73.9	459.8	95.8	2500	2714.7	27245.7	74.1
96	45	45	52	97.4	127.3	18.2	5000	4927.5	9395.3	76.9
	45	45	52	96.7	146.9	22.1	4750	4716.9	10920.9	77.4
	44	44	58	95.9	172.1	27.4	4500	4504.7	12930.9	78.3
	45	45	59	95.1	203.7	34.5	4250	4290.0	15505.6	79.3
	44	44	61	94.1	242.2	43.6	4000	4081.3	18642.2	80.2
	44	43	62	93.0	289.2	54.0	3750	3874.1	21916.7	78.9
	43	43	67	91.6	347.0	68.0	3500	3672.2	26160.5	78.5
	44	43	69	90.2	403.7	82.6	3250	3463.7	29973.1	77.3
	44	44	80	89.1	468.7	99.0	3000	3239.0	33593.7	74.7

Table 2

PRESTOLITE MODEL MTC-4001 DC MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER

PRESTOLITE STRAIGHT DC TESTS, 130-150°C TEMPERATURE RANGE

BATTERY TAP (VOLTS)	MOTOR FIELD TEMP (°C) #1	MOTOR FIELD TEMP (°C) #2	MOTOR ARMATURE TEMP (°C)	INPUT VOLTAGE (VOLTS)	INPUT CURRENT (AMPS)	OUTPUT TORQUE (Nm)	OUTPUT SPEED (RPM)	COMPENSATED OUTPUT SPEED (RPM)	COMPENSATED OUTPUT POWER (WATTS)	EFFICIENCY (%)
16	143	143	174	16.5	23.6	0.2	2500	2421.1	50.7	13.4
	143	143	174	16.4	30.3	0.9	2000	1948.6	183.7	37.9
	143	143	176	16.4	41.8	2.6	1500	1461.3	398.0	59.5
	143	143	177	16.1	69.0	7.6	1000	992.6	790.3	71.6
	142	142	179	15.4	182.0	32.0	500	522.3	1751.0	60.1
	142	142	176	14.6	305.1	61.5	250	277.6	1788.6	36.6
24	145	145	169	24.9	25.4	0.6	3500	3379.5	212.4	34.8
	145	145	168	24.8	31.2	1.1	3000	2902.5	334.5	44.7
	146	145	170	24.7	38.1	2.0	2500	2428.5	508.8	55.6
	146	145	172	24.6	50.3	3.9	2000	1953.3	798.1	66.1
	145	145	174	24.3	75.1	8.7	1500	1479.0	1348.0	74.8
	145	144	174	23.6	155.9	25.9	1000	1017.7	2761.4	73.8
	144	143	173	22.0	359.7	75.1	500	550.6	4331.9	50.2
36	144	144	160	37.3	25.9	0.6	5000	4822.8	303.2	32.5
	144	144	161	37.2	30.0	1.0	4500	4350.2	455.7	42.2
	145	145	162	37.2	35.5	1.7	4000	3873.7	689.9	54.0
	145	145	162	37.0	41.9	2.7	3500	3401.6	962.2	63.8
	146	146	165	36.9	51.0	4.2	3000	2924.9	1286.9	70.1
	146	146	166	36.7	66.2	7.0	2500	2451.8	1798.0	75.4
	146	146	167	36.3	98.4	13.6	2000	1981.3	2822.9	79.7
	145	144	167	35.5	185.8	32.4	1500	1524.1	5173.3	77.3
	145	145	165	33.5	367.3	75.4	1000	1080.1	8531.9	64.5

Table 2 Cont'd.

PRESTOLITE MODEL MTC-4001 DC MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER

DEN3-123

PRESTOLITE ELECTRIC STRAIGHT DC TESTS, 130-150°C TEMPERATURE RANGE

BATTERY TAP (VOLTS)	MOTOR FIELD TEMP (°C) #1	MOTOR FIELD TEMP (°C) #2	MOTOR ARMATURE TEMP (°C)	INPUT VOLTAGE (VOLTS)	INPUT CURRENT (AMPS)	OUTPUT TORQUE (Nm)	OUTPUT SPEED (RPM)	COMPENSATED OUTPUT SPEED (RPM)	COMPENSATED OUTPUT POWER (WATTS)	EFFICIENCY (%)
64	139	139	136	65.8	53.0	4.5	5000	4863.8	2292.9	67.6
	140	140	134	65.5	63.8	6.6	4500	4394.1	3038.3	74.4
	141	141	135	65.2	79.8	9.6	4000	3925.8	3948.3	77.3
	140	139	136	64.7	109.3	15.4	3500	3464.4	5589.3	79.9
	141	140	138	63.6	163.7	27.0	3000	3020.8	8544.7	81.6
	142	141	138	62.2	257.7	48.5	2500	2576.4	13090.8	79.4
	141	141	142	59.7	391.5	81.0	2000	2148.9	18235.3	72.8
80	138	138	136	81.8	79.1	9.2	5000	4890.3	4713.4	74.5
	139	139	136	81.1	101.6	13.6	4500	4436.6	6321.2	77.8
	141	141	138	80.3	138.1	21.1	4000	3985.7	8810.5	79.7
	142	142	140	78.9	201.0	34.9	3500	3549.6	12978.3	80.7
	145	145	145	76.9	294.6	57.4	3000	3123.2	18781.2	79.7
	146	146	146	74.1	430.1	90.5	2500	2706.5	25660.7	74.6
96	139	138	119	96.7	123.4	17.9	5000	4962.7	9306.4	78.6
	139	139	117	96.3	144.4	22.2	4750	4736.7	11016.4	79.5
	141	141	117	95.6	166.6	27.0	4500	4520.6	12787.1	80.0
	141	141	118	94.8	196.5	33.7	4250	4305.3	15200.0	80.6
	144	144	122	94.0	233.0	41.7	4000	4085.0	17845.9	79.8
	143	143	115	93.0	273.2	51.5	3750	3873.2	20897.2	79.7
	145	144	117	91.9	322.5	62.9	3500	3660.3	24120.1	77.9
	146	146	126	90.3	379.6	78.0	3250	3462.6	28294.9	77.6
	146	147	133	89.2	448.1	93.9	3000	3236.1	31834.6	74.0

Table 3

PRESTOLITE MODEL MTC-4001 DC MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER

DEN3-123

PRESTOLITE CHOPPED DC TESTS, 25-45°C TEMPERATURE RANGE, 96 VOLTS CONTROLLER INPUT TAP

MOTOR INPUT VOLTAGE NOMINAL	TEMPERATURE °C FIELD #1	FIELD #2	ARMATURE	CHOPPER INPUT VOLTAGE AVG.	RMS	CHOPPER INPUT CURRENT (AMPS) AVG.	RMS	CHOPPER INPUT POWER (WATTS)	CHOPPER OUTPUT VOLTAGE AVG.	RMS	CHOPPER OUTPUT CURRENT (AMPS) AVG.	RMS	CHOPPER OUTPUT POWER (WATTS)	MOTOR OUTPUT SPEED (RPM)	TORQUE (Nm)	POWER (WATTS)	EFFICIENCY (%)
16	38	38	57	100.5	102.1	14.8	40.2	1392.3	15.8	36.9	27.2	49.7	1334.9	2500	0.6	157.1	11.7
	38	38	57	100.1	101.7	16.6	43.4	1528.8	16.0	38.5	34.3	55.2	1495.0	2000	1.4	293.3	19.6
	39	39	57	99.9	101.5	19.0	48.4	1571.1	59.9	39.2	44.6	63.8	1706.7	1500	3.0	471.4	27.6
	40	39	57	99.4	101.1	25.5	62.9	2343.9	16.0	39.1	73.1	90.5	2258.0	1000	8.1	848.6	37.6
	40	40	59	95.3	98.2	71.1	151.9	5186.8	15.8	35.1	220.3	240.6	4715.3	500	40.8	2137.2	45.3
	43	42	64	87.9	92.9	147.8	268.5	8748.5	15.6	33.6	409.0	423.2	7731.5	250	89.4	2341.5	30.3
24	41	41	60	100.0	101.6	18.3	43.0	1753.7	23.7	44.5	27.7	49.9	1726.3	3500	0.6	220.0	12.7
	42	42	60	99.7	101.2	20.4	46.1	1930.2	23.8	45.4	133.3	54.6	1881.3	3000	1.3	408.6	21.7
	42	42	61	99.4	100.9	24.0	51.8	2277.4	24.3	47.8	40.8	62.3	2222.5	2500	2.3	602.4	27.1
	43	43	61	99.0	100.5	28.2	58.6	2657.6	24.2	48.4	52.9	72.2	2589.9	2000	4.3	901.0	34.8
	44	44	62	98.2	99.9	36.9	74.1	3350.4	24.2	47.7	78.4	96.2	3228.9	1500	9.0	1414.3	43.8
	44	44	63	94.9	97.2	76.0	141.9	6107.7	24.0	45.1	174.4	197.2	5796.3	1000	30.1	3153.4	54.4
	45	45	68	74.9	82.4	298.3	409.7	16149.8	25.1	40.3	518.6	525.4	14702.3	500	118.0	6181.1	42.0
36	40	40	60	100.0	101.5	23.7	45.5	2320.4	35.4	53.9	28.6	48.2	2179.9	5000	0.6	314.3	14.4
	41	40	61	99.7	101.1	25.8	48.5	2453.0	35.5	54.8	32.4	52.2	2380.8	4500	1.1	518.6	21.8
	42	42	59	99.2	100.8	28.9	52.7	2799.6	35.7	56.0	37.2	56.8	2642.2	4000	1.7	712.4	27.0
	43	43	62	98.7	100.3	32.7	56.2	3121.6	35.7	56.9	43.2	62.3	2939.6	3500	2.7	990.0	33.7
	41	41	62	98.3	99.9	37.0	63.6	3493.8	35.5	57.6	52.3	71.0	3347.2	3000	4.2	1320.0	39.4
	42	42	63	97.4	98.9	44.3	75.0	4122.9	35.9	58.2	67.6	85.4	3955.5	2500	7.0	1833.4	46.4
	43	43	65	96.0	97.8	61.6	101.4	5509.6	35.9	57.5	102.6	120.4	5291.1	2000	13.8	2891.5	54.6
	42	41	66	90.7	93.2	122.8	185.5	9667.8	35.8	53.8	204.3	224.5	9024.9	1500	36.1	5672.9	62.9
	45	45	73	69.6	75.9	362.9	436.1	20531.6	35.8	45.6	485.9	494.4	18813.4	1000	106.8	11188.8	59.5

Table 3 Cont'd.

PRESTOLITE MODEL MTC-4001 DC MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER

DEN3-123

PRESTOLITE CHOPPED DC TESTS, 25-45°C TEMPERATURE RANGE, 96 VOLTS CONTROLLER INPUT TAP

MOTOR INPUT VOLTAGE NOMINAL	TEMPERATURE °C FIELD #1	FIELD #2	ARMATURE	CHOPPER INPUT VOLTAGE AVG.	RMS	CHOPPER INPUT CURRENT (AMPS) AVG.	RMS	CHOPPER INPUT POWER (WATTS)	CHOPPER OUTPUT VOLTAGE AVG.	RMS	CHOPPER OUTPUT CURRENT (AMPS) AVG.	RMS	CHOPPER OUTPUT POWER (WATTS)	MOTOR OUTPUT SPEED (RPM)	TORQUE (Nm)	POWER (WATTS)	EFFICIENCY (%)
64	42	42	55	97.1	98.5	51.1	66.0	4950.4	63.2	77.1	56.3	68.6	4779.9	5000	4.6	2409.7	50.4
	43	43	56	96.1	97.5	58.7	75.0	5608.5	62.9	76.8	66.8	78.9	5463.6	4500	6.5	3064.3	56.1
	43	42	59	94.7	96.3	72.3	91.0	6796.2	63.1	76.8	83.6	96.3	6617.7	4000	9.6	4022.9	60.8
	42	42	60	93.2	94.8	95.1	117.6	8697.6	63.1	76.0	111.7	125.3	8479.5	2500	15.2	5573.4	65.7
	41	41	62	88.2	90.0	147.1	174.3	12547.5	63.2	73.4	170.1	184.3	12170.8	3000	27.7	8705.9	71.6
	40	40	64	78.3	80.3	266.2	291.3	20191.3	62.4	68.2	290.7	302.0	19377.2	2500	55.4	14509.8	74.9
	45	45	65	64.8	66.4	422.7	435.1	27796.6	58.4	61.2	432.2	444.1	26562.6	2000	91.0	19067.0	71.8
80	40	40	54	94.7	96.0	77.6	86.7	7433.6	78.7	85.7	82.3	89.2	7270.2	5000	9.0	4714.4	64.8
	42	42	56	92.4	93.8	100.6	110.2	9410.8	79.6	85.3	106.1	113.0	9186.4	4500	13.8	6505.8	70.8
	44	44	57	89.5	90.2	140.9	150.3	12680.5	78.9	83.3	146.9	153.7	12347.3	4000	22.2	9303.0	75.3
	44	43	59	83.6	84.2	209.2	215.3	17672.3	78.2	80.0	212.9	217.7	17163.4	3500	36.8	13493.6	78.6
	45	44	59	78.7	79.3	269.6	277.3	21411.9	72.7	74.6	277.1	280.3	20633.9	3000	51.8	16280.3	78.9
	45	45	61	71.6	73.0	345.3	351.7	25081.2	66.8	68.0	352.6	357.6	23952.2	2500	69.4	18176.5	75.9
96	39	39	48	92.9	94.1	104.1	107.3	9948.6	88.5	90.5	105.8	109.0	9794.4	5000	13.6	7123.9	72.7
	40	40	50	92.3	92.9	114.7	117.9	10824.0	87.5	89.1	117.3	120.0	10685.3	4750	15.9	7912.3	74.0
	41	41	56	90.3	92.0	127.6	131.1	11824.8	86.5	87.9	130.3	133.3	11640.6	4500	18.7	8815.9	75.7
	41	41	55	89.3	90.0	145.5	148.8	13190.0	84.7	86.4	148.9	152.1	13036.4	4250	22.3	9929.0	76.2
	41	41	58	88.3	88.6	164.7	168.0	14628.8	82.4	84.4	167.7	170.2	14407.3	4000	26.5	11104.9	77.1
	41	40	59	85.1	86.5	185.4	190.2	16162.7	81.2	82.7	190.1	193.8	15930.9	3750	31.3	12296.7	77.2
	40	39	61	83.9	84.7	211.5	218.2	17989.4	78.4	80.4	217.2	222.1	17688.7	3500	37.4	13713.6	77.5
	44	43	62	80.8	81.9	241.8	246.0	19884.3	76.1	77.6	246.3	250.3	19198.6	3250	43.9	14947.2	77.9

Table 4

PRESTOLITE MODEL MTC-4001 DC MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER

DEN3-123

PRESTOLITE CHOPPED DC TESTS, 25-45°C TEMPERATURE RANGE, 80 VOLTS CONTROLLER INPUT TAP

MOTOR INPUT VOLTAGE NOMINAL	TEMPERATURE °C FIELD #1	FIELD #2	ARMATURE	CHOPPER INPUT VOLTAGE AVG.	RMS	CHOPPER INPUT CURRENT (AMPS) AVG.	RMS	CHOPPER INPUT POWER (WATTS)	CHOPPER OUTPUT VOLTAGE AVG.	RMS	CHOPPER OUTPUT CURRENT (AMPS) AVG.	RMS	CHOPPER OUTPUT POWER (WATTS)	MOTOR OUTPUT SPEED (RPM)	TORQUE (Nm)	POWER (WATTS)	EFFICIENCY (%)
16	39	39	63	83.0	84.1	13.9	34.7	1100.7	15.9	34.1	24.2	41.7	1058.2	2500	0.5	131.0	12.4
	39	39	63	82.8	83.8	16.7	38.8	1313.3	16.3	35.9	32.4	48.6	1280.5	2000	0.8	167.6	13.1
	43	43	65	82.4	83.4	19.6	44.3	1540.1	16.2	36.0	43.0	57.1	1471.7	1500	2.9	455.7	31.0
	44	43	66	81.8	83.1	26.8	58.9	2045.0	16.1	35.7	70.9	83.3	1969.3	1000	7.9	827.6	42.0
	44	44	70	76.6	79.4	86.0	159.4	5012.4	16.0	31.3	227.3	241.6	4590.3	500	41.9	2194.8	74.8
	45	45	84	67.9	74.2	179.7	284.0	8150.7	15.6	28.9	404.6	414.3	7077.1	250	87.6	2294.3	32.4
24	41	40	70	83.0	84.2	18.8	38.3	1506.6	23.6	41.5	27.1	43.4	1461.1	3500	0.5	183.3	12.5
	40	40	70	82.8	83.9	21.3	42.2	1721.3	24.0	43.1	32.5	48.7	1700.7	3000	1.1	345.7	20.3
	41	41	69	82.4	83.6	24.0	45.8	1907.5	24.0	43.7	39.2	54.0	1865.1	2500	2.1	550.0	29.5
	41	41	71	82.1	83.4	27.9	52.6	2209.9	23.7	43.8	50.4	64.2	2161.2	2000	4.0	838.1	38.8
	41	41	71	81.2	82.8	37.0	68.0	2842.7	23.6	43.0	74.4	87.5	2768.7	1500	8.5	1335.7	48.2
	42	42	72	77.2	79.5	83.4	139.4	5556.3	23.3	40.7	171.5	188.0	5245.2	1000	28.6	2996.2	57.1
	45	45	76	57.1	64.5	319.1	402.1	13654.7	23.0	33.2	482.7	488.8	12053.2	500	107.5	5631.1	46.7
36	38	38	53	82.8	83.8	24.0	40.6	1979.1	35.8	51.2	28.7	43.3	1869.2	5000	0.5	261.9	14.0
	39	39	55	82.5	83.4	26.1	43.3	2126.1	35.6	51.6	32.0	46.3	2025.3	4500	1.0	471.4	23.3
	40	40	55	82.1	83.3	28.8	46.5	2338.7	35.4	52.2	36.5	51.0	2236.3	4000	1.6	670.5	30.0
	40	40	57	81.9	82.9	33.1	51.7	2656.4	35.8	53.1	43.7	56.8	2519.1	3500	2.6	953.4	37.8
	40	40	58	81.3	82.2	87.8	57.9	3008.3	35.7	53.3	51.9	64.0	2852.2	3000	4.0	1257.2	44.1
	41	41	62	80.7	81.9	46.8	70.5	3690.4	35.9	53.2	68.4	80.4	3513.0	2500	6.9	1807.2	51.4
	41	40	62	78.8	80.5	66.0	97.0	4945.2	35.7	51.9	100.6	113.4	4659.2	2000	13.6	2849.6	61.2
	40	40	63	73.4	76.4	135.5	183.1	8945.4	35.5	49.0	201.1	215.3	8397.9	1500	35.5	5578.7	66.4
	37	36	65	49.0	53.3	429.5	464.9	19127.0	34.7	38.5	477.5	476.9	17309.0	1000	104.5	10947.8	63.2

Table 4 Cont'd.

PRESTOLITE MODEL MTC-4001 DC MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER

DEN3-123

PRESTOLITE CHOPPED DC TESTS, 25-45°C TEMPERATURE RANGE, 80 VOLTS CONTROLLER INPUT TAP

MOTOR INPUT VOLTAGE NOMINAL	TEMPERATURE °C			CHOPPER INPUT VOLTAGE		CHOPPER INPUT CURRENT (AMPS)		CHOPPER INPUT POWER	CHOPPER OUTPUT VOLTAGE		CHOPPER OUTPUT CURRENT (AMPS)		CHOPPER OUTPUT POWER	MOTOR OUTPUT			
	FIELD #1	FIELD #2	ARMATURE	AVG.	RMS	AVG.	RMS	(WATTS)	AVG.	RMS	AVG.	RMS	(WATTS)	SPEED (RPM)	TORQUE (Nm)	POWER (WATTS)	EFFICIENCY (%)
64	44	44	52	80.5	81.4	52.8	60.5	4293.2	63.5	71.0	55.5	61.7	4123.6	5000	4.3	2252.4	54.6
	45	45	53	79.9	80.6	61.4	69.7	4949.9	63.2	70.7	66.0	72.1	4817.6	4500	6.2	2922.9	60.7
	45	45	54	78.3	79.1	77.1	86.6	6100.7	63.5	70.2	83.8	90.3	5942.9	4000	9.5	3981.0	67.0
	45	45	55	76.3	77.1	103.0	113.8	7859.9	63.0	68.7	110.7	117.6	7649.6	3500	14.9	5463.4	71.4
	45	45	57	71.1	72.0	163.4	172.4	11658.4	62.9	65.9	171.4	175.8	11231.0	3000	27.3	8580.2	76.4
	45	45	58	64.8	65.4	245.3	250.3	16097.7	59.4	61.3	249.9	253.4	15385.6	2500	45.3	11864.5	77.1
	45	45	59	58.1	59.3	319.8	324.9	18951.3	52.8	54.1	327.7	333.8	17703.8	2000	64.2	13451.7	76.0
80	40	39	50	78.9	79.3	72.2	74.0	5804.8	74.9	76.6	73.8	75.4	5708.7	5000	7.6	3981.0	69.7
	42	41	51	78.1	78.3	86.0	88.0	6786.3	73.3	75.2	89.3	90.0	6673.1	4500	10.3	4855.8	72.8
	41	41	54	75.4	76.6	105.9	108.9	8183.8	71.9	73.3	108.9	111.7	7924.4	4000	14.5	6076.3	76.7
	40	39	55	73.5	73.8	137.1	140.5	10158.4	68.5	70.4	140.3	142.9	9949.0	3500	21.0	7700.1	77.4
	39	39	59	69.6	70.1	182.6	187.0	12875.0	64.5	66.7	187.5	190.4	12404.8	3000	31.2	9805.9	79.0
	45	45	60	64.6	65.1	244.4	248.6	15971.3	59.7	61.3	249.3	251.9	15359.6	2500	45.3	11864.5	77.2

Table 5

PRESTOLITE MODEL MTC-4002 DC MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER

PRESTOLITE CHOPPED DC TESTS, 130-150°C TEMPERATURE RANGE, 96 VOLTS CONTROLLER INPUT TAP

MOTOR INPUT VOLTAGE NOMINAL	TEMPERATURE °C FIELD #1	FIELD #2	ARMATURE	CHOPPER INPUT VOLTAGE AVG.	RMS	CHOPPER INPUT CURRENT (AMPS) AVG.	RMS	CHOPPER INPUT POWER (WATTS)	CHOPPER OUTPUT VOLTAGE AVG.	RMS	CHOPPER OUTPUT CURRENT (AMPS) AVG.	RMS	CHOPPER OUTPUT POWER (WATTS)	MOTOR OUTPUT SPEED (RPM)	TORQUE (Nm)	POWER (WATTS)	EFFICIENCY (%)
36	141	141	173	98.8	99.8	22.8	43.4	2225.7	35.8	55.1	29.0	47.5	2145.0	5000	1.0	523.8	24.4
	141	141	175	98.3	99.3	25.3	46.9	2442.2	35.8	56.1	33.2	51.3	2337.0	4500	1.6	754.3	32.3
	142	142	176	97.8	99.0	28.4	50.7	2724.7	36.2	57.2	37.9	55.7	2608.9	4000	2.2	921.9	35.3
	142	142	179	97.7	99.1	32.3	57.3	3152.2	36.4	58.4	44.4	63.2	2978.3	3500	3.2	1173.4	39.3
	143	143	181	97.1	98.2	37.2	63.2	3522.8	36.3	58.9	54.5	71.7	3390.9	3000	4.8	1508.6	44.4
	145	145	182	96.3	97.8	45.6	76.1	4258.3	36.5	59.0	72.3	88.8	4071.4	2500	8.0	2095.3	51.5
	146	145	184	94.6	96.7	62.5	103.1	5659.6	36.4	57.9	105.6	124.5	5456.5	2000	15.1	3163.9	58.0
	145	144	186	89.5	92.7	125.6	188.3	9845.6	36.1	54.4	208.7	229.4	9449.5	1500	37.2	5845.8	61.9
	143	143	187	74.1	80.2	305.2	380.9	18367.8	35.9	48.0	432.0	441.1	17249.1	1000	91.1	9544.0	55.3
64	141	141	149	95.5	97.0	51.1	65.5	4925.1	62.9	76.9	57.9	70.0	4793.4	5000	5.6	2933.4	61.2
	141	141	150	94.9	96.4	58.0	73.5	5550.8	63.4	77.5	66.4	77.6	5353.0	4500	7.5	3535.8	66.1
	144	144	153	93.6	95.2	73.6	92.3	6919.8	63.4	77.1	86.6	99.2	6721.2	4000	10.8	4525.8	67.3
	145	145	156	91.3	93.2	99.0	120.8	8950.2	63.4	75.2	116.9	129.6	8716.1	3500	17.1	6270.1	71.9
	142	142	156	86.4	88.2	153.6	180.3	12909.5	63.0	72.7	179.9	193.1	12566.2	3000	30.4	9554.5	76.0
	147	147	157	75.4	78.0	280.4	299.6	20809.3	63.1	67.7	302.6	309.9	20031.2	2500	58.8	15400.3	76.9
80	136	135	155	93.5	94.7	79.3	87.5	7508.0	79.4	85.9	83.7	89.6	7374.1	5000	9.9	5185.8	70.3
	137	137	156	91.5	92.7	100.3	109.7	9288.1	79.1	84.6	106.1	112.6	9115.2	4500	14.5	6835.8	75.0
	137	137	158	87.5	89.0	145.3	153.3	12877.4	79.4	82.8	151.3	156.2	12637.7	4000	23.8	9973.5	78.9
	137	137	159	82.6	83.5	206.0	211.3	17281.7	77.6	79.4	210.5	214.6	16797.0	3500	36.9	13530.2	80.6
	135	135	159	77.6	78.6	265.4	272.1	20902.8	72.8	74.5	271.5	275.7	20512.6	3000	51.0	16028.9	78.1
	139	139	159	71.5	73.0	333.5	339.7	23983.0	65.7	67.3	341.3	345.7	23292.0	2500	68.5	17940.8	77.0

Table 5 Cont't.

PRESTOLITE MODEL MTC-4002 DC MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER

DEN3-123

PRESTOLITE CHOPPED DC TESTS, 130-150°C TEMPERATURE RANGE, 96 VOLTS CONTROLLER INPUT TAP

MOTOR INPUT VOLTAGE NOMINAL	TEMPERATURE °C FIELD #1	FIELD #2	ARMATURE	CHOPPER INPUT VOLTAGE AVG.	RMS	CHOPPER INPUT CURRENT (AMPS) AVG.	RMS	CHOPPER INPUT POWER (WATTS)	CHOPPER OUTPUT VOLTAGE AVG.	RMS	CHOPPER OUTPUT CURRENT (AMPS) AVG.	RMS	CHOPPER OUTPUT POWER (WATTS)	MOTOR OUTPUT SPEED (RPM)	TORQUE (Nm)	POWER (WATTS)	EFFICIENCY (%)
96	139	139	158	91.8	92.6	101.0	103.9	9467.0	87.5	89.3	103.4	105.7	9347.1	5000	13.7	7176.3	76.7
	140	139	160	90.2	91.6	112.4	115.2	10342.2	87.0	88.3	114.7	116.8	10241.6	4750	15.9	7912.3	77.3
	142	142	162	89.3	90.1	124.3	127.8	11363.9	85.9	87.1	127.0	130.0	11163.2	4500	18.8	8863.0	79.4
	144	144	164	88.5	88.9	140.6	144.5	12589.6	83.2	85.7	143.7	146.8	12389.6	4250	22.2	9884.5	79.8
	142	142	166	85.6	87.2	158.4	162.0	13871.9	82.0	83.9	161.5	164.6	13621.6	4000	26.2	10979.2	80.6
	141	141	166	84.3	85.5	180.1	184.8	15446.3	80.7	82.0	185.4	188.4	15203.5	3750	31.0	12178.8	80.1
	137	137	167	82.7	83.4	206.9	211.8	17310.8	78.1	80.0	211.6	215.1	16952.8	3500	36.6	13420.2	79.2
	145	145	168	80.3	81.4	230.4	237.1	18818.6	76.5	77.7	238.1	239.1	18307.9	3250	42.7	14538.6	79.4

Table 6

PRESTOLITE MODEL MTC-4002 DC MOTOR
GENERAL ELECTRIC EV-1 CONTROLLER

PRESTOLITE CHOPPED DC TESTS, 130-150°C TEMPERATURE RANGE, 80 VOLTS CONTROLLER INPUT TAP

MOTOR INPUT VOLTAGE NOMINAL	TEMPERATURE °C			CHOPPER INPUT VOLTAGE		CHOPPER INPUT CURRENT (AMPS)		CHOPPER INPUT POWER	CHOPPER OUTPUT VOLTAGE		CHOPPER OUTPUT CURRENT (AMPS)		CHOPPER OUTPUT POWER	MOTOR OUTPUT			
	FIELD #1	FIELD #2	ARMATURE	AVG.	RMS	AVG.	RMS	(WATTS)	AVG.	RMS	AVG.	RMS	(WATTS)	SPEED (RPM)	TORQUE (Nm)	POWER (WATTS)	EFFICIENCY (%)
36	141	141	171	82.1	83.1	24.2	39.8	1971.0	36.2	52.4	29.1	41.7	1889.5	5000	0.8	419.1	22.2
	142	142	172	81.9	82.7	26.5	42.5	2142.3	36.3	53.2	32.8	46.3	2056.3	4500	1.3	612.7	29.8
	143	143	175	81.7	82.3	29.3	46.1	2359.1	36.4	54.0	36.9	49.9	2243.6	4000	2.0	838.1	37.4
	142	142	176	81.1	82.1	33.2	51.1	2650.3	36.5	54.3	44.1	55.9	2547.4	3500	2.9	1063.4	41.7
	143	142	178	80.5	81.9	38.8	58.9	3082.7	36.5	54.2	53.9	65.7	2966.7	3000	4.3	1351.5	45.6
	143	142	181	78.1	79.7	68.3	100.1	5062.8	36.3	52.5	104.1	116.2	4877.9	2000	14.2	2975.3	61.0
	142	142	182	72.3	75.3	139.8	187.8	9147.2	36.6	50.1	203.7	218.8	8849.9	1500	35.8	5625.8	63.6
	143	143	182	53.9	58.4	361.9	402.5	17312.7	36.0	42.3	428.8	438.3	16445.6	1000	89.7	9397.3	57.1
64	138	138	170	79.4	80.0	52.0	59.1	4203.3	63.0	70.6	55.8	61.1	4060.1	5000	5.2	2723.9	67.1
	139	138	172	78.6	79.4	60.6	69.2	4851.7	62.9	70.5	65.5	72.2	4646.7	4500	6.8	3205.8	69.0
	141	140	175	76.9	78.1	76.3	85.2	5973.2	63.4	69.7	82.9	88.5	5743.5	4000	10.3	4316.3	75.2
	141	140	175	74.6	75.5	103.7	113.8	7761.0	62.9	68.1	111.1	117.2	7507.5	3500	16.1	5903.4	78.6
	140	139	177	69.8	70.5	164.6	172.0	11546.7	62.8	65.6	171.9	176.2	11234.5	3000	28.8	9051.6	80.6
	144	143	178	64.2	64.6	238.8	243.0	15240.1	59.3	60.9	245.7	248.7	14734.7	2500	45.2	11838.3	80.3
80	131	131	173	78.2	78.4	70.5	72.5	5611.3	73.7	75.6	73.5	74.8	5496.8	5000	8.1	4242.9	77.2
	131	131	174	76.4	77.3	84.7	86.8	6641.4	72.9	74.5	87.1	891.0	6484.7	4500	10.8	5091.5	78.5
	133	132	176	74.5	75.4	105.1	108.0	8022.5	71.6	72.5	108.3	110.5	7862.4	4000	15.0	6285.8	79.9
	132	132	178	72.0	73.1	135.7	139.0	9970.6	68.2	69.9	139.9	141.9	9799.5	3500	21.5	7883.5	80.4
	131	131	179	69.0	69.5	178.3	183.3	12449.7	64.0	65.9	184.9	187.9	12241.9	3000	31.5	9900.2	80.9
	134	134	181	63.8	64.3	128.6	242.7	15238.9	59.3	60.6	245.9	247.4	14793.9	2500	45.4	11890.7	80.4

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-165382		

4. Title and Subtitle	5. Report Date
STRAIGHT AND CHOPPED DC PERFORMANCE DATA FOR A PRESTOLITE MTC-4001 MOTOR AND A GENERAL ELECTRIC EV-1 CONTROLLER	April 1981
	6. Performing Organization Code: 778-36-06
7. Author(s): Paul C. Edie	8. Performing Organization Report No.: ERC TR-80169
	10. Work Unit No.
9. Performing Organization Name and Address: Eaton Corporation, Engineering & Research Center, 26201 Northwestern Hwy., P.O. Box 766, Southfield, Michigan 48037	11. Contract or Grant No.: DEN 3-123
	13. Type of Report and Period Covered: Contractor Report
12. Sponsoring Agency Name and Address: U.S. Department of Energy, Office of Transportation Programs, Washington D.C. 20585	14. Sponsoring Agency Code: DOE/NASA/0123-2

15. Supplementary Notes

Final Report. Report prepared under Interagency Agreement DE-AI01-77CS 51044. Project Manager, Edward F. McBrien, Transportation Propulsion Division, NASA Lewis Research Center, Cleveland, Ohio 44135.

16. Abstract

Both straight and chopped DC motor performance data for a Prestolite MTC-4001 motor and a General Electric EV-1 controller is presented in tabular and graphical formats. Effects of motor temperature and operating voltage are also shown. The maximum motor efficiency is between 76% and 82%, regardless of temperature or mode of operation. Chopper efficiency can be assumed to be 95% under all operating conditions. For equal speeds, the motor operated in the chopped mode develops slightly more torque and draws more current than it does in the straight DC mode.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
DC motors Chopper controller Performance and efficiency	Unclassified - unlimited STAR Category 33 DOE Category UC-96

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price*
Unclassified	Unclassified		

* For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-C-168 (Rev. 10-75)

End of Document