POWER CONTROL SYSTEMS	Document Number: A04733KC0	
	INITIAL RELEASE April 5, 1994	Last Page: 21

DOLPHIN
50KW VECTOR MOTOR
REQUIREMENTS SPECIFICATION

DOLPHIN REL ACTIVITY ORG CODE	RELEASED PRINT		
	— REV	4/14/94 REL DATE	REL BY

PCS/GMH PROPRIETARY
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1.0 INTRODUCTION

1.1 Scope of Document

This specification establishes functional, performance, design, test, manufacture, service and validation requirements for the Dolphin 50 kW Vector Motor component including encoder hardware and all associated connectors and harnesses.

1.2 Component Purpose

The purpose of this component is to generate the required shaft torque from input 3 phase power from the Dolphin Power Control Unit (PCU).

1.3 Classification

The 50 kW Vector Motor has no optional requirement and shall exist as only one type.

1.4 Usage Definition

This product is intended for use in light duty automobiles and trucks integrated with a PCU manufactured by Power Control Systems (PCS) Torrance, CA.

2.0 APPLICABLE DOCUMENTS

This section lists only those documents that are cited in this specification as sources of requirements that are imposed by this specification.

2.1 Order of Precedence

In the event of a conflict between the text of this specification and the documents cited herein, the text of this specification takes precedence. Nothing in this specification, however, supersedes applicable laws, or regulations, unless a specific exemption has been obtained and referenced.

2.2 Industry Documents

NEMA Class H Insulation Specification
IEC 529
CE 170
DIN 45665
Delco Serviceability Design Standards
GM Serviceability Design Standards

2.3 Hughes Power Control Systems Documents

2.3.1 Specifications

Dolphin Power Control Unit Requirements Specification - A04500KB0.

2.3.2 Drawings

1) A04733AA0 ; Motor Assembly
   a) A04712FX0 ; Cover, Motor Encoder
   b) A04713FX0 ; Gasket, Encoder Cover
   c) A04714FX0 ; Wire Harness, Encoder
   d) A04734AA0 ; Motor, 50kW
      i) A04734AA0-98 ; Label
      ii) A04734AA0-99 ; Motor, 50kW (detail)

3.0 REQUIREMENTS

3.1 Component Definition

The 50 kW Vector Motor shall be a three-phase, four-pole, AC squirrel cage rotor, induction motor. The motor shall be designed to provide the torque and power as required by the torque/power speed curve given in Section 3.2 of this document.

3.1.1 External Interfaces Description

The external interfaces for the 50 kW Vector Motor are shown in Figure 3.1.1-1, the 50 kW Vector Motor Functional Context Diagram, and defined in the following paragraphs.

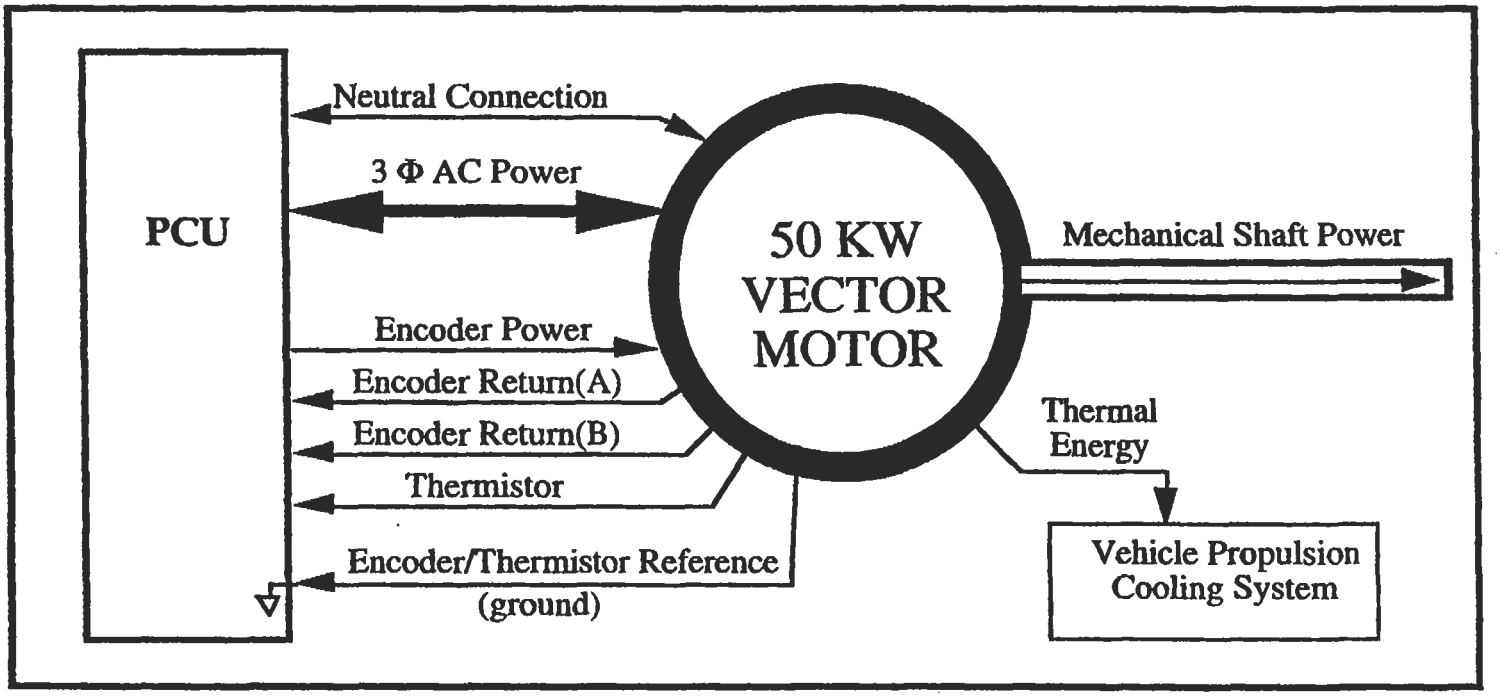


Figure 3.1.1-1 50 kW Vector Motor Functional Context Diagram

3.1.1.1 Power Control Unit (PCU)

The 50 kW Vector Motor shall accept high voltage, 3-Phase AC power from the PCU. The PCU is a voltage source current controlled inverter with 320 Volt nominal battery voltage, 400 Volts maximum. The inverter has a 10 to 18 kHz carrier frequency, with 0.5 to 600 Hz modulation frequency.

3.1.1.2 Vehicle Propulsion Cooling System

The 50 kW Vector Motor cooling system shall transfer the thermal energy to the vehicle propulsion cooling system.

3.1.2 Component Diagram

The 50 kW Vector Motor functional block diagram is shown in Figure 3.1.2-1.

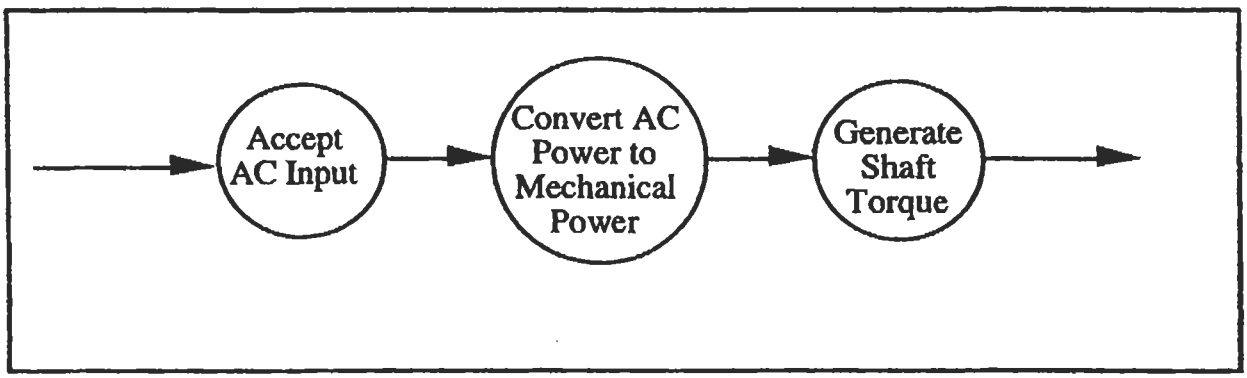


Figure 3.1.2-1 50 kW Vector Motor Functional Block Diagram

3.1.2.1 Accept Input High Voltage Three Phase AC

The 50 kW Vector Motor shall accept 3-phase, 120° out of phase, pulse-width-modulated, high voltage waveforms into its windings to generate the required magnetic field and subsequently output shaft power.

3.1.2.2 Shaft Torque and Power

The 50 kW Vector Motor shall generate a constant output shaft torque of 130 Newton-Meters from zero to 3600 RPM and thereafter maintain a constant 50kW output power up to 7500 RPM, provided the rated current and voltage is maintained.

3.1.2.3 Motor Winding Configuration

The 50 kW Vector Motor shall be wye connected with the neutral connection available.

3.1.3 Content Constraints

N.A.

3.1.4 Environmental Conditions

The 50 kW Vector Motor shall suffer no performance degradation when exposed to the following environmental conditions.

a. Operating temperatures from -40°C to 65°C.**
b. Storage temperatures from -40°C to 120°C.
c. GM 9985129 windshield washer solvent, SAE 1703 brake fluid, GM 6137 M Dextron II ATF or equivalent, GM antifreeze, GH 9985567 EHPS fluid, salt fog, surface water, jet spray, soapy water, alcohol based cleaner, and dust.
d. Humidity from 10 to 100% relative at 37°C.
e. Operational altitude of -131 to 2439 meters.
f. Storage altitude of -131 to 12,195 meters.

* Assuming liquid cooling inlet temperature is also within -40°C to 65°C.
* Temporary performance degradation is allowable under high temperature conditions, however, no permanent degradation shall result from the above listed temperatures.

3.2 Product Characteristics

3.2.1 Functional Performance

3.2.1.1 Motor Efficiency

The 50 kW Vector Motor shall meet the following efficiency requirements within the range of environmental conditions specified in section 3.1.4:

93% Minimum, @3600 RPM and 15 kW output
90% Minimum, @3600 RPM and 50 kW output

3.2.1.2 Power Factor

The 50 kW Vector Motor shall be designed to have a power factor of 0.85 minimum at 3600 RPM and 50 kW output power.

3.2.1.3 Maximum Motor Performance

The 50 kW Vector Motor shall generate a constant output shaft torque of 130 Newton-Meters from zero to 3600 RPM and thereafter maintain a constant 50kW output power up to 7500 RPM, provided the rated current and voltage is maintained. See Figure 3.2.1.3-1 for Torque and Power vs. RPM requirements.

3.2.1.4 Continuous Motor Performance

The 50 kW Vector Motor shall be designed to produce continuous Torque/Power equal to 40 N-M up to 3600 RPM, and 15 kW beyond 3600 RPM.

3.2.1.5 Motor Base Speed and RPM Rating

The 50 kW Vector Motor shall be designed to operate from 0 to 7500 RPM nominal, and up to 9000 RPM maximum (mechanical limit) with a base speed of 3600 RPM.

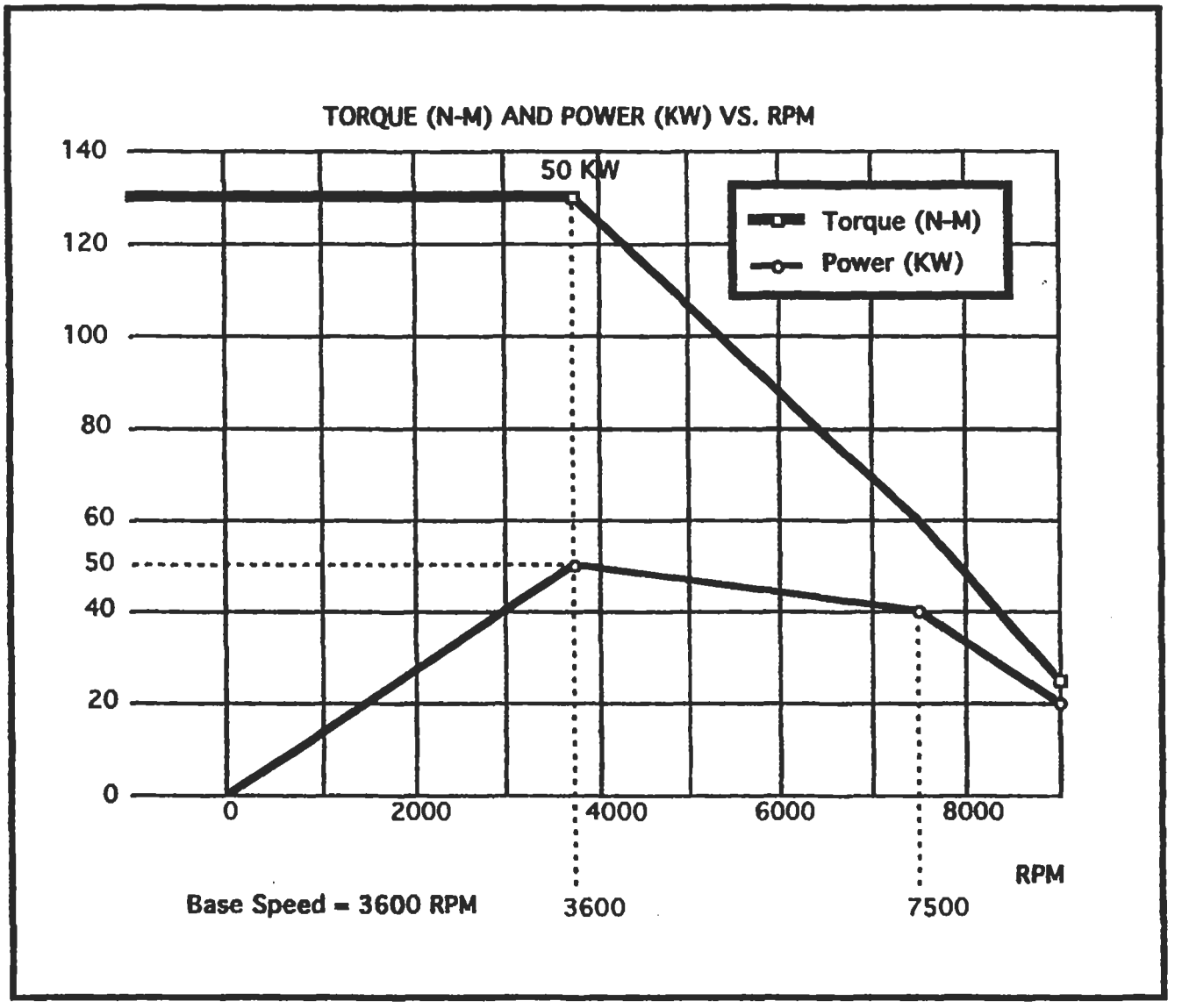


Figure 3.2.1.3-1 Motor Torque and Power vs. RPM

3.2.1.6 Torque Duty Cycle

The 50 kW Vector Motor shall be designed to produce a maximum output torque of 130 N-M for 30 seconds and 40N-M for 270 seconds at 3600 RPM as specified in Figure 3.2.1.3.3-1.

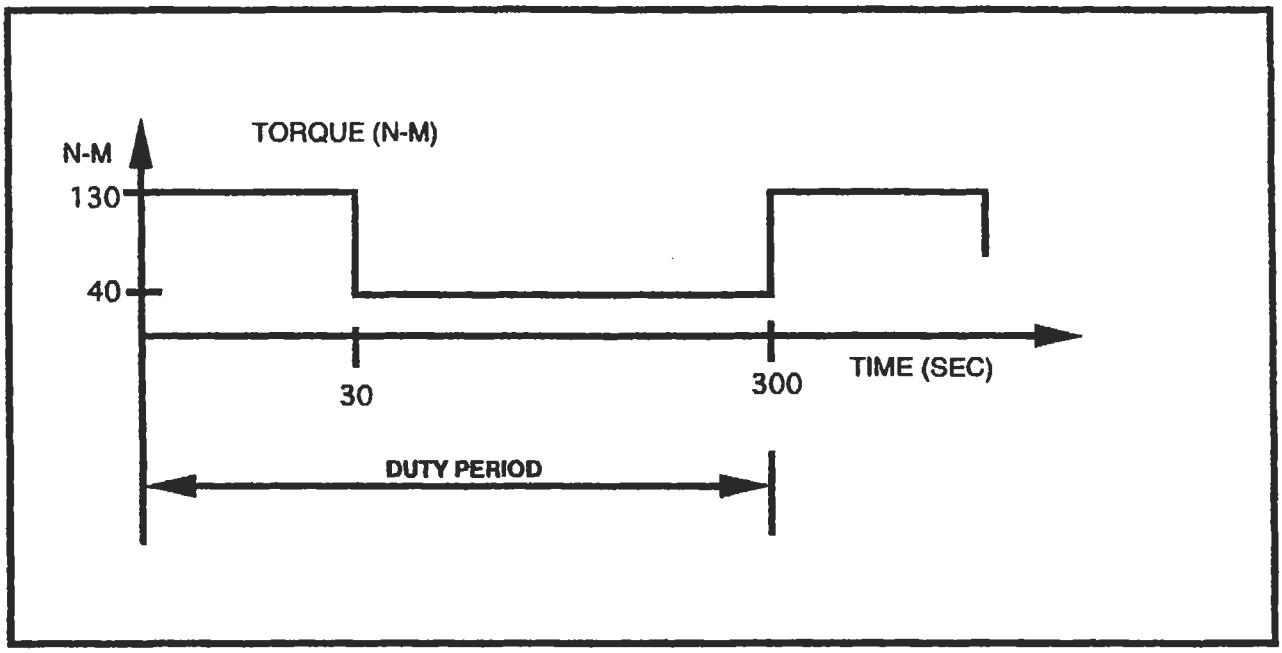


Figure 3.2.1.3.3-1 Motor Torque Duty Cycle at 3600 RPM

3.2.1.7 Shaft Power

The 50 kW Vector Motor shall be designed to produce peak shaft power of 50 kW at 3600 RPM for a duration of 30 seconds minimum and 15kW at 3600 RPM for 270 seconds as shown in Figure 3.2.1.3.4-1.

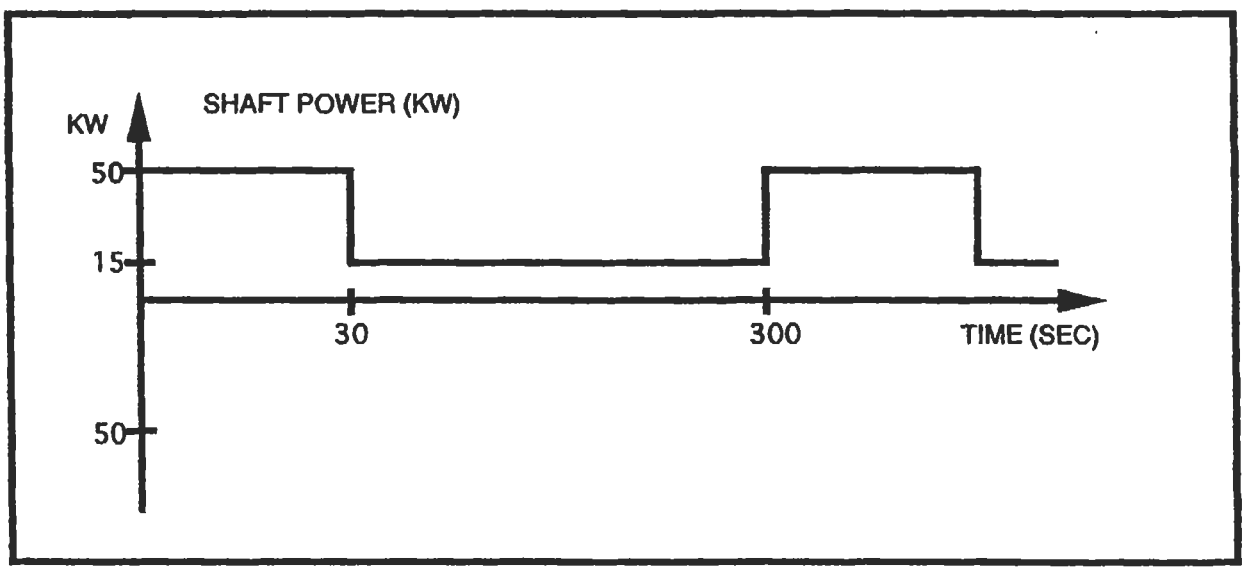


Figure 3.2.1.3.4-1 Motor Shaft Power at 3600 RPM

3.2.1.8 Balance

3.2.1.8.1 Static Balance
The rotor static imbalance shall not exceed 9.0 gr. cm.

3.2.1.8.2 Dynamic Imbalance
The rotor dynamic imbalance shall not exceed 4.5 gr. cm/plane.

3.2.1.9 Grade Angle
The 50 kW Vector Motor shall be designed to be tipped at any angle without fluid loss or degradation to performance or physical isolation (section 3.7) requirements specified herein.

3.2.2 Physical Characteristics

3.2.2.1 Dimensions
The 50 kW Vector Motor shall be designed according to the Outline and Mounting (O&M) Drawing No. A04734KX0. Dimensions are specified here for reference:

Outside Diameter:	270 mm maximum, including cooling jacket
Length:	388 mm maximum, including encoder housing and cable clearance of 28 mm

3.2.2.2 Mass
The 50 kW Vector Motor weight shall not exceed 60 Kg.

3.2.2.3 Thermal Requirements
a. The 50 kW Vector Motor shall be designed to be liquid cooled. The liquid (20% to 80% ethylene glycol & water) shall flow through an external case within the motor housing.

b. The 50 kW Vector Motor shall dissipate no more than 5000 Watts of thermal energy to the vehicle propulsion cooling system.

3.2.2.3.1 Pressure Drop
The inlet coolant passage to outlet coolant passage pressure drop shall not exceed 30 kPa at a flow rate of 16±0.5 liters/min. of 50/50 ethylene glycol/water coolant.

3.2.2.3.2 Maximum Pressure
The motor coolant passage shall be designed to withstand an operating inlet coolant pressure of 310 kPa without coolant leakage to external or internal interfaces or to the rotor cavity.

3.2.2.4 Color and Finish
The 50 kW Vector Motor shall be coated with an electrostatic epoxy or equivalent finish to meet the requirements of the environment described in this document.

3.2.3 Reliability

3.2.3.1 Operating Life
The operating life of the 50 kW Vector Motor shall be 5000 hours minimum. 2000 hours at the duty cycle shown in Figure 3.2.1.3.-1, and 3000 hours at 7500 RPM, at 15 kW of continuous power operation.

3.2.3.2 Safety Critical Failures
The probability of occurrence of a single point failure that jeopardizes the safety of the passengers, driver, or repair personnel, and/or causes severe irreparable damage to the vehicle and/or chargers shall be zero.

3.2.3.3 Failures of Motoring Function
The probability of a failure in the 50 kW Vector Motor that results in a failure of motoring function shall be minimized and defined as follows. A failure of motoring function is defined as failing performance requirements as documented in section 3.2.1, derated 10% of the values specified.

	Probability of Motoring Function Failure
at less than 4000 hours:	≤ .005
for duration of motor life:	≤ .040

3.2.4 Durability
The 50 kW Vector Motor shall be designed to withstand the shock and vibration as specified in this section.

3.2.4.1 Transit Drop Shock
The 50 kW Vector Motor shall incur no physical damage from the shock sustained due to a transit drop as simulated by dropping the 50 kW Vector Motor from a height of 122 cm onto a solid 5 cm thick plywood base backed by concrete or a rigid steel frame with the 50 kW Vector Motor properly installed in its shipping container. The drop shall be performed on each face, edge and corner of said shipping container.

3.2.4.2 Vibration

3.2.4.2.1 Minimum Natural Frequency
The minimum natural frequency of the 50 kW Vector Motor shall be 30 Hertz.

3.2.4.2.2 Non-Operational Random Vibration

3.2.4.2.2.1 Vibration During Shipping

The 50 kW Vector Motor shall be able to withstand the rail shipping without damage as simulated by subjection to the test spectra described in the following figure for 2 hours per axis at the indicated power spectral densities.

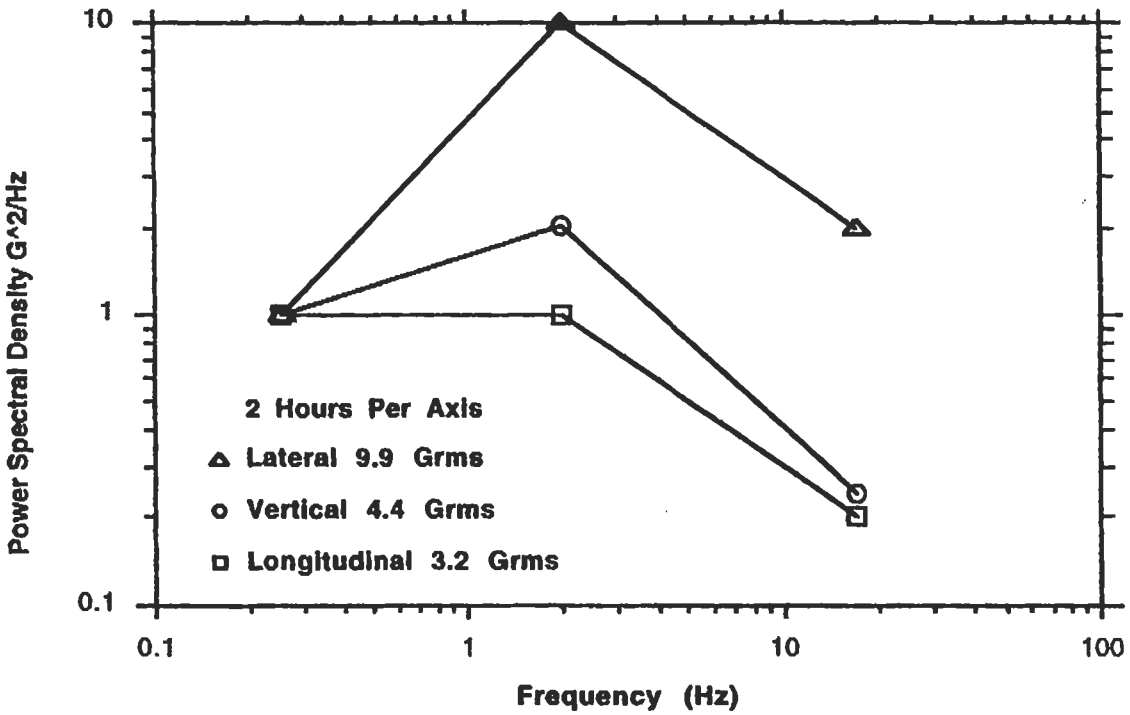


Figure 3.2.4.2.2.1-1 Random Vibration During Shipping Data

3.2.4.2.3 Operational Random Vibration

The 50 kW Vector Motor shall be able to withstand the operational (road and drive unit) random vibration without damage which shall be simulated by subjection to the test spectra described in the following figure for 2 hours per axis at the corresponding level.

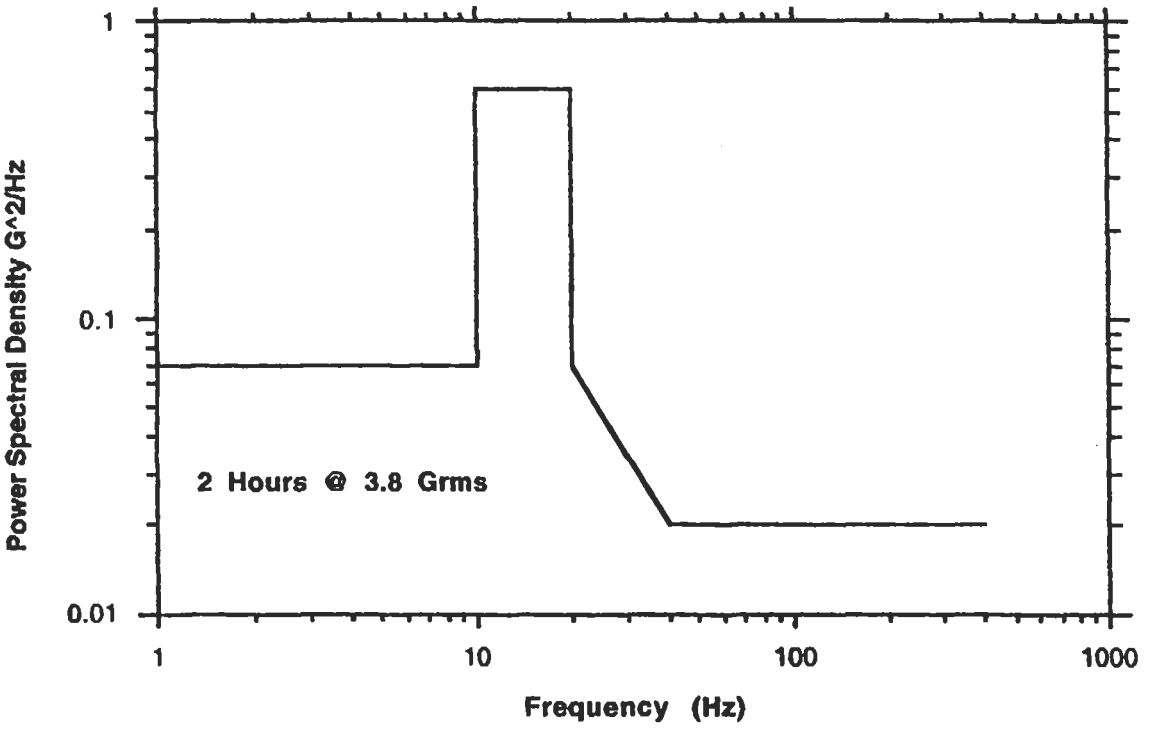


Figure 3.2.4.2.3-1. Operational Vibration, Vertical Vibration Data

3.2.4.2.4 Operational Sinusoidal Vibration
The 50 kW Vector Motor shall meet the vibration requirement per Section 3.2.4.2.3, Operational Random Vibration.

3.2.4.3 Drop Test
The 50 kW Vector Motor shall be designed to withstand a drop from a height of 250 mm to a solid concrete surface while oriented in either direction along any of its three perpendicular axis. This drop shall cause no damage to the motor's internal components or compromise the motor's functionality in any measurable manner.

3.2.5 Maintenance, Service, and Repair
The 50 kW Vector Motor shall be a Field Replaceable Unit (FRU).

3.2.5.1 Preventive Maintenance
The 50 kW Vector Motor shall require no preventive maintenance for the first 5000 hours of operation and shall subsequently undergo a preventive maintenance procedure designed by the manufacturer as specified following each usage interval equivalent to 3000 hours of operation at 7500 RPM and 12 kW (15.5 N-M of torque).

3.2.5.2 Service
The 50 kW Vector Motor shall be designed with removable endbells, rotor, and bearings using standard fasteners. All items must conform to uniform metric standards. A list of special tools for service or disassembly, including price, manufacturer, and quantity required shall be supplied to PCS.

3.2.5.3 Repair
Procedure and maximum repair cycle time 4 hours.

3.2.6 Safety
The 50 kW Vector Motor shall comply with the IP55 safety requirements.

3.3 Design and Construction

3.3.1 Bearing Class and Lubrication
The motor bearing type selection and lubrication shall be designed integral to the motor. Sealed, grease packed bearings shall be required.

3.3.2 Insulation
The 50 kW Vector Motor shall be triple insulated to NEMA Class "H" requirements.

3.3.2.1 Dielectric
The 50 kW Vector Motor shall be designed such that an applied voltage between any winding to ground of 1500 V_{RMS}, at 55±5 Hz, for a duration of 60±5 seconds, shall not cause any motor insulation deterioration or damage. The dielectric shall maintain a minimum isolation resistance of 3MΩ under application of 500 Volts DC between windings and ground for 60±5 seconds.

3.3.3 Enclosure
a. The 50 kW Vector Motor shall be totally enclosed with a shielded four wire (three phases, and neutral) "pigtail" power harness and a shielded five wire encoder harness.
b. The motor enclosure, pigtails, and pigtail interfaces shall be dust proof and water proof according to IEC 529 and CE 170 Classifications (or NEMA equivalents).
d. The motor enclosure shall meet the IP55 degree of protection.
e. All external metallic parts shall be protected from atmospheric agents described in 3.1.4.

3.3.4 Motor Housing Requirements
The following requirements apply to cast motor housings and end bells only. It is not mandatory for motors to be manufactured from cast components.

3.3.4.1 Material
The motor housing and end bells shall be cast from 356 Aluminum Alloy or equivalent. The castings shall be heat treated to T51 temper.

3.3.4.2 Quality Conformance

The castings shall meet all requirements of MIL-STD-2175, Grade D.

3.4 Documentation

The 50 kW Vector Motor shall be delivered with the following documentation in English with metric and MKS units:

a. All engineering drawings for assembly and fabricated items.
b. A copy of the internal requirements specification generated by supplier.
c. Motor acceptance test results for every motor delivered to Power Control Systems.

3.5 Support of Component After Sale

The 50 kW Vector Motor supplier shall comply with the following component support requirements after the sale:

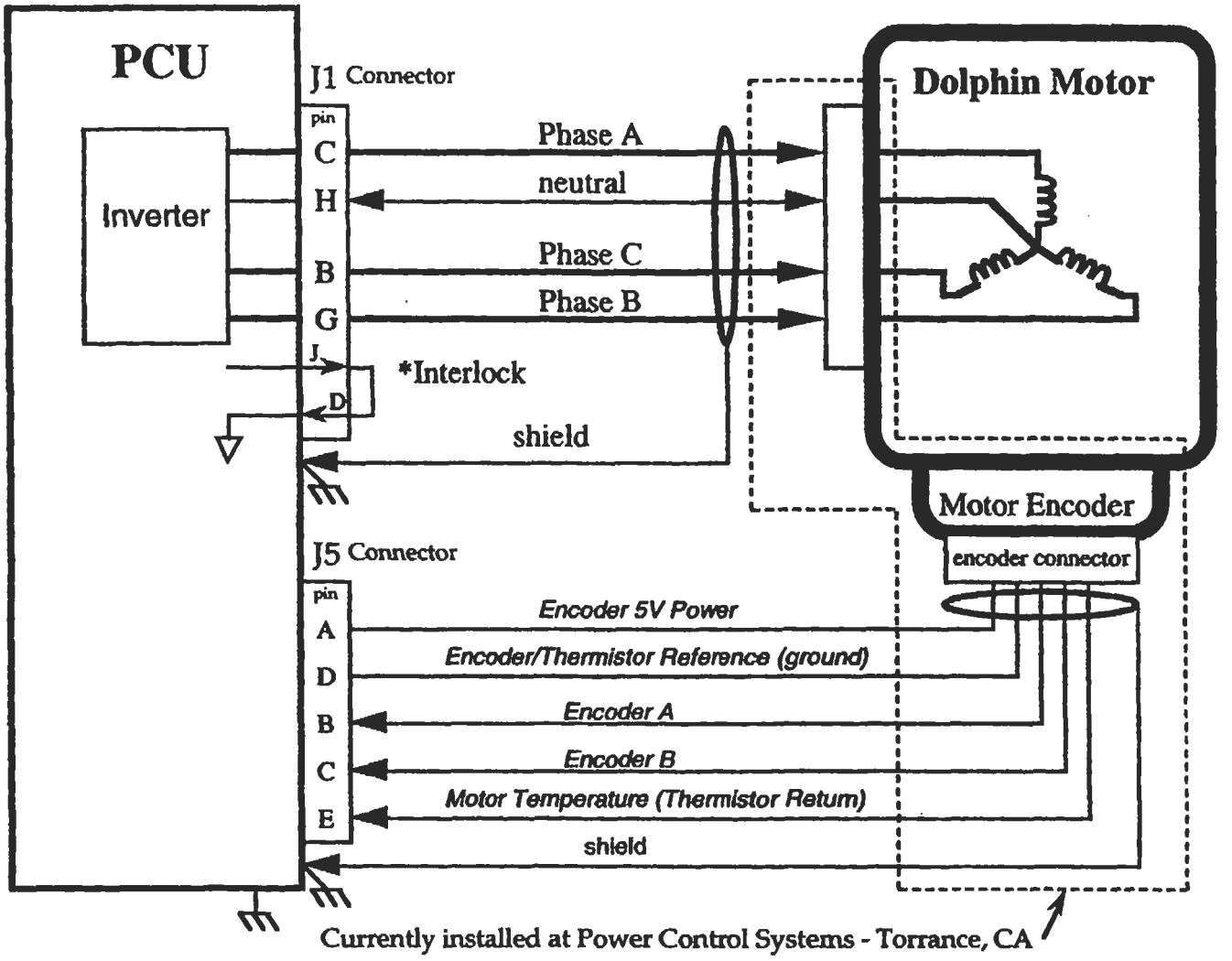
3.6 Component Operator Training

N/A

3.7 Component Implementation

3.7.1 Electrical Interface Requirements

The 50 kW Vector Motor external electrical interfaces are shown in Figure 3.7.1-1 and specified in this section.



* Interlock loop contained in mating connector

Figure 3.7.1-1 50 kW Vector Motor to PCU Interfaces

3.7.1.1. Motor Power Interface

The 50 kW Vector Motor shall accept variable, three-phase, AC power and shall provide a neutral for this power. The interface requirements for the three phase input and associated neutral connection are as follows:

Max. Input Voltage:	195 VAC Line to Line
Input Current:	0 ~ 200 Amps RMS
Input Frequency:	0 ~ 300 Hz
Max. Output Power:	50 kW (Mechanical Power)
Chassis Isolation:	> 3.0 MΩ/phase to chassis

The phase-to-phase electrical phase shift shall be 120° ± 0.6°

3.7.1.2. Motor Status Interface

The 50 kW Vector Motor shall be provided with 5V DC power and a reference ground. The motor shall use the provided power and reference, the rotating motor shaft, and the motor temperature to generate two encoder signals and one motor temperature signal as described in this section.

3.7.1.2.1. Encoder Power

Voltage:	5±0.5V DC w.r.t. Encoder/Thermistor Reference
Current:	0.25 A maximum

3.7.1.2.2. Encoder/Thermistor Reference

Voltage:	0±0.5V DC
Return Current:	0.5 A maximum

3.7.1.2.3. Encoder A & Encoder B

The motor shall provide two separate encoder signals. Encoder A and Encoder B shall be 50% duty cycle PWMs at 256Hz/revolution(of the motor shaft) to represent motor shaft speed. Encoder B shall be +90° out of phase with respect Encoder A to represent the motor direction of rotation.

Voltage:	0±.25 to 5±0.5V DC w.r.t. Enc./Therm. Ref.
Output Current:	100mA maximum
Output Frequency:	0 ~ 38.4 kHz(=9000RPM)

3.7.1.2.4. Motor Temperature

The motor shall contain a 10kΩ thermistor connected between the Motor Temperature signal and the Encoder/Thermistor Reference to indicate motor temperature.

Voltage:	0±.25 to 5±0.5V DC w.r.t. Enc./Therm Ref.
Current:	100mA maximum

Part number 10K3D232 made by Fenwal matches the desired resistance versus temperature transfer function requirement.

3.7.2 Mechanical Interface Requirements

3.7.2.1. Motor Power Interface (Motor Cables)

The shielded four-wire pigtail design requirements are as follows:

Size: 6 AWG in one bundle
(neutral wire may be 8 AWG)

Length, termination, shielding, etc. per drawing A04733AA0.

3.7.2.2. Motor Status Interface (Encoder Cable)

The shielded five-wire pigtail design requirements, length, termination, shielding, etc. are per drawing A04733AA0 and A04706AA0-A (Encoder Wire Harness).

3.7.2.3. Motor Ground

The 50 kW Vector Motor shall be designed to ground its chassis via a groundstrap connected to an end bell bolt or motor mount.

3.7.2.4. Connectors/Termination

There shall exist two (2) wired harnesses to the 50 kW Vector Motor. The termination connectors and their characteristics are listed in Table 3.7.2.3-1, 50 kW Vector Motor Connectors. These are provided for reference only.

Motor Power Harness (part of motor assembly part# A04731AA0)				
Connector to MOTOR J1		harness wiring	Connector to PCU J1	
Pin No. ; signal names	Part Number		Pin No. ; signal names	Part Number
motor harness hardwired to motor - no removable connector	n.a.	4 wire + shield Phase A Phase B Phase C Neutral	pin C; PHASE A pin G; PHASE B pin B; PHASE C pin H; NEUT(neutral) pin D; INTLKA(interlock) pin J; PINTLK(interlock)	CA08C0M-E28-A16PB-44 (CANNON)

Motor Encoder Harness (part# A04706AA0)				
Connector to MOTOR J2		harness wiring	Connector to PCU J5	
see encoder harness drawing for connector construction	drawing # A04706AA0	5 wire + shield 5 volts ground Encoder A Encoder B Temp.	pin A; P5V pin B; ENC1A pin C; ENC1B pin D; AGND (ground) pin E; MOTOR_A_TEMP	CA08C0M-E14S-5S-B-44 (CANNON)

Table 3.7.2.3-1 50 kW Vector Motor Connectors

3.7.2.5. Thermal Interfaces

a. The maximum inlet fluid temperature shall be 65°C.

b. The maximum inlet fluid pressure limit shall be 310 kPa (45 PSI), with a maximum pressure drop 30 kPa (4.4 PSI).

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Quality Control

4.1.1. Minimum Manufacturing Inspection Requirements
An Inspection and Acceptance control document for each motor shall be provided to PCS and maintained by the motor manufacturer. At a minimum this document shall contain the information shown in the following Inspection & Acceptance Document example.

Inspection & Acceptance Document (example)

inspection description	pass	inspector	date
Encoder side end bell			/ /
Load side end bell			/ /
Housing			/ /
Rotor shaft			/ /
Rotor casting			/ /
Stator winding			/ /
Stator Impregnation			/ /
Rotor balance and coating			/ /
Final assembly			/ /
Leak Test			/ /
Isolation Test			/ /
No load test			/ /
Rated load test			/ /
Maximum load test			/ /
NAME PLATE			/ /

4.1.2. Manufacturing Process Flow

The motor manufacturer shall create a Manufacturing Process Flow Chart with a quality control procedure and maintain this documentation for presentation to PCS.

Inspection level I. Component receiving

- Magnetic wire
- Housing
- Foundry process control
  - Gas porosity test
  - Strength test
- Mechanical tolerances
  - Rotor shaft
  - Bearing housing
  - Housing

Inspection level II, Sub assembly

- Winding and termination quality
- End winding fasteners, lacing tape
- Varnish and bake process, (Temperature, time, material)
- Motor cables and terminations

Inspection level III, Assembly

- Stator core insertion
- Gasket and sealer
- End bell attachments
- Cable attachment to the end bell
- Verify torque on the end bell bolts
- Rotor shaft rotation friction and axial movement

4.1.3 Minimum Acceptance Test Requirements

The following are the minimum test requirements for the motors to be purchased. Test 1. and test 2. must be a part of casting foundry quality assurance and inspection program. All the motors must be shipped with the following test data and compliance certification (Inspection & Acceptance Document see previous paragraph).

1. Pressure test the entire motor housing and fittings after the final assembly using deionized water or gas to 310kPa, (45 PSI). No leakage is allowed. The duration of this test shall be a minimum of 1 minute.

2. Pressure drop test the motor and fittings after final assembly using deionized water. The duration of this test is a minimum of 1 minute with a maximum deviation in pressure drop of +/- 10% at the rated flow rate of 4 gallons per minute +/- 10%.

3. Isolation test all motors ("High Potential" test). Test isolation of all connections to motor housing. Minimum isolation of 3.0 MΩ required.

4. No load test at the base speed of 3600 RPM with base voltage applied. Record all the terminal values.

5. Rated load test (15kW) at the base speed for a minimum of 2 minutes at ambient inlet temperature. Record all the terminal values.

6. Maximum load test (50kW) at the base speed for a minimum of 1 minute at ambient inlet temperature. Record all the terminal values.

4.2 Validation Test

The validation test is a one time test performed on finite number of the motors. These motors must be randomly selected from each production lot. The 50 kW Vector Motor shall be validated to verify conformance to the requirements specified in Sections 3.0 of this document. At minimum the IEC or NEMA guidelines need to be followed. The motors will be tested under the category totally enclosed drip proof type. Any failure of any motor undergoing validation test shall require immediate notification of PCS before disassembly of motor to allow PCS first inspection if deemed necessary by PCS. A comprehensive failure analysis must be performed and corrective actions shall be taken. Depending on the consistency of validation results PCS may require additional samples be validated. Following is a minimum test that shall be performed by the motor manufacturer.

1. Insulation and housing corrosion test, accelerated for equivalent of 5000 hours of operation. To be performed on 1 motor.

2. Fungus growth, accelerated for 5 years life equivalent. To be performed on 1 motor.

3. Rated load operation (15kW) at the rated voltage and speed. If 120 Hz supply is not available this test can be run at 50/60Hz utility supply with appropriate voltage and power level. Five (5) samples shall be ran for 5000 hours each or accelerated equivalent.

4. High temperature power cycle test the first 5 motors with the following power cycle schedule at the rated terminal values at base speed with inlet fluid temperature set at 65°C. Output shaft power of 50kW for 30 seconds and 15 kW for 4.5 minutes (5 minutes each cycle). Duration of this test is 25 minutes (5 cycles). The end bell temperature inside the encoder housing at the outer radius of the bearing must be recorded. The motor bearing temperature shall stabilize below 85°C during the test. Record all the terminal values. The bearing temperature measurement location is as marked on the inner edge of the encoder housing within the outer diameter of the bearing radius.

5. Power cycle endurance test (50kW for 30 seconds, 15kW for 4.5 minutes at base speed with 45 Degrees C. Inlet temperature). A minimum of 8 motor samples. If any of the units fail before the desired schedules, the test will be terminated.

24 hrs operation	48 Hrs operation	240 Hrs operation	until failure
unit 1	units 2 and 3	units 4, 5 and 6	units 7 and 8

5.0 PROVISIONS FOR DELIVERY

5.1 Shipping

The 50 kW Vector Motor shall be packaged according to the "50kW Motor Shipping Container" drawing, #A04733MB0, and shipped dry to PCS.

6.0 NOTES

6.1 Acronyms, Abbreviations, and Symbols

EHPS ..... Electro Hydraulic Power Steering
GMUTS ..... General Motors Unified Test Specification
Grms ..... gravitational root mean square
HPCS ..... Hughes Power Control Systems
HV ..... High Voltage
IEC ..... International Electrotechnical Committee
kPa ..... kilo Pascals
kW ..... kilowatts
N.A ..... Not Applicable
NEMA ..... National Equipment Manufacturers of America
N-M ..... Newton-meters
PCS ..... Power Control Systems
PCU ..... Power Control Unit
PWM ..... Pulse-Width-Modulated
RPM ..... rotations per minute
SAE ..... Society of Automotive Engineers
w.r.t. ..... with respect to