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ERC TR-8186

Straight and Chopped DC Performance Data for a General Electric 5BY436A1 DC Shunt Motor with a General Electric EV-1 Controller

Paul C. Edie
Eaton Corporation
Engineering & Research Center

October 1981

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Under Contract DEN 3-123

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SUMMARY

This report is intended to supply the electric vehicle manufacturer with performance data on the General Electric 5BY436A1 shunt wound DC motor with a General Electric EV-1 Chopper Controller. Data is provided for both straight and chopped DC input to the motor, at 2 motor temperature levels. Straight and chopped DC testing was done in the armature control mode at full field current for six values of armature voltage and one value of controller voltage. Straight DC testing was also done in the field control mode at full armature voltage for four values of field current. 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 approximately 86% at low operating temperatures in the straight DC mode. 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 assumed 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.

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 General Electric 5BY436A1 shunt wound motor with a General Electric model EV-1 controller. This controller is designed for use with series motors. However, for the convenience of this test program, it was adapted to the shunt motor by adding a small choke in series with the motor. 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 General Electric 5BY436A1 shunt wound DC motor. This motor is shown in Figure 1, with a print detailing critical dimensions in Figure 2. Weight of this motor is 99.3 kg (219 lbs.) with all mounting hardware attached. The following nameplate data appears on the motor:

Model	5BY436A1
HP	20
Motor Winding	SHUNT
Volts	96
Amps	175
RPM	2500/5000
Identification No.	MP-1-67 MP

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

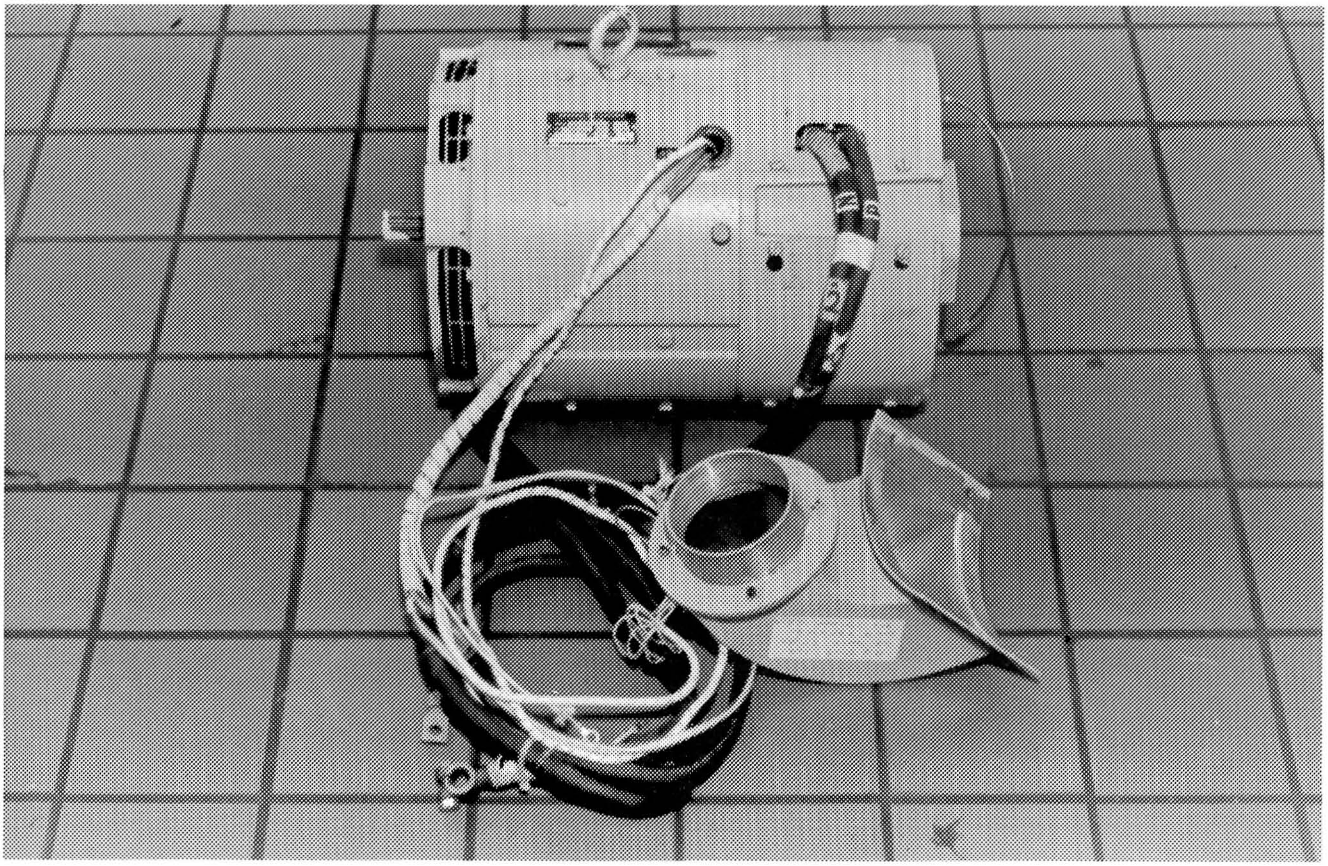


Figure 1 GE 5BY436A1 Motor

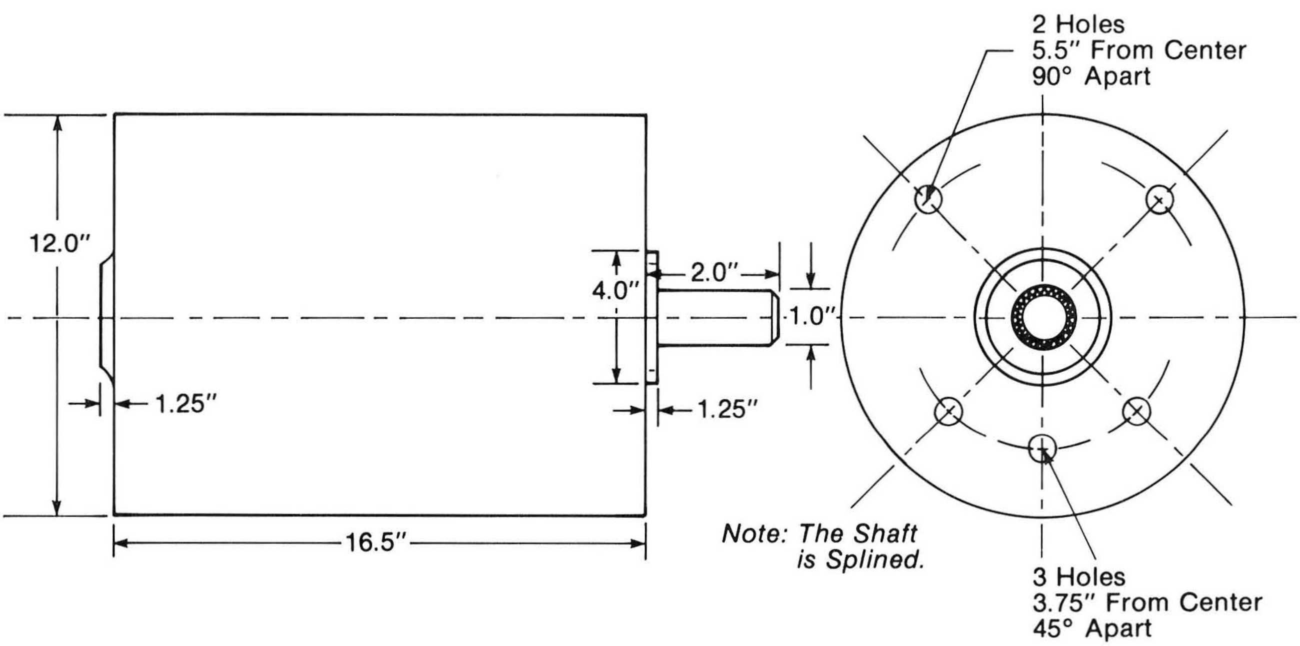


Figure 2 Outline Drawing of GE 5BY436A1 Motor

Description of Controller

The chopper/controller tested in conjunction with the General Electric 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.

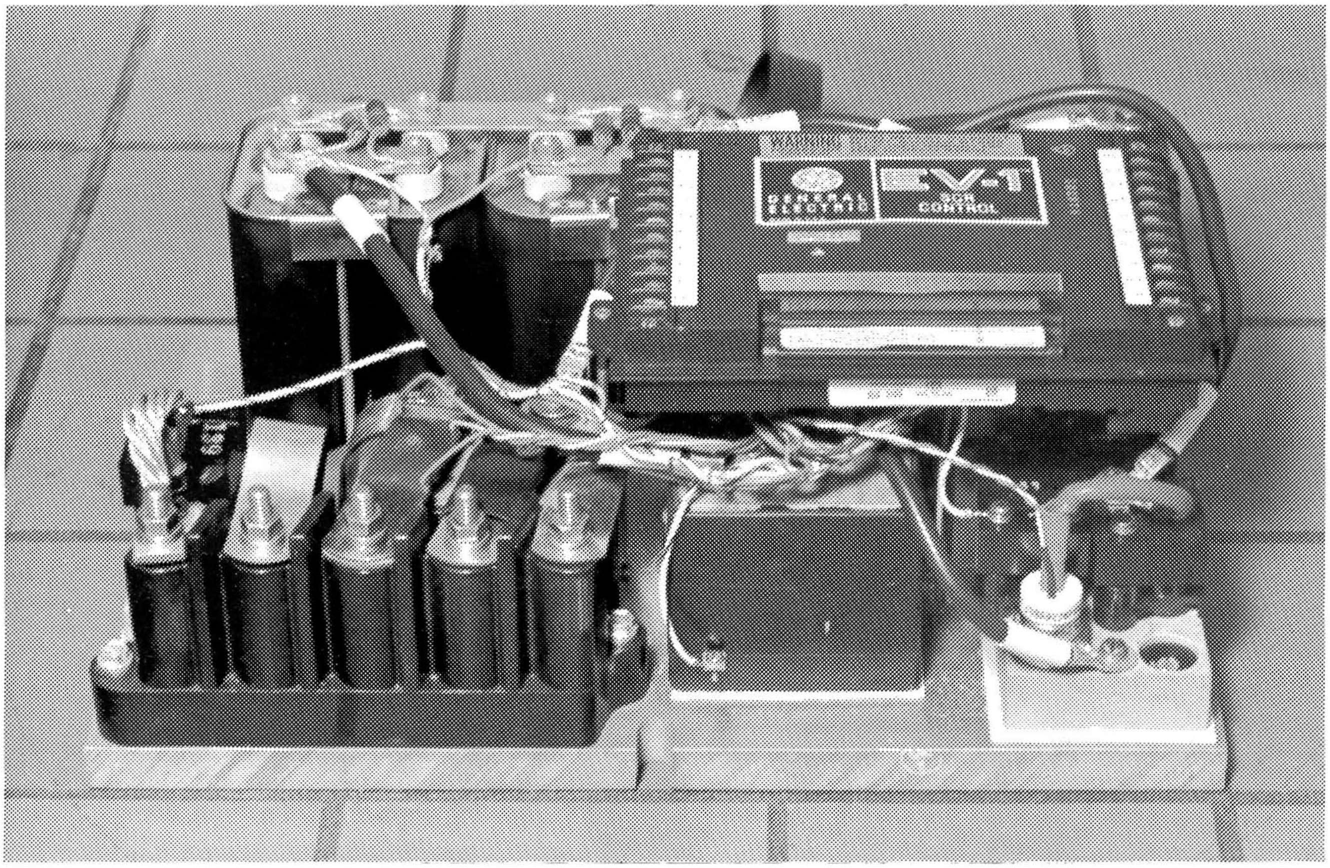


Figure 3 General Electric Model EV-1 Controller

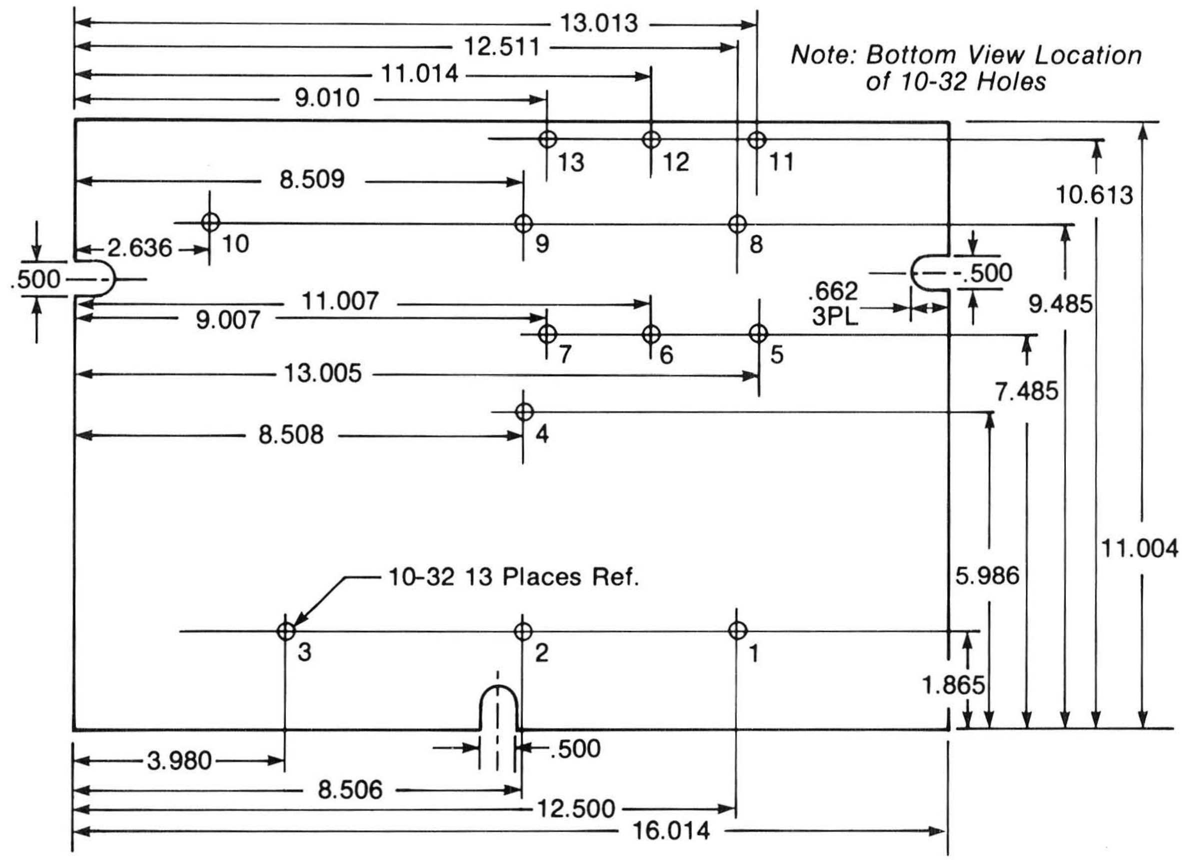


Figure 4 Drawing of General Electric EV-1 Controller Base Plate

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 volt 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.

Power for the motor field windings was supplied by a Sorenson DCR-150-18B DC power supply, rated at 150 volts at 18 amps. The supply had provisions for constant current and constant voltage operation.

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.

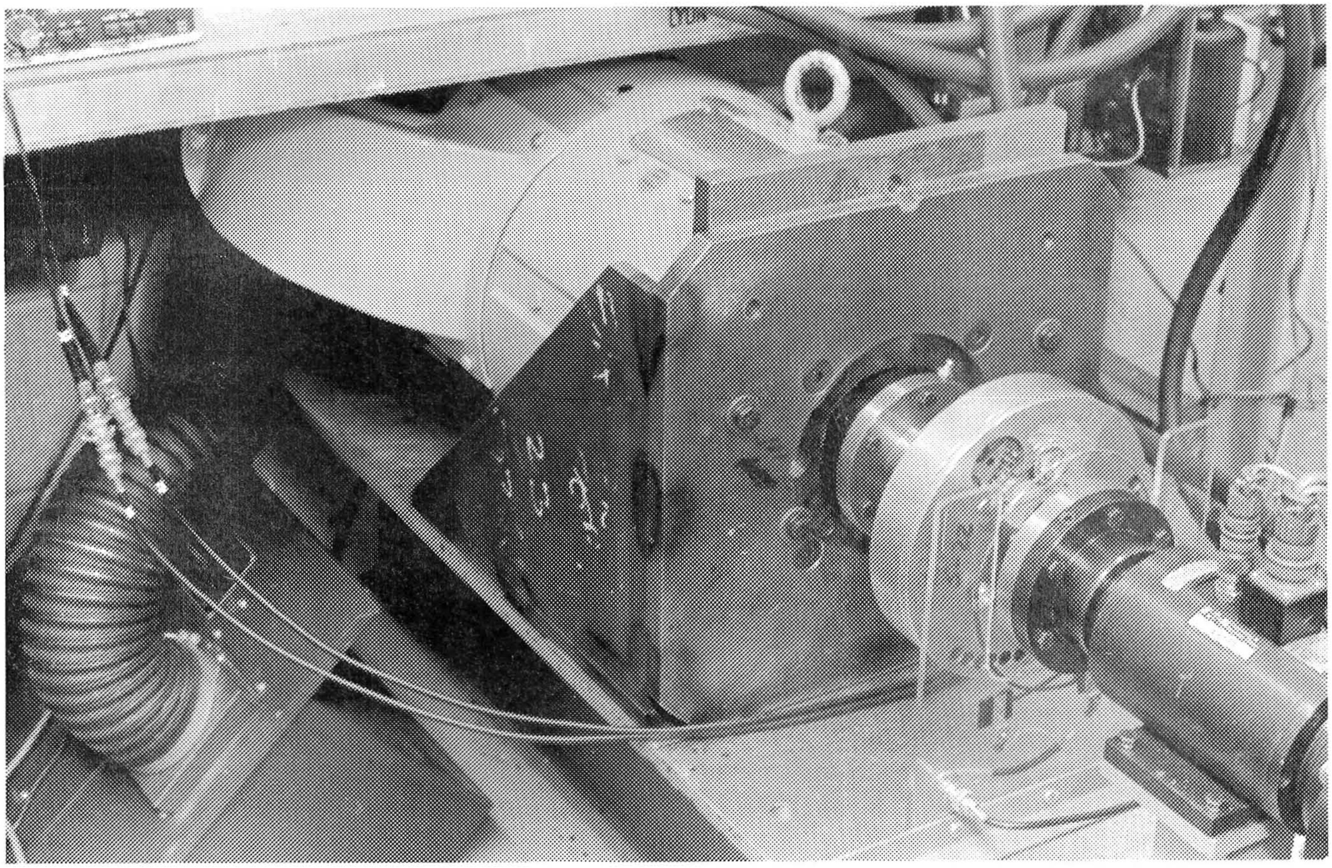


Figure 5 Mounting of Motor and Torque Transducer

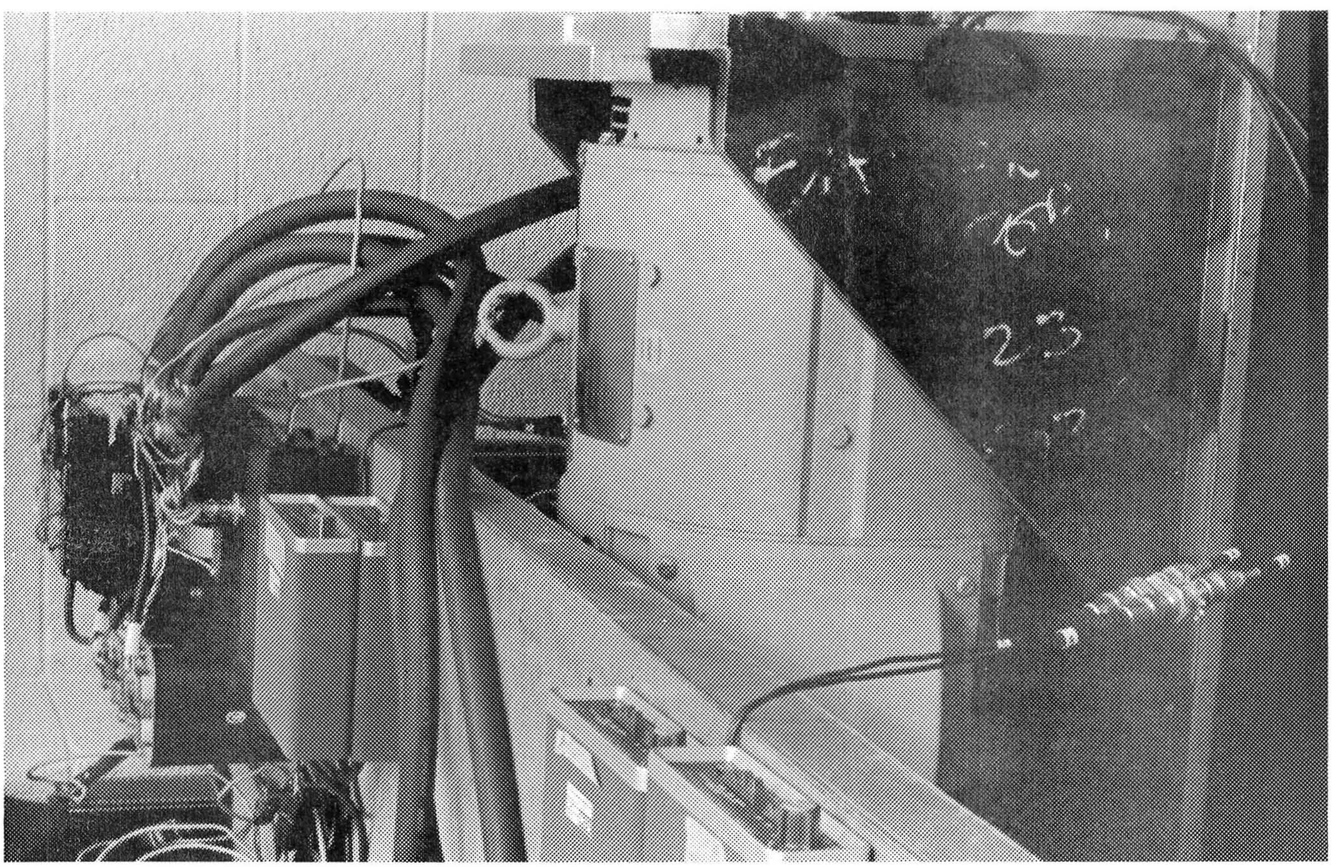


Figure 6 Mounting of Motor and Controller

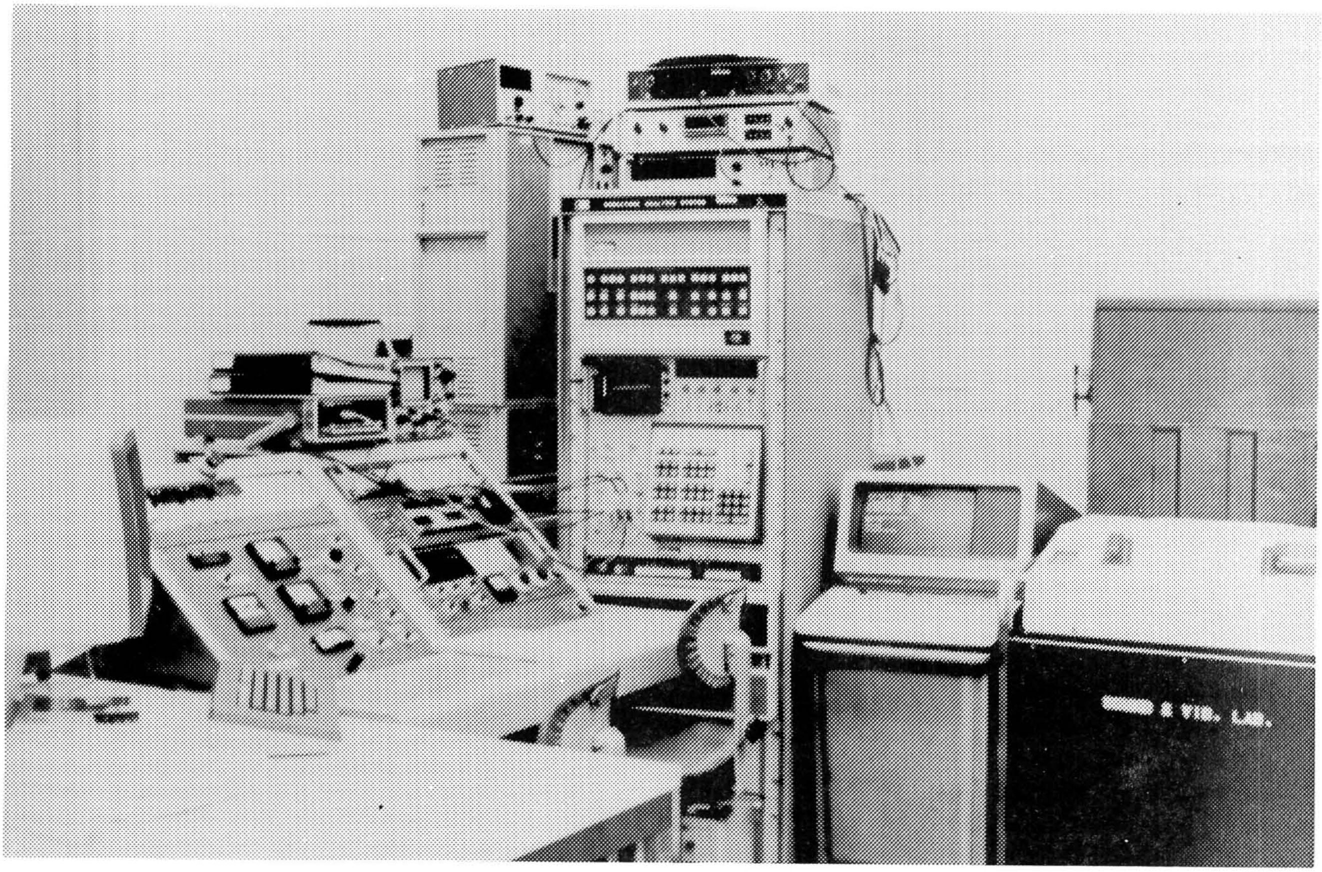


Figure 7 Control and Intrumentation Consoles

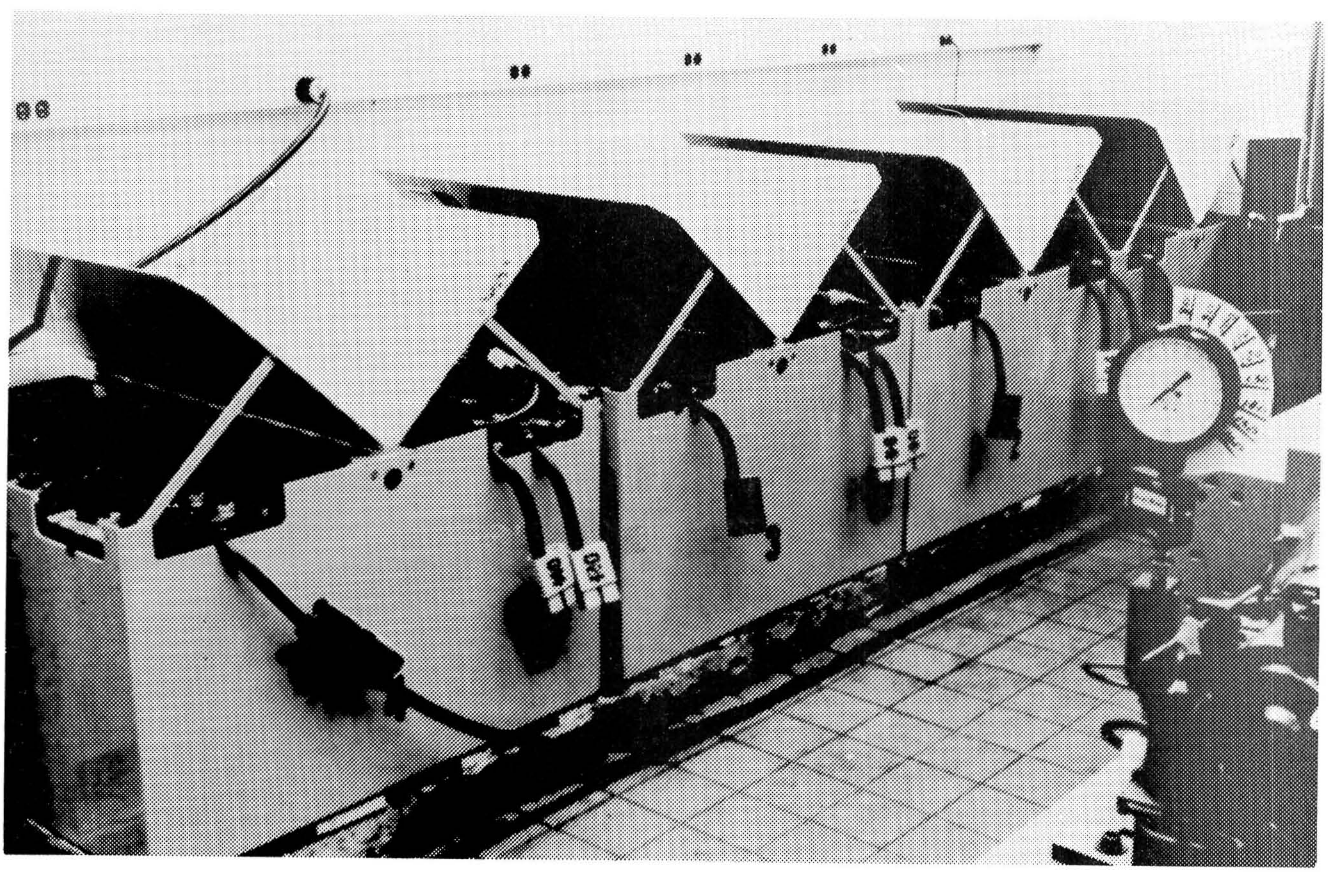


Figure 8 Battery Power Supply

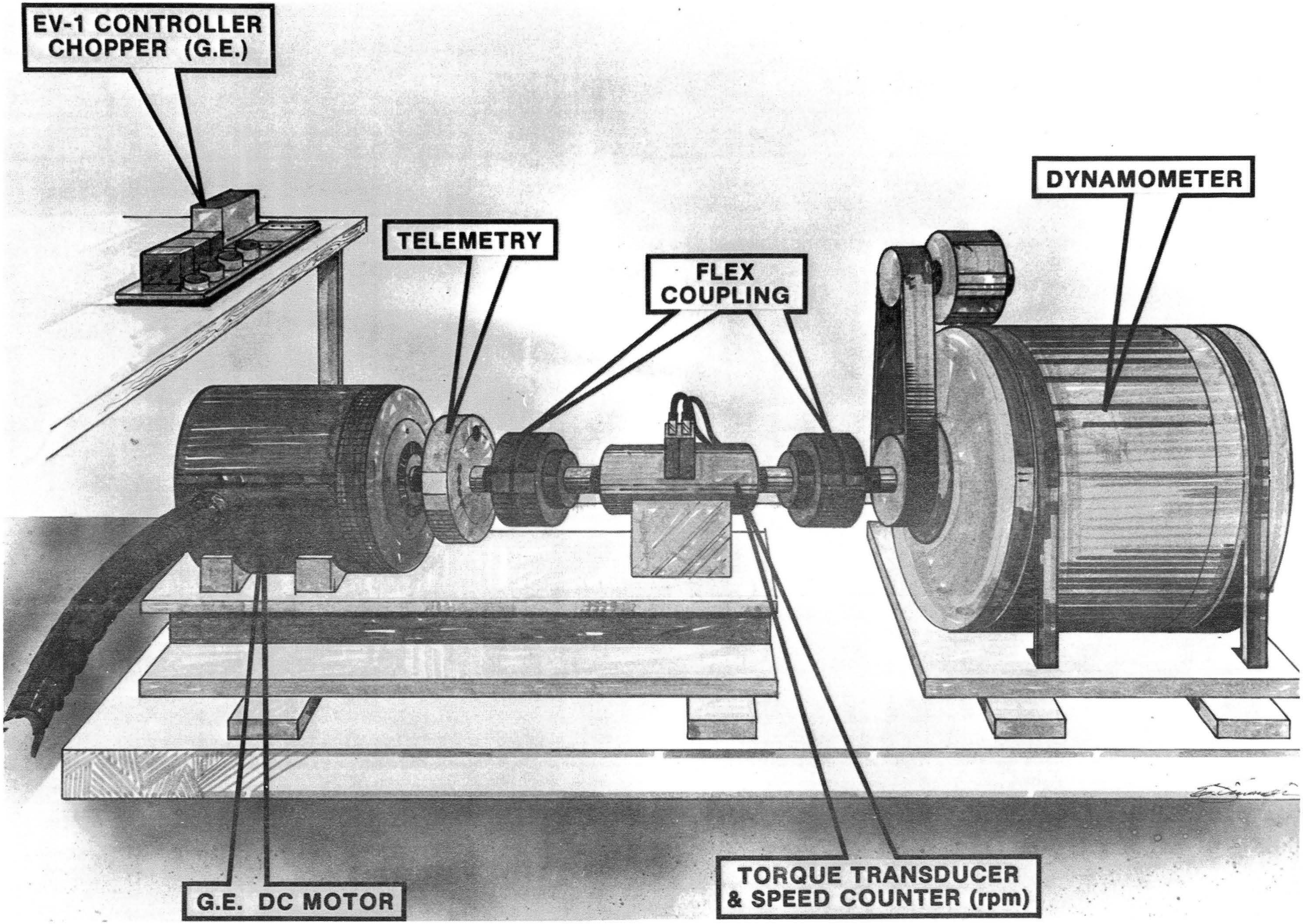


Figure 9 Motor Mounting and Transducer Configuration

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 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. Test Sequence

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 operating the motor with the frame wrapped with layers of fiberglass insulation. Once the desired temperature range had been reached, the motor was driven up in speed with the field supply set at the desired current level. When the voltage level generated by the motor armature matched the desired motor operating voltage, the main contactor was closed supplying power from the batteries to the motor. This resulted in a near "zero torque" data point, at which data was recorded. Once completed, the motor was slowed by a small increment (the magnitude depending on the particular field current being supplied) for a second data point. This procedure continued until the torque transducer limit was reached, or the system became unstable. Since this motor was not a stabilized shunt type, at reduced values of field current the motor would load to a point where instability of operation would occur. At this point, data acquisition was ceased. 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 identical increments to record motor hysteresis. When completed, the next voltage tap was selected, and tested as before. Six motor input voltage levels were selected: 24, 36, 48, 64, 80, and 96 volts. Four values of field current were also selected at 11, 5, 4, and 3.2 amperes. 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 a 96-volt level to the controller. It was discovered that, during motor operation, a high value of duty cycle from the controller would cause instability. To improve this condition, a series choke was added at the output of the chopper to the armature. This choke was rated at 1.0 mh at 0.011 ohms. While this greatly improved stability, operating at extremely high values of duty cycle was still not possible. Thus, the chopped data was not taken at the 96-volt input level to the motor. The internal IR drop of the choke also limited the amount of data possible at the 80-volt level, before the average value of voltage to the motor fell off. 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, and series choke.

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 10 and depicted graphically in Figures 12 through 23. As indicated in the "Test Procedures" Section of this report, three separate test runs were made at each test condition. Each run started at "zero torque" 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:

$$\text{compensated speed} = \text{test speed} \left(\frac{V_{IDEAL} - R_A I_A}{V_{TEST} - R_A I_A} \right)$$

0.01920 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

$$n = \frac{\text{power out}}{(V_{arm} \times I_{arm}) + (V_{field} \times I_{field})}$$

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

$$n = \frac{\text{power out}}{\text{power in} + (V_{field} \times I_{field})}$$

and plotted against speed for each power level using a best fit program.

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

1. Equations were calculated for controller efficiency $\left(\frac{\text{power out}}{\text{power in}}\right)$ 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 narrow 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 through 8. 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 12 through 19. 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 discernible temperature effects appear in both the torque-speed and efficiency-speed curves. For the torque-speed plots, the high temperature curves (Figure 13A) are shifted slightly to the left of the corresponding low temperature curve. This shift 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 speed will decrease.

For the efficiency-speed curves, the high temperature efficiency of the motor is less than the low temperature efficiency for a given output power level. Peak efficiency appears at moderate loads, reasonably high speeds, and maximum voltage. The efficiency drops below 75% only at light loads or low voltage levels.

As field is weakened, the motor base speed increases for a given armature voltage, and the curves continue to appear as expected. Motor efficiency, as shown in Tables 3, 4, 5, 6, 7, and 8, maintains approximately the same maximum level as for the full field data at similar operating temperatures.

3. Chopped DC Results

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

Table 9	25-45°C	96 Volt Input
Table 10	130-150°C	96 Volt Input

This data is also depicted graphically in Figures 20-23.

The voltages refer to the nominal input voltages to the chopper.

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 20 through 23. 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 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 approached 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. However, the chopped efficiency levels never match the straight DC levels, due to the lack of system stability at 100% chopper duty cycles. 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 20A, and 22A) show that the curve for maximum voltage approaches the next lower voltage curve for high values of torque. This phenomenon is caused by the impedance of the power source and series choke. The corresponding tabulated data shows that for the highest voltage curve in each category, the chopper duty cycle approaches 100% and that a constant voltage cannot be maintained at the chopper output terminals as torque is increased. As the highest voltage curve approaches the region of coincidence, the chopper duty cycle is near 100% for the second highest voltage curve.

Photographs of scope traces for all channels of input data at two different operative points appear in Figures 10 & 11.

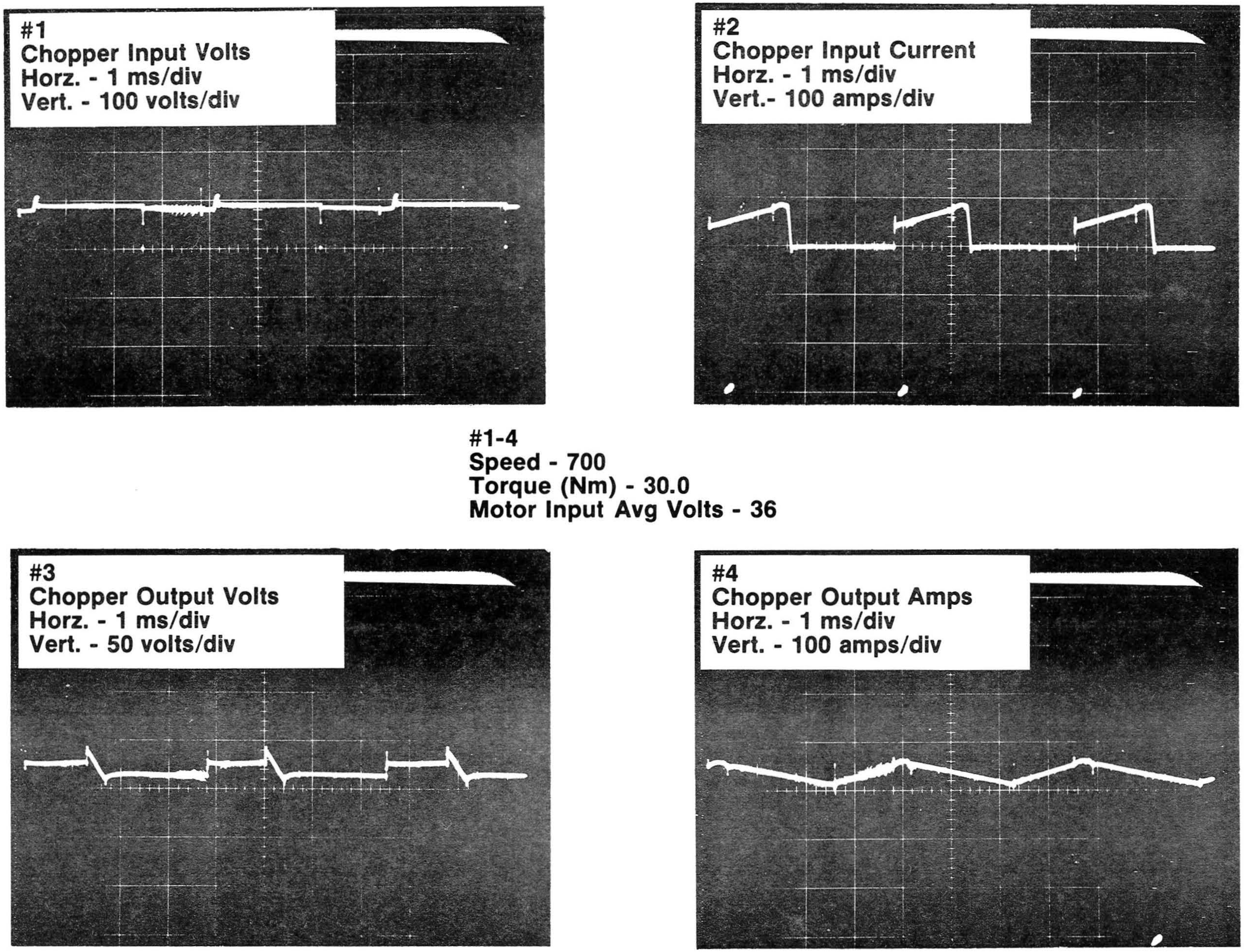
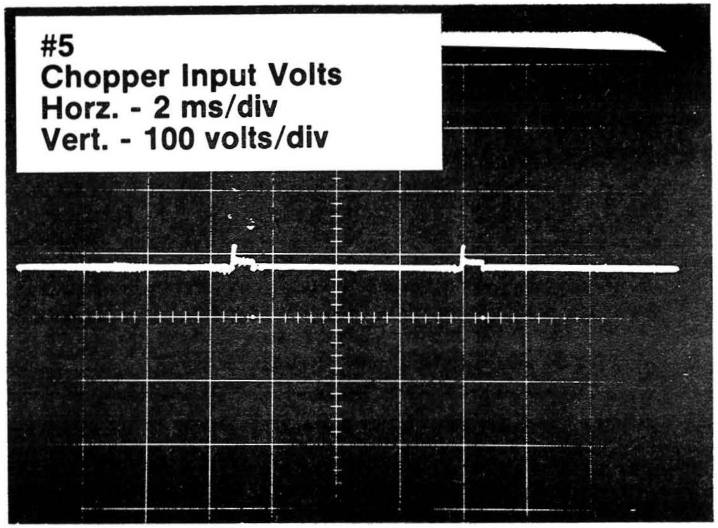
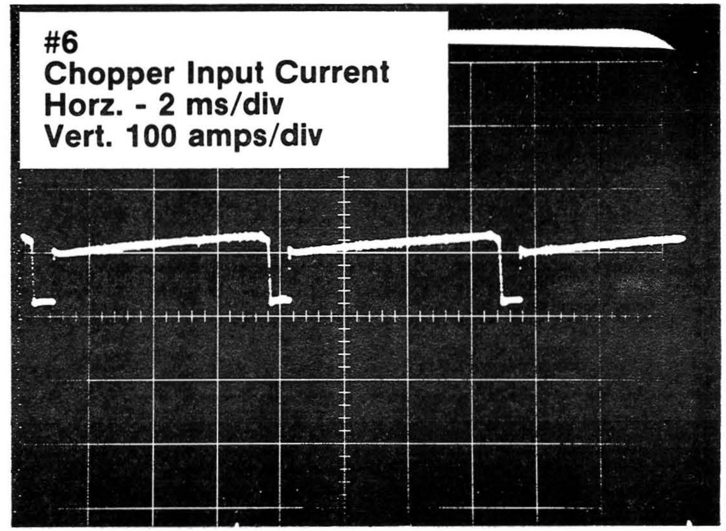
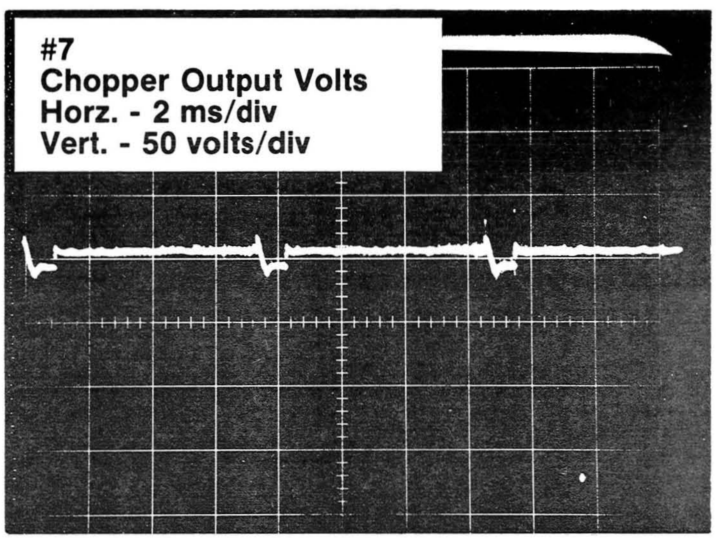


Figure 10 Scope Traces





#5-8
Speed - 1600
Torque (Nm) - 42.0
Motor Input Avg Volts - 60



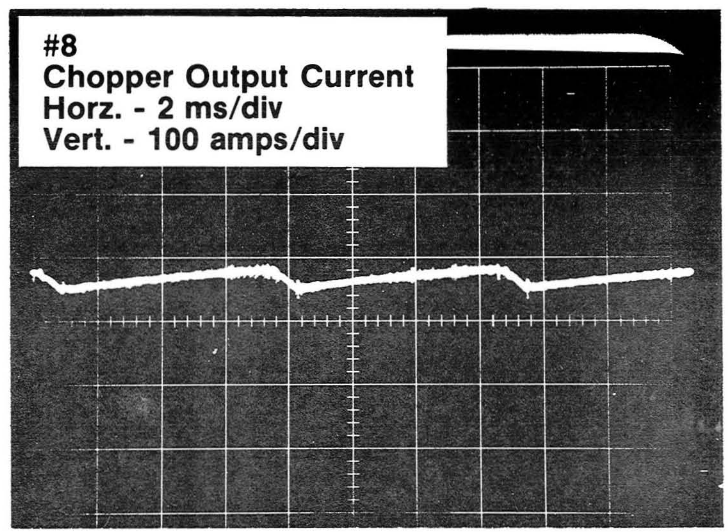


Figure 11 Scope Traces

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.

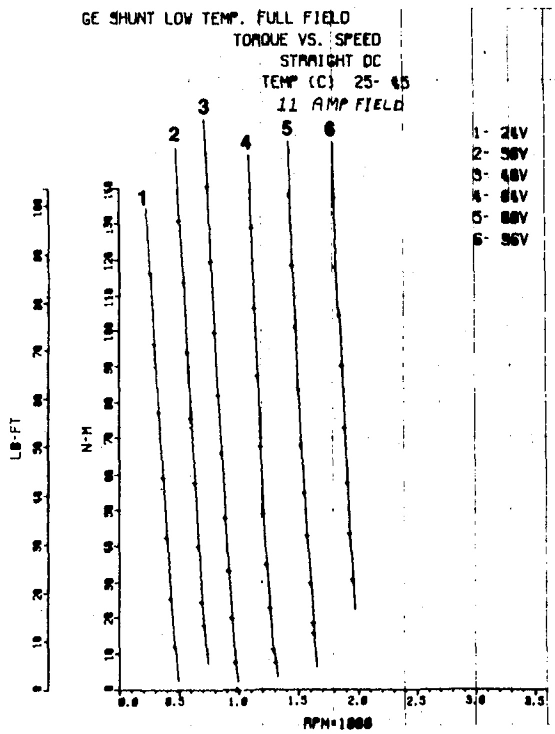
4. Test Results

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

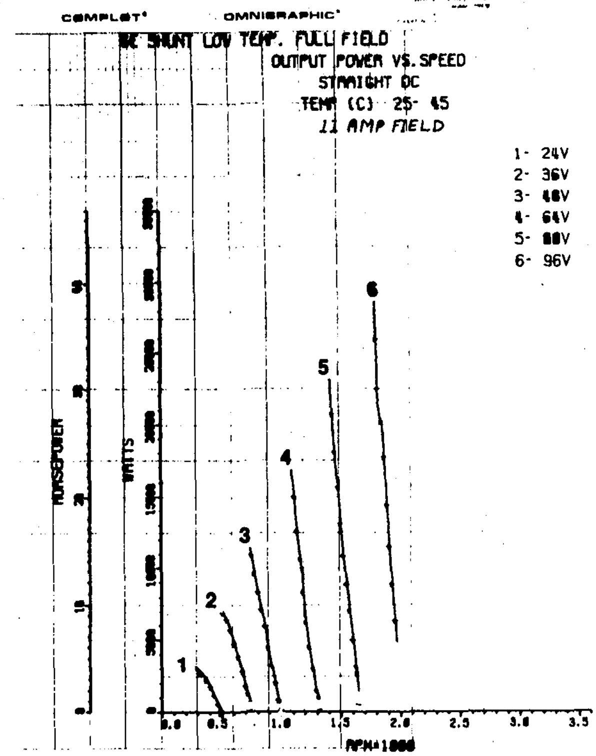
   b. The maximum efficiency of the motor was approximately 86% at low operating temperatures in the straight DC mode. However, at low chopper duty cycles the motor efficiency may be considerably less than it is on straight DC.

   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.

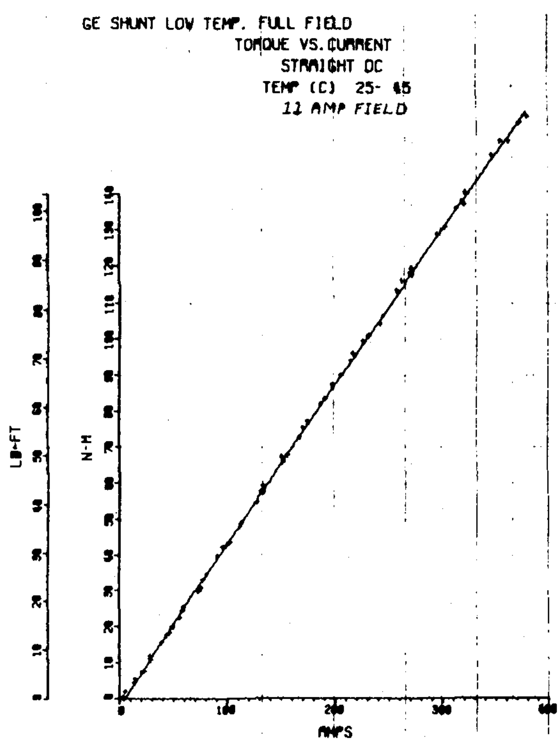
   d. The hysteresis effects of the motor alone, as well as the motor-controller combination, are negligible and can be ignored.



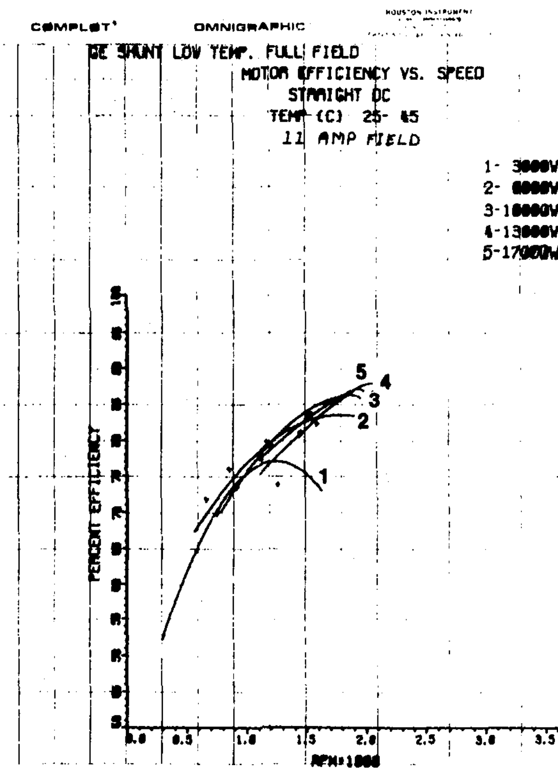
A. Speed - Torque Characteristics - Full Field - Low Temperature



B. Output Power Characteristics - Full Field - Low Temperature

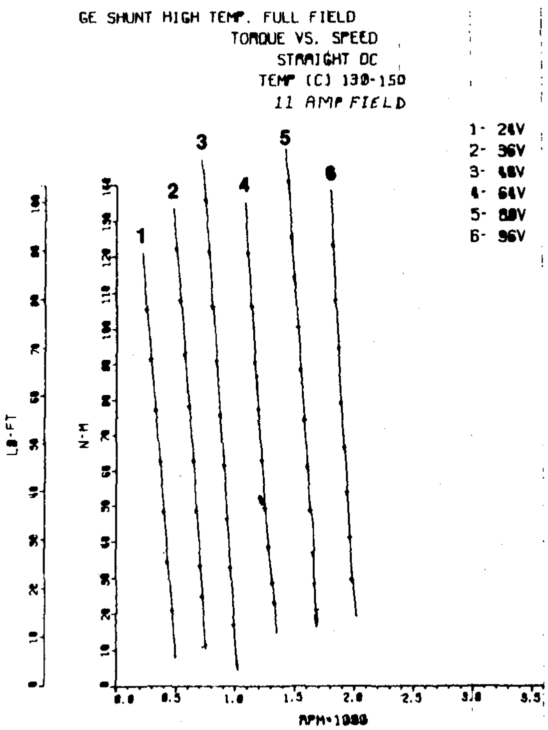


C. Torque - Current Characteristics - Full Field - Low Temperature

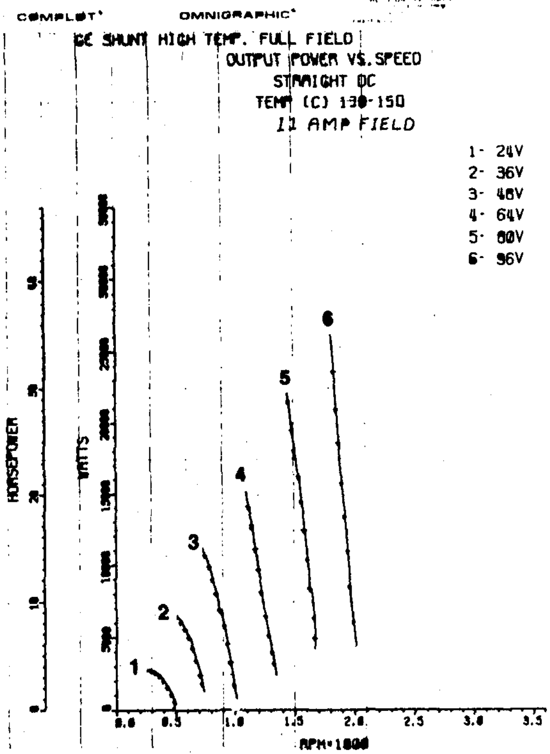


D. Efficiency - Speed - Power Relationships - Full Field - Low Temperature

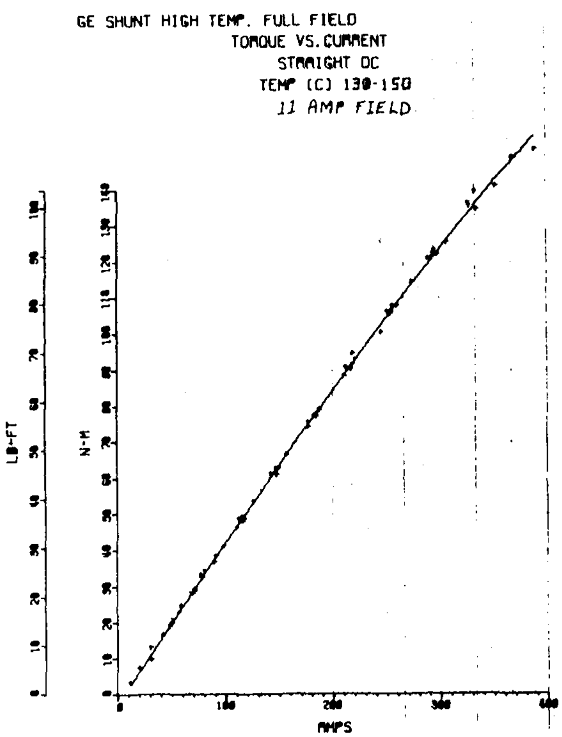
Figure 12 Low Temperature - Straight DC - Full Field



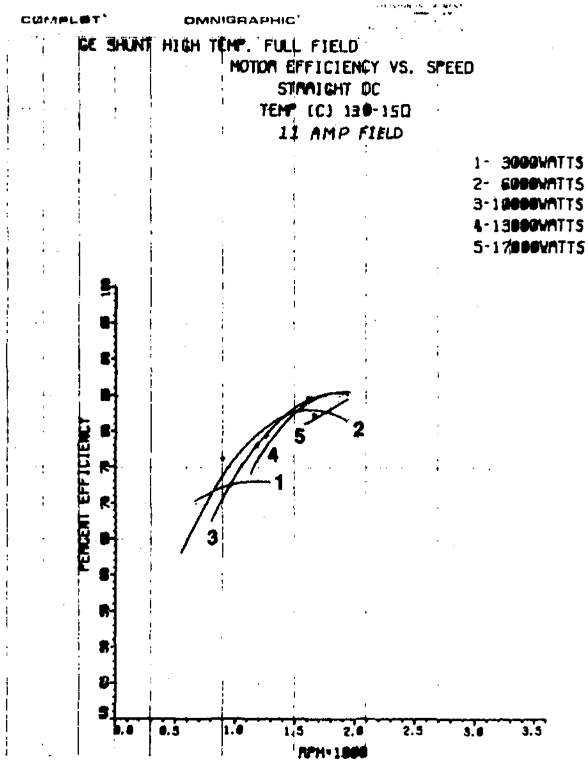
A. Speed - Torque Characteristics - Full Field - High Temperature



B. Output Power Characteristics Full Field - High Temperature

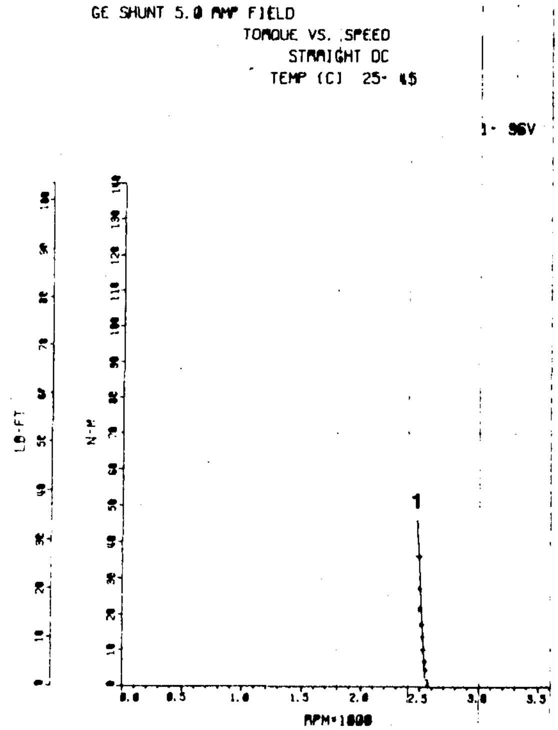


C. Torque - Current Characteristics - Full Field - High Temperature

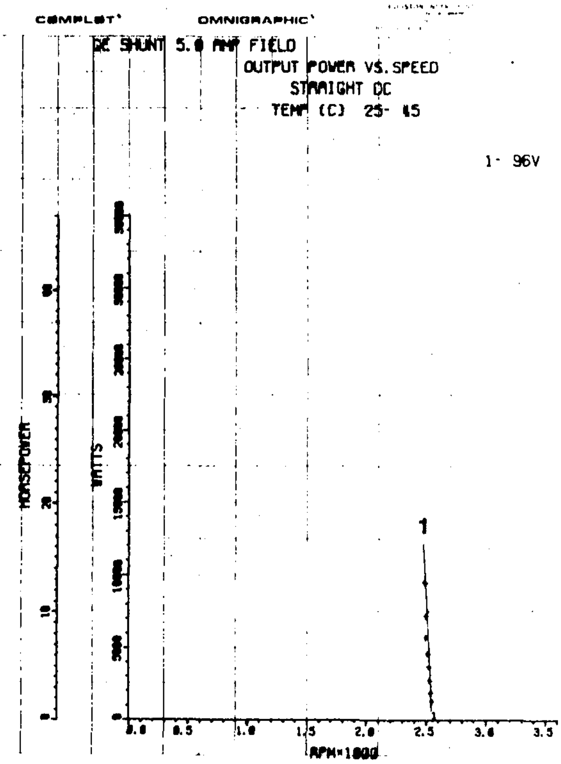


D. Efficiency - Speed - Power Relationships - Full Field - High Temperature

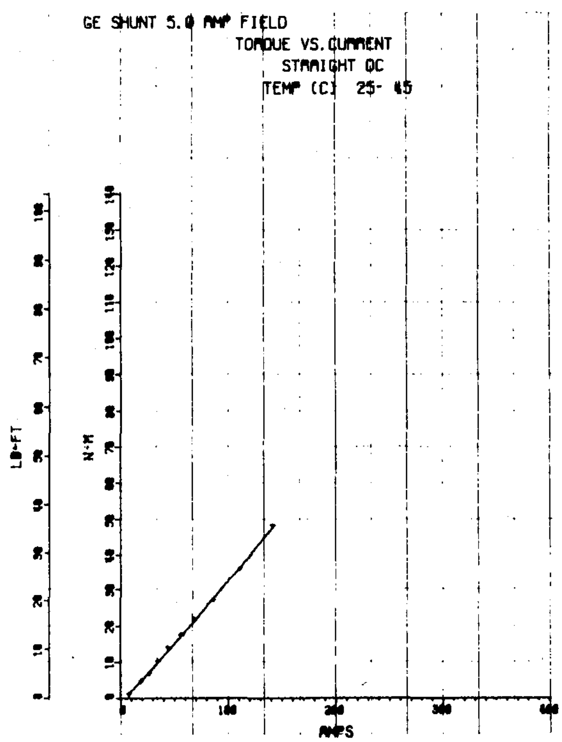
Figure 13 High Temperature - Straight DC - Full Field



A. Speed - Torque Characteristics - 5.0 Amp Field - Low Temperature

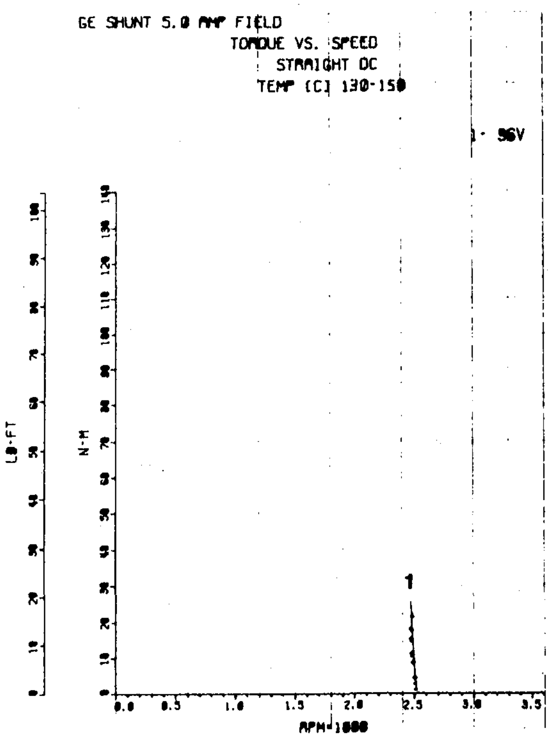


B. Output Power Characteristics - 5.0 Amp Field - Low Temperature

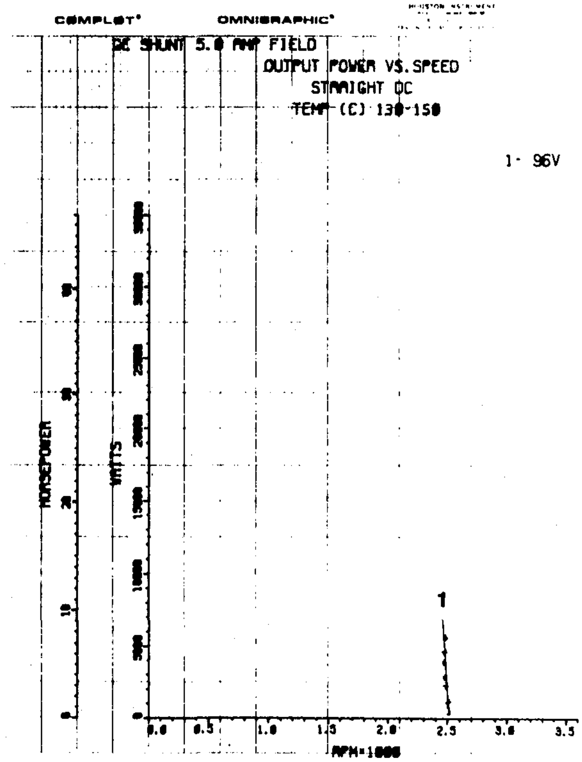


C. Torque - Current Characteristics 5.0 Amp Field - Low Temperature

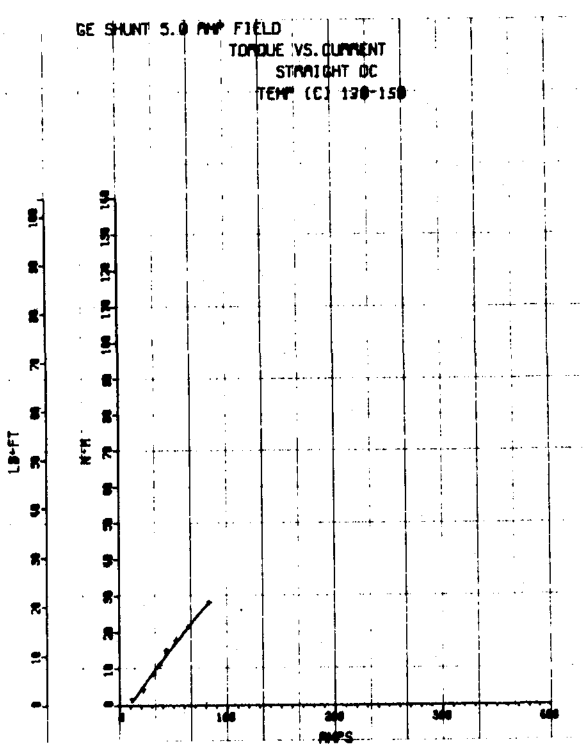
Figure 14 Low Temperature - Straight DC - 5 Amp Field



A. Speed - Torque Characteristics - 5.0 Amp Field - High Temperature

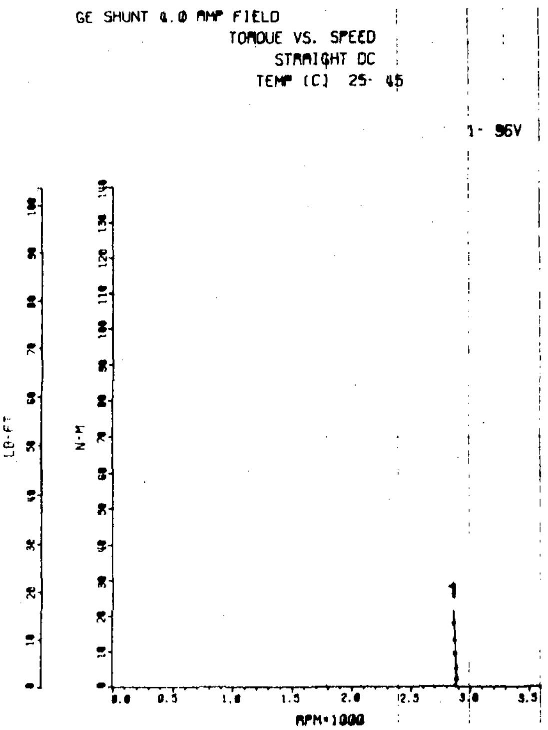


B. Output Power Characteristics - 5.0 Amp Field - High Temperature

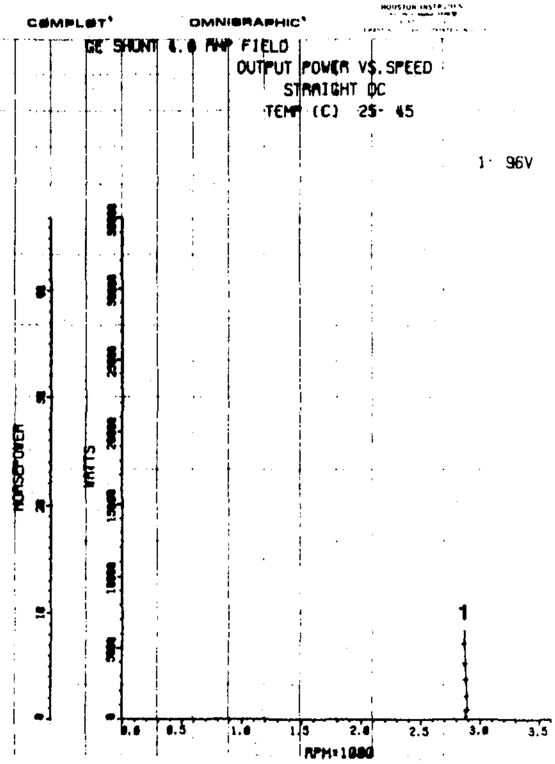


C. Torque - Current Characteristics - 5.0 Amp Field - High Temperature

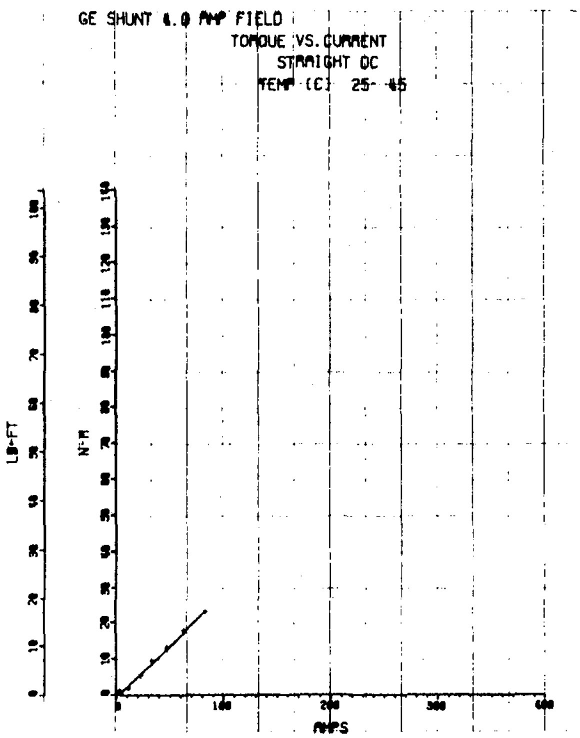
Figure 15 High Temperature - Straight DC - 5 Amp Field



A. **Speed - Torque Characteristics - 4.0 Amp Field - Low Temperature**

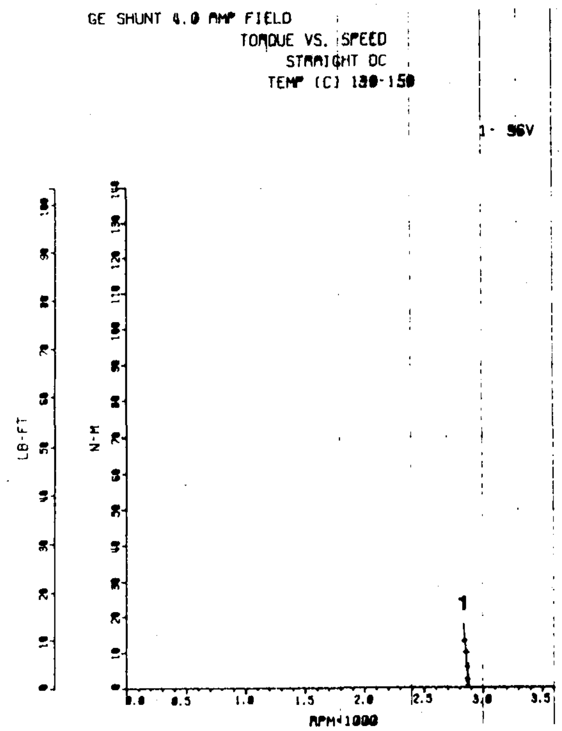


B. **Output Power Characteristics - 4.0 Amp Field - Low Temperature**

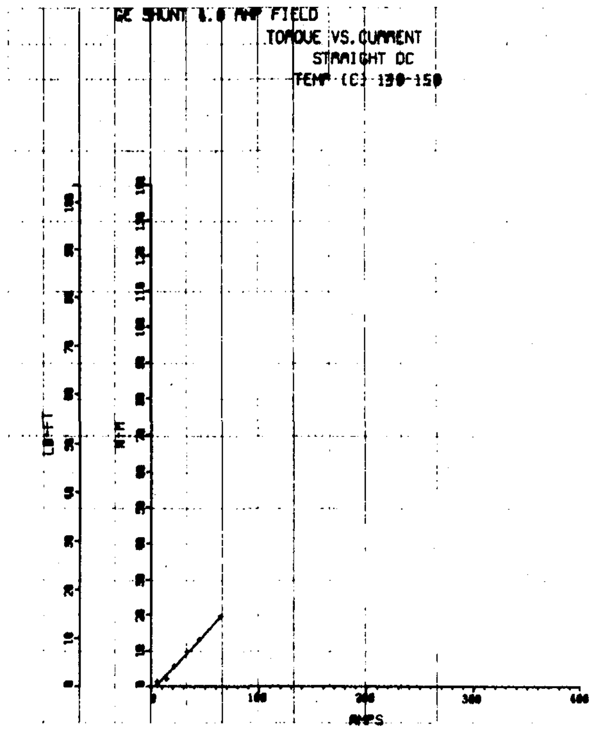


C. **Torque - Current Characteristics - 4.0 Amp Field - Low Temperature**

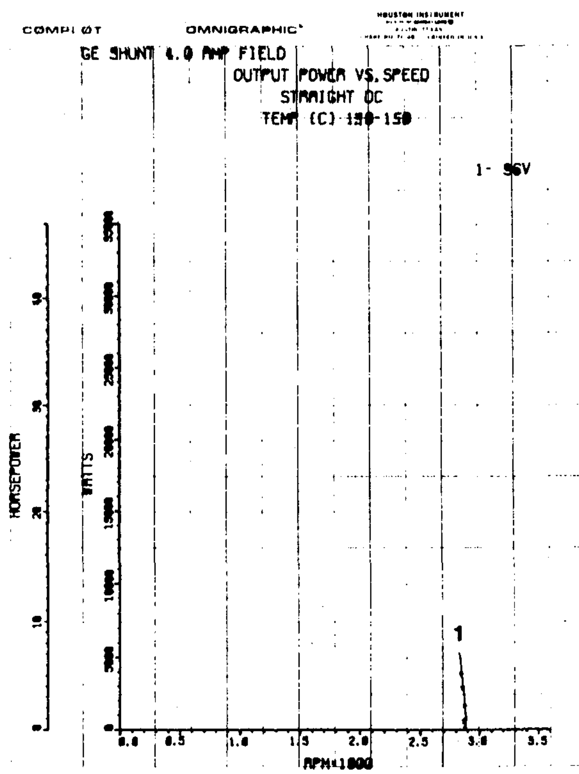
Figure 16 Low Temperature - Straight DC - 4 Amp Field



A. Speed - Torque Characteristics - 4.0 Amp Field - High Temperature

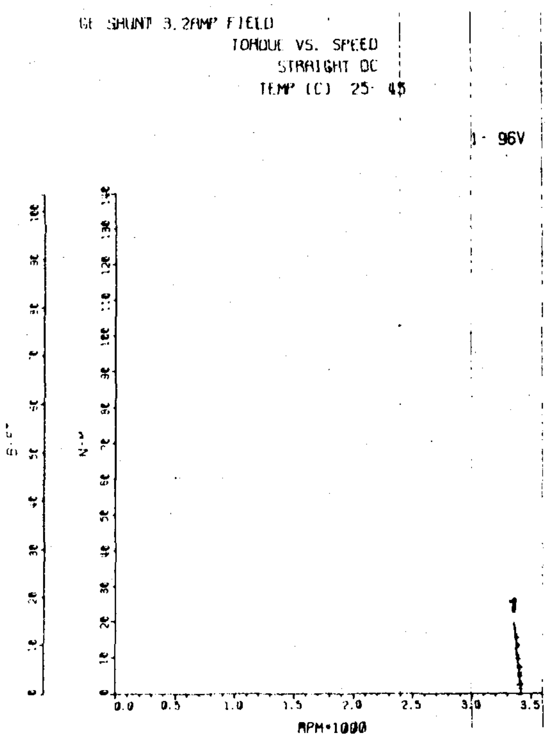


B. Output Power Characteristics - 4.0 Amp Field - High Temperature

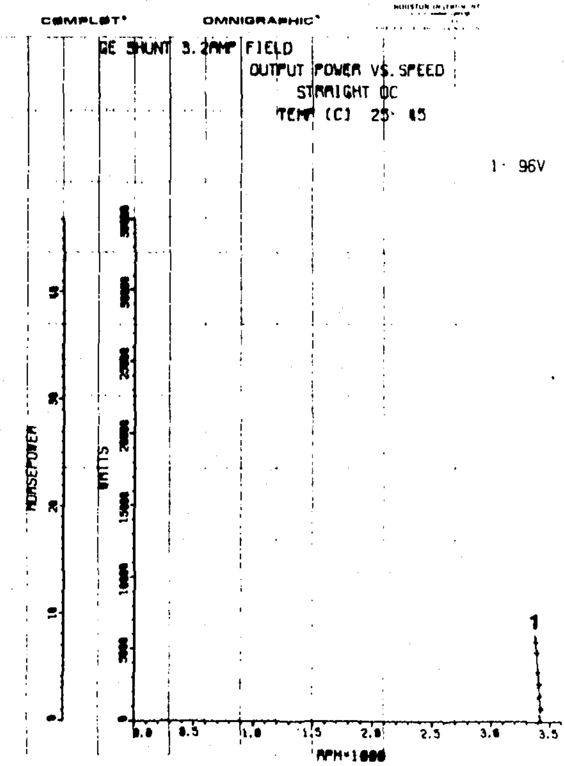


C. Torque Current Characteristics - 4.0 Amp Field - High Temperature

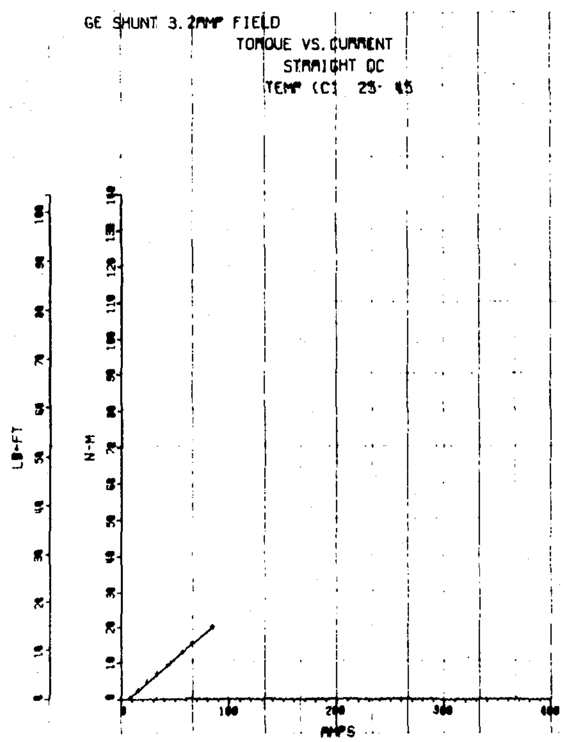
Figure 17 High Temperature - Straight DC - 4 Amp Field



A. Speed - Torque Characteristics - 3.2 Amp Field - Low Temperature

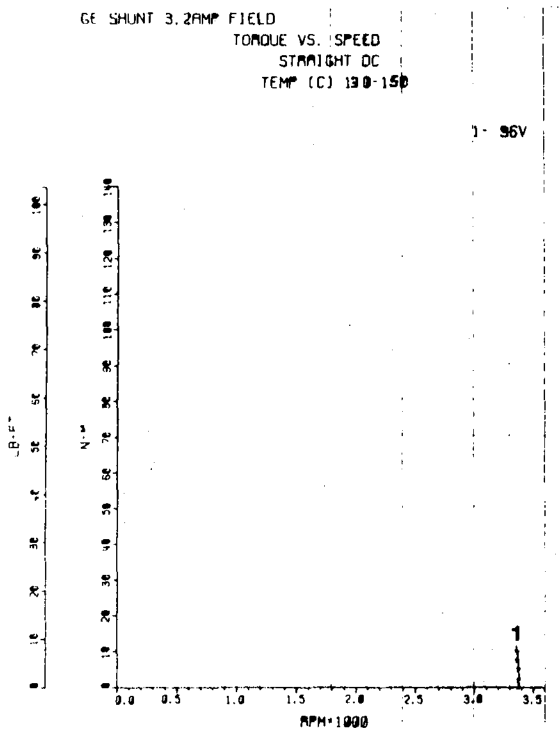


B. Output Power Characteristics - 3.2 Amp Field - Low Temperature

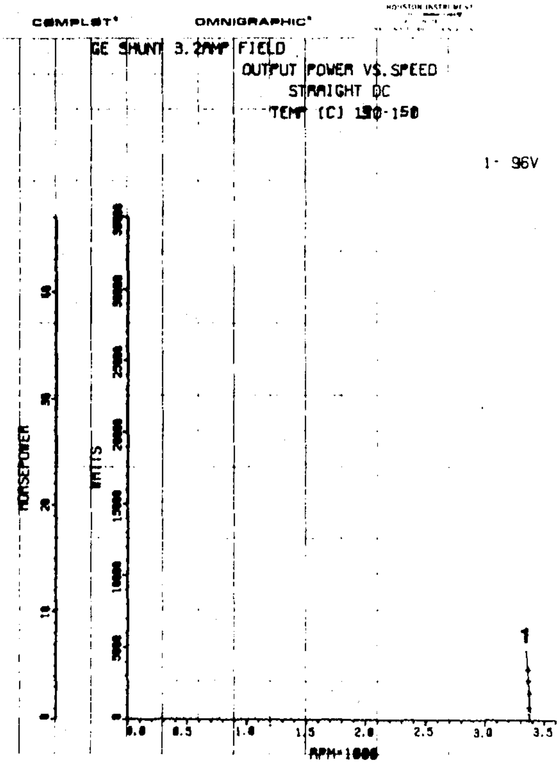


C. Torque - Current Characteristics - 3.2 Amp Field - Low Temperature

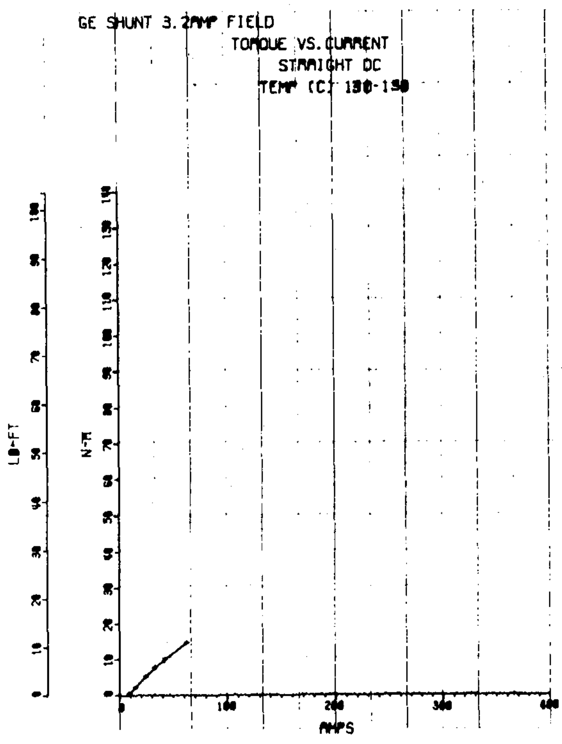
Figure 18 Low Temperature - Straight DC - 3.2 Amp Field



A. Speed - Torque Characteristics - 3.2 Amp Field - High Temperature

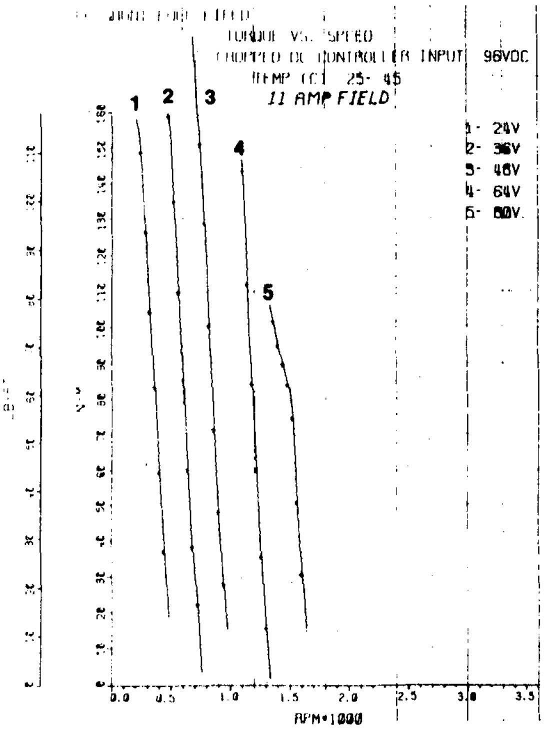


B. Output Power Characteristics - 3.2 Amp Field - High Temperature

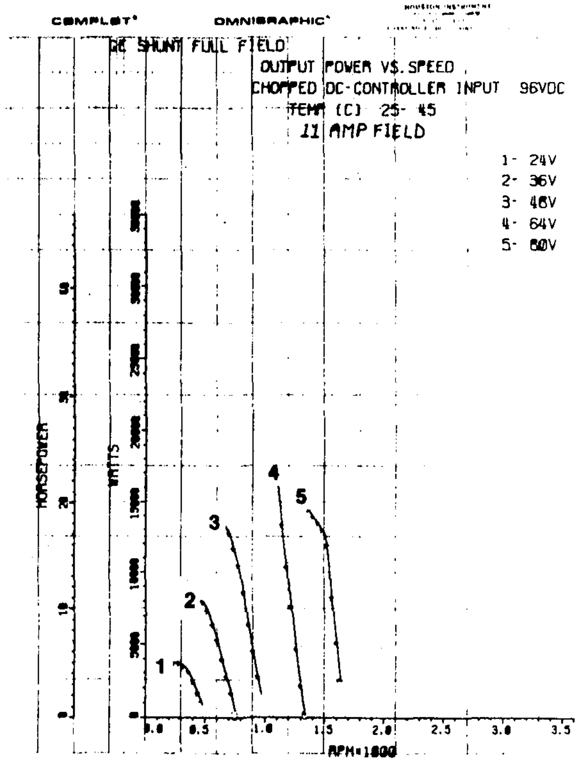


C. Torque - Current Characteristics - 3.2 Amp Field - High Temperature

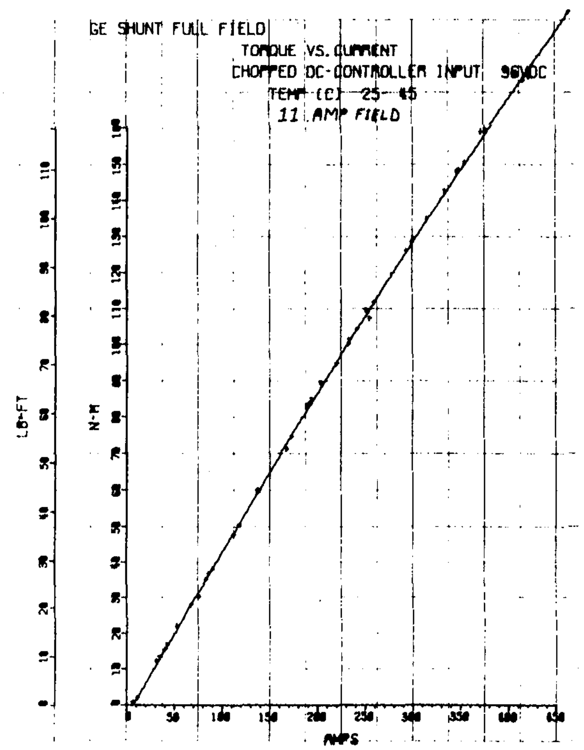
Figure 19 High Temperature - Straight DC - 3.2 Amp Field



A. Speed Torque Chacteristics - Full Field - Low Temperature

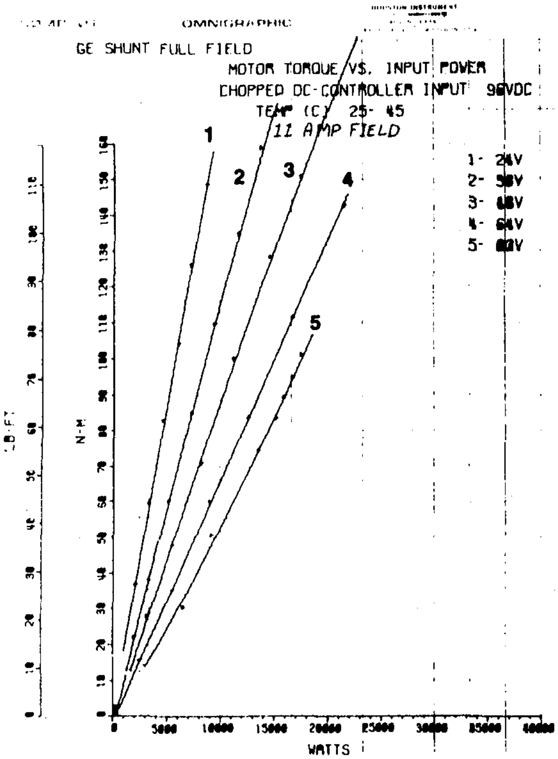


B. Output Power Characteristics - Full Field - Low Temperature

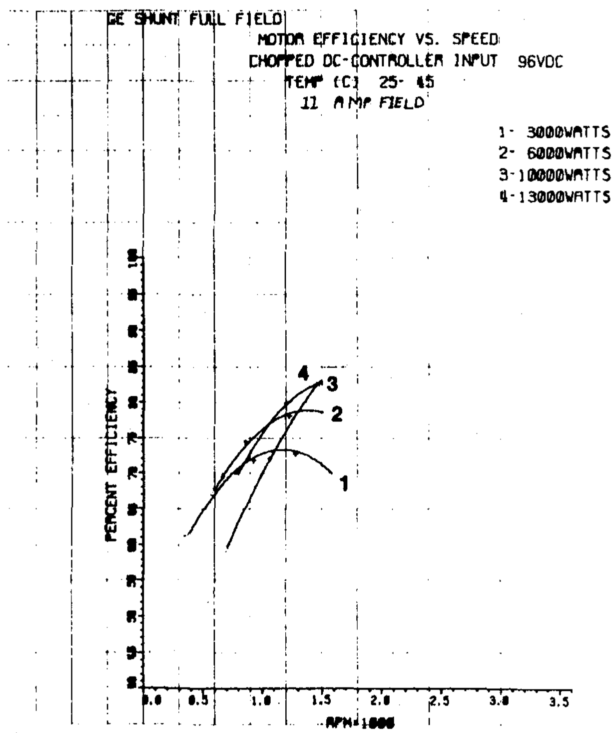


C. Torque - Current Characteristics - Full Field - Low Temperature

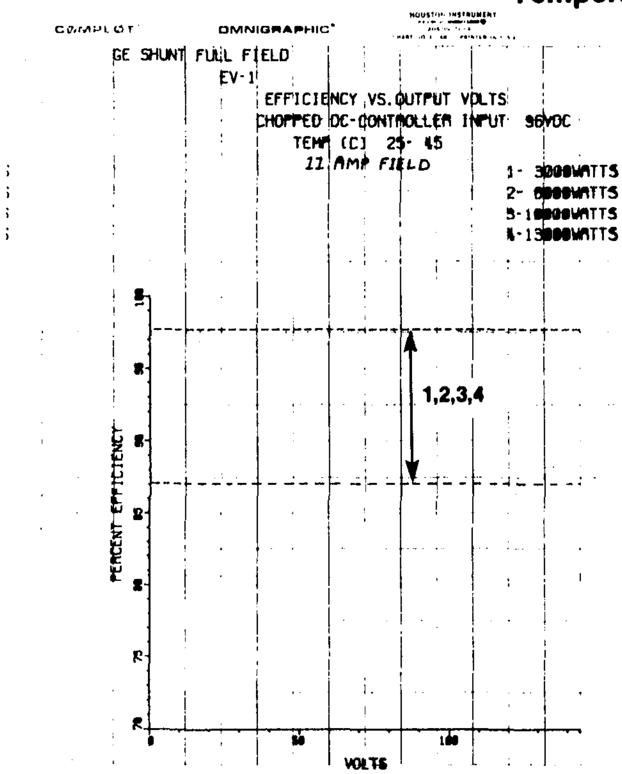
Figure 20 Low Temperature - Chopped DC - Full Field



A. Torque - Power - Voltage Relationships - Full Field - Low Temperature

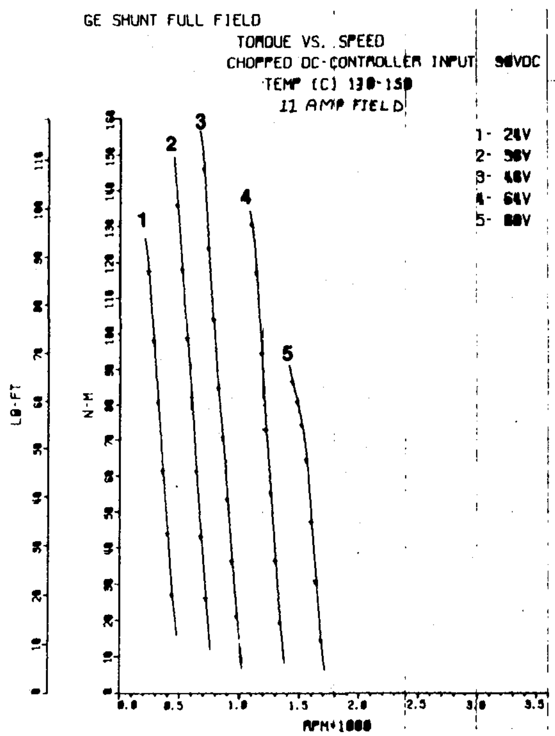


B. Motor Efficiency - Speed - Power Relationships - Full Field - Low Temperature

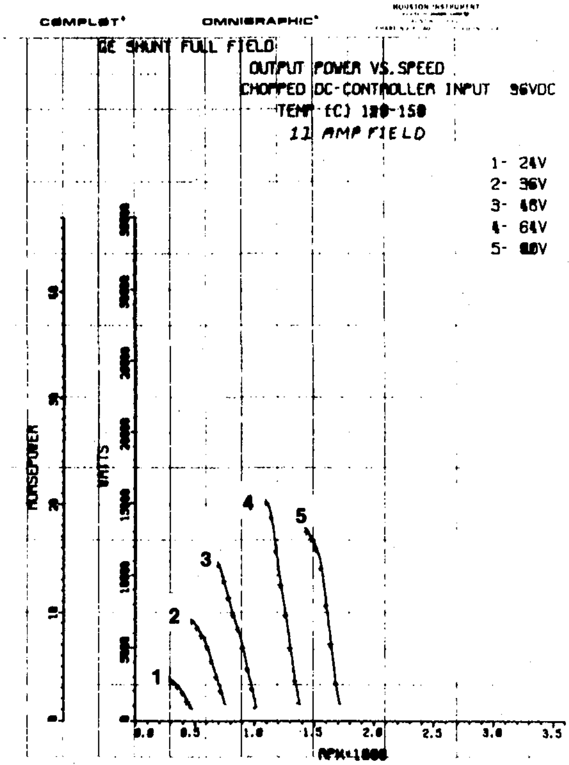


C. Controller Efficiency - Full Field - Low Temperature

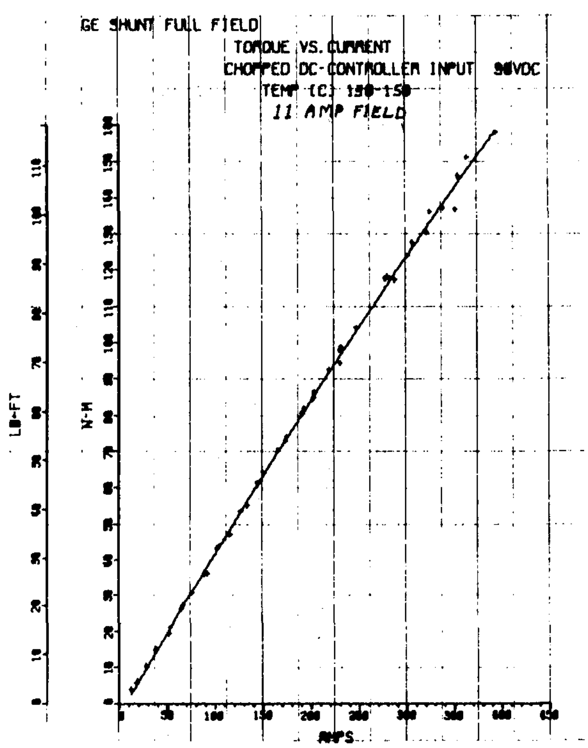
Figure 21 Low Temperature - Chopped DC - Full Field



A. Speed Torque Characteristics - Full Field - High Temperature

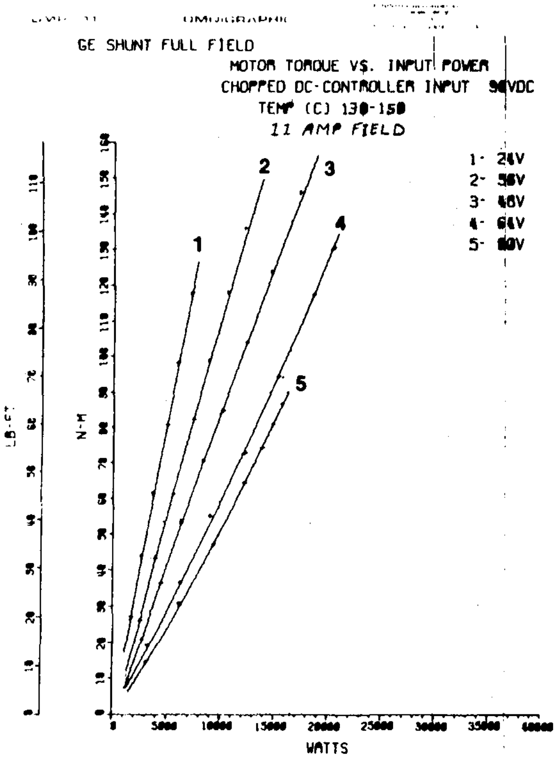


B. Output Power Characteristics - Full Field - High Temperature

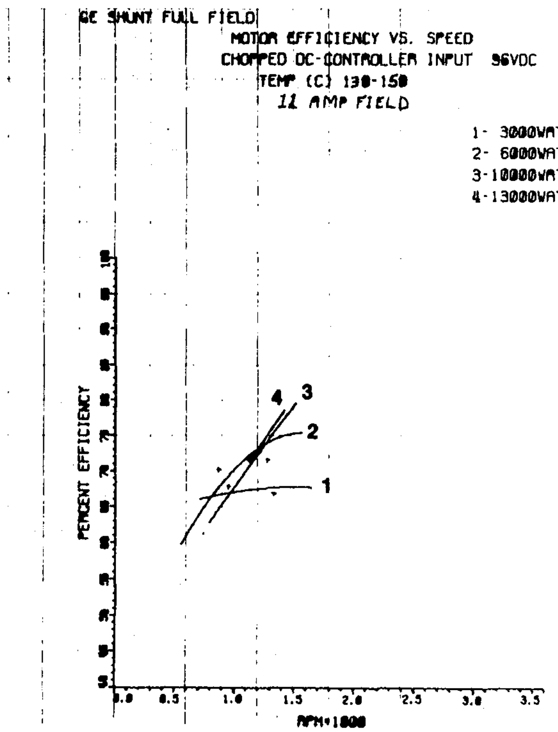


C. Torque - Current Characteristics - Full Field - High Temperature

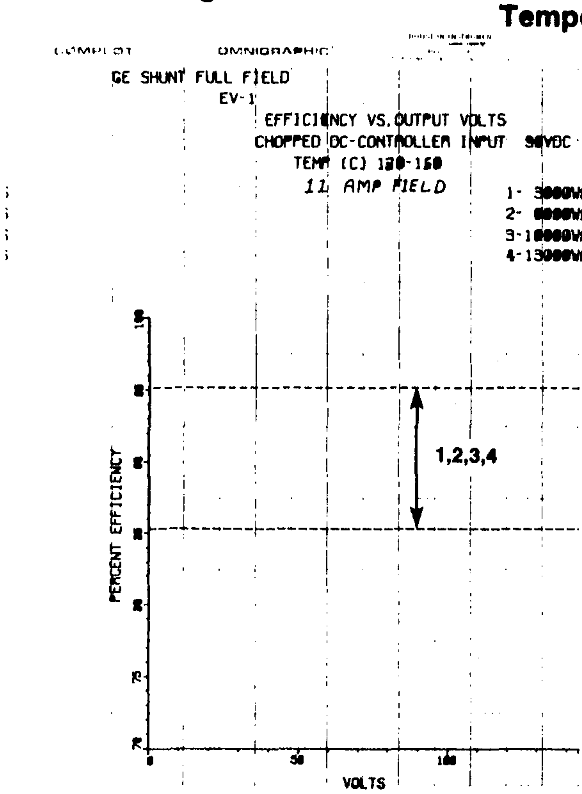
Figure 22 High Temperature - Chopped DC - Full Field



A. Torque - Power - Voltage Relationships - Full Field - High Temperature



B. Motor Efficiency - Speed - Power Relationships - Full Field - High Temperature



C. Controller Efficiency - Full Field - High Temperature

Figure 23 High Temperature - Chopped DC - Full Field

TABLE 1

GENERAL ELECTRIC MODEL 5BY436A1 DEN3-123
DC SHUNT MOTOR
(FIELD LOSSES = 54 VOLTS x 11 AMPS = 594 WATTS)

GE SHUNT - FULL FIELD 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 (%)
24	44	44	66	24.8	3.3	0.5	520	502.8	26.4	3.9
24	45	44	66	24.6	29.0	12.0	480	468.3	591.3	45.0
24	45	44	66	24.3	60.6	25.5	440	434.0	1164.4	56.1
24	45	44	66	23.9	96.3	42.6	400	401.8	1800.9	61.9
24	45	44	65	23.6	133.3	59.3	360	367.1	2290.4	61.0
24	45	44	64	23.3	175.3	77.4	320	331.0	2695.6	57.4
24	45	44	63	22.9	217.3	96.3	280	296.2	2960.6	53.6
24	45	44	62	22.6	263.3	116.3	240	259.9	3180.3	48.4
24	45	44	61	22.2	313.9	136.0	200	222.7	3186.7	42.0
36	43	43	53	37.6	14.3	5.7	780	747.2	448.1	39.4
36	43	43	53	37.4	44.4	17.9	740	712.3	1341.5	59.3
36	44	44	60	37.2	58.2	24.4	720	695.4	1785.3	64.4
36	44	44	65	36.6	91.5	40.0	680	668.3	2812.6	71.0
36	45	44	66	36.3	131.3	57.8	640	635.3	3863.6	71.7
36	45	44	66	35.7	170.8	75.7	600	605.2	4820.3	71.7
36	45	44	65	35.4	214.9	94.3	560	570.7	5662.4	68.7
36	45	44	63	34.8	257.6	113.8	520	540.6	6472.9	67.4
36	44	44	63	34.5	303.1	131.0	480	505.7	6970.2	62.8
36	45	44	61	34.1	354.5	154.8	440	470.6	7664.8	60.2
48	44	44	61	50.5	4.1	0.4	1060	1008.1	42.4	5.3
48	44	43	62	50.2	23.1	7.8	1020	974.2	799.5	45.4
48	44	44	62	49.7	49.0	20.1	980	946.8	2002.3	65.8
48	44	44	64	49.2	77.9	33.3	940	917.3	3213.9	72.3
48	44	44	64	48.5	111.9	48.1	900	890.0	4504.2	74.5
48	44	44	65	47.9	152.0	66.0	860	861.9	5985.2	75.7
48	44	44	64	47.4	186.7	82.2	820	830.9	7186.2	75.8
48	45	45	63	46.8	226.4	99.6	780	802.0	8404.5	74.8
48	45	44	62	46.3	271.9	119.6	740	770.9	9700.8	73.3
48	45	44	61	45.5	322.0	140.7	700	743.9	11012.6	71.9
48	45	45	62	44.8	379.6	161.5	660	716.3	12171.6	68.9

TABLE 1 (cont.)

GENERAL ELECTRIC MODEL 5BY436A1 DC SHUNT MOTOR (FIELD LOSSES = 54 VOLTS x 11 AMPS = 594 WATTS)

GE SHUNT - FULL FIELD 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	35	35	50	67.5	5.6	2.2	1400	1327.0	307.2	31.5
64	36	36	52	66.4	20.9	7.5	1360	1309.9	1047.4	52.6
64	36	36	53	66.4	29.1	11.1	1340	1290.5	1507.2	59.4
64	36	35	53	65.8	56.1	22.6	1300	1263.5	3004.4	69.8
64	36	35	54	65.3	81.7	34.9	1260	1234.3	4532.4	76.1
64	36	36	54	64.6	112.9	49.0	1220	1207.6	6225.9	78.6
64	36	36	54	63.8	151.1	67.5	1180	1184.2	8410.3	81.8
64	36	36	54	62.9	197.8	87.4	1140	1162.2	10687.4	81.6
64	36	36	53	62.3	244.5	106.6	1100	1132.1	12697.6	79.9
64	37	36	52	61.4	296.0	129.0	1060	1109.1	15053.6	79.9
64	36	36	52	60.5	346.0	150.8	1020	1085.6	17224.7	79.7
80	43	42	69	83.7	14.1	4.5	1740	1663.2	787.5	44.2
80	42	41	69	83.4	39.7	15.8	1700	1630.7	2710.9	69.1
80	43	42	69	82.6	47.0	18.5	1680	1627.2	3167.3	70.5
80	43	42	69	81.8	74.2	29.9	1640	1603.6	5044.8	75.4
80	43	43	70	81.3	99.9	43.0	1600	1574.1	7121.7	81.4
80	43	43	69	80.4	128.2	54.8	1560	1551.3	8944.5	81.7
80	43	42	69	79.7	156.3	68.0	1520	1525.3	10913.0	83.2
80	43	42	69	78.9	191.1	83.7	1480	1501.3	13221.3	84.0
80	43	42	68	78.1	231.4	101.1	1440	1478.1	15733.0	83.9
80	42	42	68	77.3	271.1	118.5	1400	1452.1	18104.9	83.7
80	42	42	66	76.3	318.7	138.2	1360	1432.0	20822.4	83.2
80	42	42	66	75.3	372.2	159.8	1320	1411.0	23723.8	82.5
96	42	41	64	100.1	50.4	20.2	2060	1947.5	4196.5	74.1
96	41	41	66	99.1	76.7	31.0	2020	1955.5	6378.2	77.5
96	41	41	65	98.4	103.3	43.7	1980	1931.0	8878.6	82.2
96	42	41	66	97.5	134.2	57.7	1940	1910.4	11597.9	84.4
96	42	41	65	96.6	168.1	72.9	1900	1888.8	14487.5	85.7
96	42	41	65	95.6	206.3	90.3	1860	1868.8	17755.4	87.0
96	41	41	64	94.8	242.4	104.5	1820	1844.6	20281.4	85.7

TABLE 1 (cont.)

GENERAL ELECTRIC MODEL 5BY436A1 DEN3-123
DC SHUNT MOTOR
(FIELD LOSSES = 54 VOLTS x 11 AMPS = 594 WATTS

GE SHUNT - FULL FIELD 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 (%)
96	42	41	66	94.2	272.8	118.0	1780	1815.3	22537.8	85.4
96	42	41	65	92.8	321.2	137.3	1740	1803.9	26059.3	85.6
96	42	42	68	91.6	362.2	154.7	1700	1789.1	29120.9	85.9

TABLE 2

GENERAL ELECTRIC MODEL 5BY436A1 DEN3-123

DC SHUNT MOTOR

(FIELD LOSSES = 66 VOLTS x 11 AMPS = 726 WATTS)

GE SHUNT - FULL FIELD 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 (%)
24	135	134	160	25.1	20.7	7.6	520	497.5	397.8	31.8
24	135	134	161	24.8	51.7	21.1	480	464.2	1065.6	51.1
24	135	134	162	24.5	81.4	34.5	440	430.1	1561.2	57.1
24	135	134	162	24.2	115.6	48.4	400	396.7	2020.2	57.1
24	135	134	162	23.9	147.4	62.7	360	362.0	2388.1	56.0
24	134	134	162	23.6	185.3	77.3	320	326.1	2652.2	51.8
24	133	133	160	23.4	218.6	91.7	280	288.5	2783.5	47.5
24	133	133	159	23.2	254.2	105.7	240	251.2	2793.7	42.0
24	133	132	158	22.7	294.0	122.5	200	214.8	2768.5	37.3
36	133	133	169	37.5	31.3	10.0	780	748.6	787.6	41.3
36	132	131	170	37.0	58.8	25.1	740	720.4	1902.5	65.3
36	134	134	172	36.6	76.8	33.4	720	707.0	2484.5	69.9
36	134	133	173	36.4	111.9	48.7	680	672.4	3445.4	71.5
36	134	134	174	35.8	147.0	62.9	640	644.9	4268.0	71.0
36	134	134	175	35.5	185.3	78.4	600	610.3	5034.3	68.6
36	133	133	173	35.2	221.1	93.1	560	573.9	5621.7	65.8
36	133	133	171	34.7	260.2	108.0	520	542.8	6168.0	63.0
36	134	133	171	34.5	297.9	122.3	480	505.9	6509.9	58.9
36	134	133	171	33.8	334.5	134.8	440	474.8	6734.1	55.7
48	127	127	164	50.0	12.5	3.6	1060	1017.7	385.5	28.4
48	127	126	164	49.5	42.5	16.9	1020	989.3	1759.1	62.0
48	126	126	172	48.9	79.0	32.8	980	962.1	3320.3	72.0
48	126	126	170	48.4	110.2	46.4	940	932.9	4554.4	74.8
48	126	126	171	47.7	142.2	61.6	900	905.7	5870.1	77.8
48	126	127	169	47.4	177.2	75.8	860	871.7	6952.1	75.9
48	127	126	170	46.7	212.3	91.0	820	846.0	8100.1	75.8
48	126	126	169	46.3	251.1	106.4	780	812.0	9090.3	73.3
48	127	127	168	45.7	292.1	121.3	740	782.5	9986.8	70.7
48	125	125	170	45.3	327.6	135.9	700	748.0	10695.5	68.4
48	130	130	167	44.7	368.5	149.6	660	718.5	11309.4	65.4

TABLE 2 (cont.)

GENERAL ELECTRIC MODEL 5BY436A1
DC SHUNT MOTOR
(FIELD LOSSES = 66 VOLTS x 11 AMPS = 726 WATTS)

GE SHUNT - FULL FIELD 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	132	132	170	66.3	31.1	13.4	1400	1351.0	1904.8	68.0
64	134	134	170	65.5	57.7	23.2	1360	1328.3	3242.4	71.7
64	136	136	172	65.4	71.2	28.9	1340	1311.7	3988.5	73.8
64	136	136	174	65.0	91.3	38.6	1300	1280.5	5200.5	77.7
64	136	136	176	64.3	115.5	49.3	1260	1253.2	6500.5	79.4
64	136	136	178	63.7	148.9	63.0	1220	1225.7	8124.7	79.2
64	136	136	177	63.1	182.4	77.5	1180	1197.2	9762.2	79.4
64	137	137	175	62.5	217.0	90.7	1140	1170.0	11165.4	77.8
64	135	135	172	61.8	254.1	106.3	1100	1143.2	12786.0	77.5
64	135	134	171	61.3	289.1	121.2	1060	1110.7	14175.5	76.4
64	134	134	170	60.6	327.0	136.5	1020	1084.5	15575.5	75.5
80	137	137	184	82.0	50.6	20.1	1740	1698.1	3591.2	73.3
80	133	133	160	81.7	69.3	28.5	1700	1664.7	4991.8	77.8
80	140	140	188	81.0	89.8	36.9	1680	1659.5	6442.9	80.2
80	141	140	190	80.3	117.4	48.8	1640	1633.0	8384.7	82.2
80	141	140	191	79.6	147.8	61.4	1600	1607.6	10385.5	82.8
80	141	141	191	78.8	177.1	74.5	1560	1584.5	12420.2	84.2
80	142	141	189	78.2	210.3	88.5	1520	1556.5	14493.5	84.0
80	143	142	194	77.4	245.3	100.6	1480	1532.9	16225.3	82.0
80	142	142	191	76.9	273.3	114.7	1440	1502.3	18130.1	83.0
80	144	144	193	76.1	306.3	125.6	1400	1478.1	19533.2	81.0
80	142	142	190	75.4	352.6	141.2	1360	1451.9	21570.1	78.6
80	143	143	189	74.4	389.1	151.9	1320	1429.7	22849.8	76.7
96	131	130	149	98.2	48.2	19.1	2060	2013.1	4045.6	73.8
96	131	131	150	97.6	71.1	29.5	2020	1986.8	6166.8	80.1
96	131	131	152	96.8	98.4	41.2	1980	1964.3	8515.0	82.7
96	131	131	154	95.8	125.4	53.8	1940	1945.2	11011.6	86.1
96	131	131	154	95.0	156.8	66.7	1900	1920.7	13479.2	86.0
96	131	131	153	94.3	187.0	79.3	1860	1894.2	15804.4	85.7
96	131	131	153	93.4	218.4	94.8	1820	1872.2	18674.1	88.0

TABLE 2 (cont.)

GENERAL ELECTRIC MODEL 5BY436A1

DC SHUNT MOTOR

(FIELD LOSSES = 66 VOLTS x 11 AMPS = 726 WATTS)

GE SHUNT - FULL FIELD 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 (%)
96	131	131	154	92.5	255.7	108.0	1780	1851.8	21042.5	85.9
96	131	131	151	91.6	294.5	123.4	1740	1830.1	23761.3	85.4
96	130	130	151	90.6	333.0	139.7	1700	1808.3	26579.5	85.7

TABLE 3

GENERAL ELECTRIC MODEL 5BY436A1 DEN3-123

DC SHUNT MOTOR

(FIELD LOSSES = 22 VOLTS x 5 AMPS = 110 WATTS)

GE SHUNT - 5A FIELD 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 (%)
96	33	33	42	101.2	8.5	1.4	2720	2581.3	380.2	39.0
96	33	33	42	101.3	19.8	5.0	2700	2558.6	1346.0	63.6
96	33	33	42	100.9	27.8	7.2	2680	2549.2	1931.1	66.0
96	33	33	41	100.5	35.1	10.5	2660	2539.2	2805.2	76.8
96	33	33	42	100.2	44.9	14.2	2640	2529.2	3778.8	81.6
96	33	33	42	99.7	57.4	17.7	2620	2522.1	4696.9	80.2
96	33	33	42	99.4	69.8	22.1	2600	2510.7	5838.0	82.5
96	33	33	42	98.7	87.5	27.5	2580	2509.5	7261.1	82.7
96	35	35	42	98.1	111.7	36.4	2560	2503.5	9588.0	86.3
96	33	33	42	97.4	142.1	48.5	2540	2501.6	12765.6	91.1

TABLE 4

GENERAL ELECTRIC MODEL 5BY436A1 DEN3-123
DC SHUNT MOTOR
(FIELD LOSSES = 32 VOLTS x 5 AMPS = 160 WATTS)

GE SHUNT - 5A FIELD 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 (%)
96	130	130	144	101.7	12.2	1.9	2680	2530.7	505.9	36.0
96	131	131	144	101.6	22.7	4.6	2660	2513.6	1216.6	49.1
96	131	130	144	101.5	32.5	8.8	2640	2496.9	2311.9	66.6
96	131	131	144	101.2	37.9	11.1	2620	2484.4	2901.5	72.3
96	131	131	145	100.6	44.2	15.2	2600	2479.3	3965.1	85.7
96	131	131	146	99.8	53.5	18.0	2580	2480.6	4697.9	85.4
96	132	132	145	98.7	65.1	21.6	2560	2489.1	5656.9	85.5
96	132	132	142	98.4	84.4	28.4	2540	2476.2	7399.2	87.0

TABLE 5

GENERAL ELECTRIC MODEL 5BY436A1
DC SHUNT MOTOR
(FIELD LOSSES = 18 VOLTS x 4 AMPS = 72 WATTS)

GE SHUNT - 4A FIELD 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 (%)
96	34	33	33	102.0	4.5	1.3	3080	2900.1	396.7	74.4
96	33	33	33	101.3	12.0	2.2	3060	2900.0	671.3	51.9
96	34	33	33	100.8	23.7	5.5	3040	2895.5	1675.6	67.8
96	34	33	33	100.4	34.1	9.3	3020	2888.2	2826.1	80.5
96	34	34	33	99.9	48.2	13.1	3000	2882.8	3973.4	81.0
96	34	34	34	99.4	64.5	17.9	2980	2875.8	5416.2	83.2
96	34	34	34	98.9	84.0	23.2	2960	2872.8	7012.5	83.3

TABLE 6

GENERAL ELECTRIC MODEL 5BY436A1

DC SHUNT MOTOR

(FIELD LOSSES = 24 VOLTS x 4 AMPS = 96 WATTS)

GE SHUNT - 4A FIELD 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 (%)
96	129	129	143	101.5	6.1	1.4	3060	2893.5	426.2	61.4
96	130	130	144	101.4	15.1	2.2	3040	2877.6	666.1	41.4
96	131	130	145	100.7	22.3	5.8	3020	2878.9	1756.9	75.5
96	132	131	145	100.6	34.0	9.9	3000	2863.4	2952.5	84.0
96	132	132	146	100.3	45.3	13.2	2980	2850.6	3959.0	85.4
96	132	132	146	99.9	65.1	19.6	2960	2843.9	5864.8	88.8

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TABLE 9
"GENERAL ELECTRIC MODEL 5BY436A1
DC SHUNT MOTOR"
"GENERAL ELECTRIC EV-1 CONTROLLER"
(FIELD LOSSES = 54V x 11A = 594 WATTS)

GENERAL ELECTRIC SHUNT - FULL FIELD CHOPPED D.C. TESTS, 25-45°C TEMPERATURE RANGE, 96 VOLTS CONTROLLER INPUT TAP

MOTOR INPUT VOLTAGE	TEMPERATURE °C			CHOPPER INPUT VOLTAGE		CHOPPER INPUT CURRENT (AMPS)		CHOPPER INPUT POWER	CHOPPER OUTPUT VOLTAGE		CHOPPER OUTPUT CURRENT (AMPS)		CHOPPER OUTPUT POWER	M O T O R O U T P U T			
NOMINAL	FIELD #1	FIELD #2	ARMATURE	AVG.	RMS	AVG.	RMS	(WATTS)	AVG.	RMS	AVG.	RMS	(WATTS)	SPEED (RPM)	TORQUE (Nm)	POWER (WATTS)	EFFICIENCY (%)
24	39	39	60	100.8	87.3	12.3	40.3	1210.5	24.0	25.6	42.8	50.7	1016.4	480	17.3	873.7	54.0
24	48	47	66	99.3	99.8	27.0	66.6	2485.3	24.3	25.6	87.1	91.0	2108.3	440	37.1	1717.5	63.3
24	39	39	61	96.9	97.5	47.5	101.7	4058.5	24.4	28.6	138.6	141.4	3387.9	400	59.6	2508.3	62.7
24	39	39	61	94.2	95.5	72.0	137.5	5763.5	24.2	32.7	189.7	199.8	4634.4	360	83.3	3155.2	60.0
24	40	40	62	91.5	92.8	100.0	173.4	7611.0	24.4	36.3	242.2	248.5	6178.6	320	104.5	3518.4	51.7
24	41	41	60	88.6	90.8	128.1	210.0	9219.9	24.0	36.1	294.4	300.3	7255.3	280	126.5	3726.7	47.3
24	41	41	53	85.2	88.0	165.8	251.1	11257.8	24.2	36.5	349.0	356.2	8748.3	240	148.8	3757.5	40.0
24	41	40	69	82.3	85.5	200.6	286.9	13169.2	24.2	36.3	377.2	385.8	9318.7	200	159.8	3362.7	33.8
36	40	40	55	101.6	102.2	6.7	15.0	524.1	36.1	36.6	12.4	22.3	445.1	760	2.2	175.9	16.9
36	40	40	56	99.4	100.1	24.2	43.3	2292.2	36.6	37.8	53.1	58.4	2022.1	720	22.3	1689.3	64.3
36	40	40	56	97.9	98.7	39.3	65.8	3668.8	36.0	37.5	91.2	94.1	3436.6	680	38.3	2740.2	67.7
36	40	41	58	95.0	96.0	64.1	98.6	5693.8	36.1	39.5	138.0	144.3	5228.3	640	60.3	4060.5	69.4
36	41	40	57	91.6	92.9	97.8	145.0	8118.8	36.1	43.1	194.3	200.7	7322.5	600	85.3	5384.9	67.7
36	40	39	54	87.5	89.7	138.9	193.9	10739.6	35.8	44.8	251.7	258.3	9502.9	560	110.0	6481.3	63.9
36	40	39	52	82.9	85.8	188.3	246.7	13628.9	35.7	44.1	315.5	319.4	11685.6	520	135.1	7391.6	59.9
36	39	40	52	78.4	81.8	240.0	297.3	16306.2	35.7	43.7	371.7	375.5	13814.4	480	159.3	8045.2	55.6
36	40	40	66	72.8	76.5	297.1	349.9	19175.7	36.2	44.1	417.1	423.3	15608.2	440	173.5	8032.2	49.4
48	35	35	59	100.0	100.9	19.2	42.4	1815.0	48.0	49.4	32.0	42.4	1567.6	980	12.4	1278.6	58.9
48	36	36	60	97.6	98.7	37.6	70.6	3594.1	48.1	49.4	68.6	73.5	3243.0	940	28.0	2769.3	71.9
48	36	35	60	94.9	95.6	64.6	103.6	5799.4	48.0	49.8	113.1	118.6	5580.7	900	48.0	4545.3	73.3
48	36	36	60	90.6	91.7	103.5	149.9	8825.3	48.0	52.8	168.9	174.7	8306.8	860	71.4	6460.7	72.3
48	37	36	60	85.4	87.3	156.2	204.8	12297.3	48.0	53.8	233.8	241.1	11247.6	820	100.5	8670.8	72.9
48	38	38	59	79.2	82.0	220.3	266.8	16422.7	48.1	55.4	299.8	305.3	14625.7	780	128.8	10570.4	69.2
48	39	39	57	74.7	77.4	280.6	315.6	19438.9	48.0	53.4	355.3	359.8	17546.5	740	151.0	11756.8	64.5
48	38	37	54	68.1	70.7	309.8	390.3	23266.4	47.8	51.7	423.1	426.6	20859.3	700	174.6	12859.5	59.7
48	39	39	57	61.5	63.1	438.1	442.2	26570.3	48.8	50.4	465.0	464.8	22919.8	660	192.2	13346.8	56.5

TABLE 9 (cont.)
"GENERAL ELECTRIC MODEL 5BY436A1
DC SHUNT MOTOR"
"GENERAL ELECTRIC EV-1 CONTROLLER"
(FIELD LOSSES = 54V x 11A = 594 WATTS)

GENERAL ELECTRIC SHUNT - FULL FIELD CHOPPED D.C. 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	41	41	50	100.8	101.0	5.3	25.3	521.3	63.9	64.6	7.5	19.7	420.6	1340	1.0	141.0	13.8
64	41	41	50	97.8	98.5	28.1	54.3	2896.8	63.6	64.5	40.9	48.2	2559.2	1300	15.7	2147.5	67.8
64	41	41	51	94.8	95.7	60.5	86.5	5824.9	63.7	64.9	84.8	90.2	5487.8	1260	35.5	4706.3	77.1
64	41	41	52	89.9	91.2	105.4	131.1	9435.7	63.8	66.0	138.8	143.8	9038.1	1220	60.2	7727.5	79.9
64	42	41	51	85.4	86.7	156.4	183.4	13100.3	63.3	66.5	192.7	198.0	12653.7	1180	84.1	10441.4	78.5
64	43	42	51	78.9	80.5	226.0	246.2	17656.7	63.7	66.3	259.9	266.2	16856.9	1140	112.0	13433.9	76.7
64	41	41	50	72.0	72.6	313.8	321.5	22727.0	63.5	64.8	334.1	335.6	21585.9	1100	143.1	16562.0	74.4
64	41	41	51	71.1	71.8	326.0	330.7	23348.3	62.1	63.1	346.7	348.6	21954.3	1060	148.3	16539.7	73.0
80	32	32	39	98.1	99.1	30.4	38.3	3151.4	79.1	80.1	35.3	48.1	2869.0	1640	13.5	2329.5	67.0
80	33	33	39	94.6	95.6	65.4	75.0	7044.0	78.7	79.7	76.7	77.8	6585.8	1600	30.7	5168.2	71.7
80	33	33	39	90.4	91.3	105.2	112.5	9728.3	78.5	79.7	119.1	121.4	9165.8	1560	50.8	8338.1	85.1
80	33	33	40	85.4	86.6	162.7	166.7	14500.6	78.5	79.3	173.9	176.2	13661.6	1520	74.8	11962.6	83.6
80	32	32	38	83.2	84.4	184.2	188.2	16126.3	77.2	78.0	193.1	196.3	15248.0	1480	83.9	13064.8	82.1
80	32	32	38	82.4	83.6	194.0	198.5	16854.0	75.5	76.6	204.4	208.6	15921.3	1440	89.7	13590.5	81.9
80	32	32	39	80.7	81.7	208.2	214.6	17534.6	73.8	75.0	221.0	223.9	16755.5	1400	95.1	14008.4	80.4
80	32	32	39	80.2	81.2	220.3	225.7	18422.7	72.7	73.8	234.0	239.7	17560.5	1360	101.6	14538.3	79.7
80	37	37	41	79.2	79.4	241.1	245.4	19621.3	72.0	72.9	255.4	256.5	18772.5	1320	107.6	14943.9	76.8

TABLE 10
"GENERAL ELECTRIC MODEL 5BY436A1
DC SHUNT MOTOR"
"GENERAL ELECTRIC EV-1 CONTROLLER"
(FIELD LOSSES = 66V x 11A = 726 WATTS)

GENERAL ELECTRIC SHUNT - FULL FIELD CHOPPED D.C. TESTS, 110-145°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 (%)
24	142	141	166	100.1	100.0	11.7	23.9	1148.2	24.3	25.7	38.9	43.0	1025.2	480	15.3	772.7	43.9
24	142	141	169	99.2	99.3	19.5	38.6	1874.2	24.3	26.1	67.2	72.0	1711.3	440	27.3	1263.9	51.6
24	141	141	171	97.4	97.9	31.8	59.4	2915.3	24.1	26.1	105.0	107.5	2682.0	400	44.2	1860.2	54.3
24	142	141	171	95.7	96.3	42.7	77.9	4131.2	24.1	29.9	144.4	149.3	3800.8	360	61.6	2333.3	51.3
24	141	141	169	93.1	94.3	68.4	117.9	5672.5	24.1	33.3	190.7	197.2	5059.2	320	80.8	2720.5	46.8
24	141	141	163	90.9	93.0	87.5	145.3	6898.7	24.0	35.3	230.1	236.5	6056.7	280	98.2	2893.0	42.5
24	140	140	159	88.3	90.9	114.0	180.0	8576.5	24.2	36.0	278.5	285.7	7269.5	240	117.8	2974.7	37.0
24	144	143	171	85.8	89.5	132.7	202.6	9577.0	23.9	36.1	306.3	311.8	7856.4	200	127.9	2691.4	31.2
36	134	133	149	98.5	99.4	12.3	22.6	1208.0	36.2	37.4	28.3	35.4	1108.9	760	10.6	847.6	46.0
36	134	133	149	97.2	97.9	27.1	45.2	2758.6	36.3	38.1	65.4	70.0	2547.9	720	26.3	1992.4	60.6
36	134	134	157	94.8	96.1	45.4	70.7	4228.2	36.3	38.8	102.6	107.5	4001.2	680	43.4	3105.1	65.4
36	134	134	153	92.5	93.8	68.5	101.3	5953.8	36.2	41.0	145.9	150.9	5670.3	640	61.4	4134.6	64.4
36	134	134	156	89.6	91.3	99.2	140.8	8081.3	36.3	43.6	193.0	200.1	7498.5	600	82.2	5189.2	62.8
36	134	133	153	86.3	89.2	124.9	172.6	9803.6	36.1	44.8	231.5	237.5	8926.3	560	99.0	5833.2	60.2
36	133	133	153	83.2	85.9	163.6	214.3	12090.6	36.1	44.5	279.9	286.2	10644.3	520	118.3	6472.4	56.7
36	131	131	155	79.5	82.7	200.9	254.5	14166.6	36.1	45.1	325.1	329.0	12316.6	480	136.3	6883.6	52.6
36	136	136	185	74.2	78.1	254.2	303.5	17227.2	36.4	46.4	364.2	367.9	14295.7	440	151.4	7009.0	46.5
48	139	138	165	98.2	98.9	9.8	17.2	969.6	47.6	48.6	18.5	24.9	890.5	1020	5.7	611.7	37.7
48	140	140	167	96.0	97.2	28.3	41.4	2963.3	47.7	49.1	53.6	58.0	2751.9	980	21.2	2186.0	62.6
48	139	139	168	93.8	95.3	50.4	67.0	4845.5	47.7	49.2	89.7	94.4	4506.1	940	36.4	3600.1	68.5
48	140	139	169	91.1	92.8	73.4	98.5	6771.9	47.5	50.0	126.8	132.7	6334.6	900	53.6	5075.6	71.6
48	140	140	171	88.4	90.3	103.8	134.0	8830.3	47.3	52.0	166.3	173.1	8359.6	860	70.7	6397.3	70.1
48	141	141	167	85.7	88.3	129.0	163.6	11069.5	47.6	54.1	203.3	208.9	10241.7	820	84.9	7324.9	66.5
48	142	142	166	82.0	84.4	168.5	205.2	13536.8	47.7	54.6	247.6	253.0	12442.6	780	104.2	8551.5	64.7
48	141	141	158	77.8	80.4	219.3	253.9	16074.8	47.8	53.7	301.5	304.3	14775.1	740	124.1	9662.4	62.1
48	138	137	155	72.2	74.8	280.0	309.7	19254.1	47.5	52.2	354.9	358.0	17450.6	700	146.2	10767.8	59.0
48	141	141	170	67.7	69.9	334.7	359.8	21793.7	47.6	51.6	394.9	393.6	19468.5	660	158.2	10985.8	54.2

TABLE 10 (cont.)
"GENERAL ELECTRIC MODEL 5BY436A1 DC SHUNT MOTOR"
"GENERAL ELECTRIC EV-1 CONTROLLER"
(FIELD LOSSES = 66V x 11A = 726 WATTS)

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GENERAL ELECTRIC SHUNT - FULL FIELD CHOPPED D.C. TESTS, 110-145°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	136	136	146	98.9	99.6	13.6	20.3	1503.0	63.9	64.7	20.0	24.7	1321.9	1380	6.5	943.8	45.9
64	137	136	149	96.3	97.2	36.3	46.3	3579.6	63.9	64.9	52.2	57.1	3295.6	1340	19.5	2749.3	68.1
64	137	137	151	93.2	94.4	63.2	78.8	6607.6	63.9	65.2	92.7	96.6	6289.1	1300	36.6	5006.2	71.1
64	137	137	153	89.4	91.1	101.4	116.5	9661.5	63.6	65.5	133.8	137.1	9027.1	1260	55.3	7331.2	74.8
64	137	136	153	86.1	87.9	137.9	159.1	13264.6	63.3	66.2	173.9	178.0	12359.4	1220	73.1	9383.3	71.4
64	136	136	152	80.6	81.9	196.3	214.4	16447.7	63.6	66.4	230.6	233.5	15449.0	1180	94.6	11745.0	72.3
64	136	136	153	75.5	76.7	257.8	267.0	19694.6	63.7	65.7	287.7	292.5	18684.8	1140	117.4	14081.6	72.2
64	136	136	152	72.4	73.1	296.6	304.6	21799.6	62.7	64.0	321.5	325.2	20605.6	1100	130.7	15126.9	70.6
64	136	136	153	71.2	72.1	317.1	319.9	22588.4	61.6	62.7	339.4	341.5	21351.8	1060	137.3	15312.9	69.1
64	139	139	164	69.3	70.8	325.2	331.3	22949.1	58.5	60.1	352.0	353.9	21141.1	1020	137.0	14702.8	66.9
80	134	133	125	97.9	99.1	12.3	17.0	1291.2	79.6	80.6	12.7	17.7	1122.6	1720	4.1	742.0	40.0
80	134	133	126	96.3	96.9	32.9	38.7	3476.1	79.5	80.4	38.5	42.7	3136.8	1680	14.8	2616.1	67.4
80	134	133	126	92.9	93.9	63.0	69.0	6709.2	79.5	80.4	76.7	79.6	6185.5	1640	31.0	5349.2	77.1
80	133	133	127	88.9	90.4	100.3	111.7	10292.2	79.1	80.3	116.1	121.0	9398.2	1600	47.4	7979.6	78.5
80	134	134	127	86.0	87.1	141.6	146.9	13390.1	78.7	79.8	150.7	154.5	12295.0	1560	64.5	10586.8	81.0
80	134	133	127	83.4	85.1	163.9	167.5	15189.0	78.1	78.9	174.8	177.3	13950.9	1520	74.4	11898.6	80.7
80	134	134	127	82.6	83.9	178.4	183.4	16168.4	76.9	77.6	190.7	193.3	14935.0	1480	80.9	12597.7	80.1
80	134	134	127	81.7	82.7	191.8	196.3	17004.8	75.6	76.6	203.6	207.0	15754.8	1440	86.6	13120.8	79.3
80	135	134	127	80.7	81.6	205.0	209.9	17918.9	73.8	75.0	219.2	221.7	16567.4	1400	92.7	13654.9	78.6

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16. Abstract

Both straight and chopped DC motor performance data for a General Electric 5BY436A1 motor with 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 approximately 85% at low operating temperatures in the straight DC mode. 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.

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