AMETEK, Inc.

Technical & Industrial Products

627 Lake Street
Kent, Ohio 44240

User's Guide

NUMBER 4930746

Low Voltage Brushless DC Controller
48140-00
48140-50 (RoHS)
20 Amp Motor/Blower Controller with DSP

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Proprietary Notice

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1.0 Introduction

This User's Guide will provide general information on the use and operation of AMETEK's Brushless DC controllers and their interfaces. Actual motor / blower performance will depend upon the specific controller model, motor characteristics, and the user's application.

AMETEK's Low Voltage Brushless DC Motor / Blower Control modules are a series of commutation, current limit, and speed control electronics that may be used to power a variety of brushless DC motors and blowers. These controllers are available with a wide range of options and most user-specific applications can be accommodated.

The electronics module utilizes a bi-directional, four quadrant "Speed Control" circuit. Speed control is achieved by pulse width modulating a 3-phase trapezoid waveform. The duty cycle of this waveform is controlled by the User's Input Command (AN/IN) voltage, or the voltage from an internal reference (POT1). The User's Input Command (AN/IN) or the internal reference voltage directly controls the duty cycle of the pulse-width modulated voltage applied to the motor phases.

Protection features include over-temperature sensing, cycle by cycle current limiting, and current limit shutdown. This control also features current and voltage limit in braking mode.

WARNING: THIS PRODUCT IS NOT NORMALLY OPERATED AT VOLTAGES THAT ARE CONSIDERED TO BE POTENTIALLY DANGEROUS! HOWEVER, AS IN ANY DEVICE USING ELECTRICAL POWER, FAILURE TO OBSERVE APPROPRIATE SAFETY PRECAUTIONS COULD RESULT IN SERIOUS BODILY INJURY, INCLUDING DEATH IN EXTREME CASES.

We recommend that adequate instructions and warnings by the Original Equipment Manufacturer (OEM) include labels clearly stating the precautions necessary for this type of equipment in the application.

WARNING: THESE CONTROLLERS OPERATE ONLY WITH DC VOLTAGE APPLIED AT THE INPUT TERMINALS. AT NO TIME IS AC VOLTAGE TO BE APPLIED TO THE INPUT TERMINALS. DAMAGE TO THE CONTROLLER IS ALMOST CERTAIN THIS IS DONE.

NOTE: Please refer to AMETEK Safety Bulletin number 4930700.

2.0 Electrical Performance Characteristics

DC Power Input:

Model(s) 48140-00(-50) can handle DC inputs of: 16-52 VDC (J2,2-3), with a maximum current of 20 Amperes continuous. Input voltage range is 11-18 VDC when J2 is set to position1-2. Operating the control with the jumper at the incorrect position relative to operating voltage may damage the control.

Note: Care should be taken to observe proper supply polarity when connecting power to the unit. Reverse voltage will damage the controller.

Connectors:

Rotor Position Sensors and User I/O (J4):

Molex P/N 15-42-7012 or equivalent. Molex P/N 22-56-6127 and P/N 16-02-0103 or equivalent may be used for mating connector housing and terminal.

Power and Phase Leads:
Screw type terminal block, Weco part number 150-A-111/05
Note: 10-18AWG wire range, maximum tightening torque is 0.5 N*m/4.5 lb*in

Ambient Temperature:

Operational: -20^{o}C to $+50^{o}$C Storage: -40^{o}C to $+85^{o}$C

PWM Frequency: 20 kHz

3.0 Installation

Interface:
Please refer to the Controller Hook-up Diagrams in Section 9.0 for model(s) 48140-00(-50). The commutation electronics allows for 60^{o} or 120^{o} commutation. See the Commutation Diagram in Section 10 for proper alignment of motor rotor position sensors and motor phases.

Use care when making initial power connections. Application of improper input power polarity or improper connection to the motor phase outputs may result in damage to the motor and possibly the control. Make sure that motor Rotor Position Sensor (Hall Effect) power and signals are properly connected. Ideally a current limited DC power supply should be used if you are not 100% sure about proper connection.

Power Input and Output:

Weco Screw Terminal Connector, J1:

Pin 1	Supply Ground Input
Pin 2	Motor Phase C Output
Pin 3	Motor Phase B Output
Pin 4	Motor Phase A Output
Pin 5	+V Power Input

Note: Connections are different than model 48134-00

Rotor Position Sensor and User I/O, Molex Dual Row Connector, **J4**:

Motor

J4

Pin 1	Ground return for Rotor Position Sensors
Pin 2	Rotor Position Sensor H1 Input
Pin 3	Rotor Position Sensor H2 Input
Pin 4	Rotor Position Sensor H3 Input
Pin 5	+Vreg Output (+12Vdc), used to power Rotor Position Sensors (Hall Effect devices), Note: This output is current limited at 8 mA.

Customer Digital I/O

J4-6 – Input Control operates normally with no input or J4-6 connected to signal ground. When J4-6 is connected to +12Vdc*, the control will brake until the motor stops. The control will limit braking to a level that keeps the bus voltage within acceptable limits (will not exceed 54Vdc). The control will also limit braking current. This will vary braking time depending on inertia of the load and motor characteristics. This input takes priority over all other run commands.

J4-8 – **Output** This output provides a +5Vdc signal that can be used as the supply voltage for a 3-wire potentiometer (Used with input J4-12 for speed control)

J4-9 – Input Output Enable

S2 Off - If there is no input or it is connected to ground, the control will run. When this input is connected to +12VDC*, the control will not operate.

S2 On- If S2 is ON, the control will operate when this input is connected to +12VDC* and will not operate if the input is connected to ground or left unconnected.

J4-10 – Input Direction Default input determines direction of motor rotation (looking into shaft end of motor)
CCW – Counter Clockwise CW - Clockwise
CW is enabled when input is not connected or connected to signal ground.
CCW is enabled when input is connected to +12VDC*.

J4-11 – Output Tach This output provides a +5Vdc square-wave signal that indicates motor speed. Motor speed can be calculated from the following equation.

FOUT (Hz) = (Motor RPM/120)(Motor Poles)

J4-12 – <u>Input</u> This input accepts a 0 to +5Vdc signal to control motor speed. This input can also accept the wiper of a 3-wire potentiometer for speed control (the potentiometer is also connected to supply pins J4-8 (+5Vdc) and J4-7 (ground).
Note: This input controls motor speed when DIP switch position 3 is OFF.

NOTE 1 Direction can be changed during operation.
The control will decelerate at a controlled rate and reverse direction without cycling power.

2 High inertia loads will be braked automatically. The control will measure bus voltage during braking and reduce the duty cycle if it exceeds a safe level.
The control will also limit braking current to a maximum of 20Amps.

***** 12VDC used as logic high is default. This can be changed to other voltages including the input power (+11VDC to +52VDC).

Jumper Settings:

J2 Position 1-2 for 11-18VDC operation.
J2 Position 2-3 for 16-52VDC operation **(closest position to terminal block J5).**
Caution should be taken. Misplacement of jumper setting could destroy the control.

<u>Dipswitch Settings</u>

The dipswitch is only initialized when power is turned on. Therefore changes should only be made when there is no power on the controller.

Electrical spacing of hall devices:

<u>Dip-switch S1 position 1 set to OFF</u>.
60 degree electrical spacing

<u>Dip-switch S1 position 1 set to ON</u>.
120 degree electrical spacing

Note: Electrical spacing does not indicate how many poles are on the rotor. Different commutation sequences are used for each setting. Sometimes a motor will run with the incorrect setting, however it will draw excessive current.

Output Enable:

<u>Dip-switch S1 position 2 set to OFF</u>.
Control will operate with **J4-9** unconnected (or connected to signal ground).
Control will not operate with **J4-9** connected to +12VDC*

<u>Dip-switch S1 position 2 set to ON</u>.
Control will operate with **J4-9** connected +12VDC*
Control will not operate with **J4-9** unconnected (or connected to signal ground).

Speed Adjustment:

Dip-switch S1 position 3 set to OFF.
User's Analog Input Command Voltage Range: 0 to +5 VDC linear.
Note: This input will withstand full supply voltage input, however maximum motor speed is reached at 5Vdc.
Optional: When external 0-5Vdc is used for speed control, POT1 can be used to set maximum current limit from 0-20amps. This is useful for motors that are rated at less than 20Amps continuous.

Dip-switch S1 position 3 set to ON
Internal Speed Set: Internal potentiometer (POT1) allows manual control of voltage applied to motor / blower. This is a 12 turn potentiometer. Turning the potentiometer in the clockwise direction increases speed (duty cycle). There is a linear relationship between the number of turns and motor speed.

Acceleration:

Dip-switch S1 position 4 set to OFF.
The control will accelerate the motor from 0 RPM to max speed within 1 second

Dip-switch S1 position 4 set to ON.
The control will accelerate the motor from 0 RPM to max speed within 10 seconds
This is useful for high inertia loads likes fans and pumps to prevent high starting current.

4.0 Operation

Prior to initial application of power, re-check all connections.

Speed Adjustment:

Various speed adjustment modes are available. The range of control will depend on the motor winding and power supply voltage. The frequency to voltage conversion ratio may be altered as required for specific applications.
In general, the module has been designed to operate with specific standard motors offered by AMETEK. The control electronics has a built-in potentiometer that may be used to directly control speed or the user may input an analog voltage to adjust motor speed.

Presently the voltage to frequency conversion allows for operation from a minimum of 100 RPM to a maximum of 24,000 RPM. If warranted, the speed control loop can be customized to better meet the end users requirements.

Internal Control:

This mode is selected when DIP switch S1, position 3 is in the ON position.
In this mode, no voltage is required at the Analog Speed-Input pin. The internal potentiometer (POT1) is connected to the drive electronics and may be used to directly control motor speed over the desired range. POT1 is a 12 turn potentiometer and has a linear speed/turn ratio (i.e. 1 turn CW increases speed by 1/12 full speed).

Potentiometer Fully Counter-Clockwise:	Motor off
Potentiometer Fully Clockwise:	Maximum Motor RPM

Analog Control:

This mode is selected when DIP switch S1, position 3 is in the OFF position.
In this mode, an analog signal between 0 to 5 VDC applied to the Analog Speed-Input pin (J4-12) and is used to control motor speed. There is a linear relationship between input voltage and speed (i.e. with 1V input the motor will be running at 1/5 of full speed)
Note: This input will withstand full supply input voltage, however maximum motor speed is reached at +5Vdc.

Analog Speed-Input Pin J4-12 = 5 Volts:	Maximum Motor RPM
Analog Speed-Input Pin J4-12 = 0 Volts:	Motor Off

When external analog speed control is used, the potentiometer adjusts current limit.
Current limit can be adjusted from 0 amps up to 20 Amps maximum.
Note: If you are not getting full performance from this control, the pot should be turned fully clockwise.
Full CW = 20 Amps current limit
Full CCW = 0 Amps current limit
It is a linear relationship between number of turns and current limit.
At 6 turns CW starting at full CCW gives 10 amps current limit.

Initial Power Up

With the Speed Command Input voltage set to minimum, or with the internal potentiometer set fully counter clockwise apply DC power to the unit. Increase the Speed Command Input voltage, or adjust the potentiometer to obtain the desired speed.

The Fout pin, J4-11, may be monitored with an oscilloscope to ensure motor rotation. The pulse width of this output will vary depending upon the motor and speed range selected. The circuit consists of an operational amplifier connected to a bipolar transistor that is current limited to a maximum of 8ma (0.008A). Motor speed can be calculated with the following equation:

$$\textbf{Fout (Hz)} = (\text{Motor RPM}/120)(\text{Motor Poles})$$

NOTE: For initial testing, the user may wish to apply main power with motor operation disabled using the O/E input on J4-9. With the unit disabled, use an oscilloscope to monitor the rotor position sensor inputs while rotating the motor manually to ensure that proper switching of these inputs occurs. Each input can be checked separately by connecting the scope between J4-1 (ground) and J4-2, J4-3 and J4-4.

5.0 Detailed Operation

Input DC power is applied to the power output stage and the internal, low voltage supply. The low voltage power source supplies the analog and digital circuits with approximately 12 VDC and 3.3Vdc for the DSP and associated circuitry.
The electronics module implements six-step commutation of the brushless DC motor using hall effect devices to detect rotor position. The hall effect signal is used to select which MOSFET transistors in the power output stage are turned ON to enable rotation in the desired direction. The hall effect signals are also used to generate a tachometer feedback signal that indicates motor speed.

The analog command input (AN/IN) may be used to adjust the motor speed. Dipswitch S1.3 determines whether the controller uses the AN/IN signal or the internal potentiometer. Switching frequency of the power MOSFET's on the power stage are set at 20 kHz. This frequency ensures good bandwidth and minimum current ripple in the stator.

A sensing resistor in the lower bus supply line is used to measure current. In Current Limit (C/L), the duty cycle of the PWM Modulator is shortened in proportion to the over-current condition and limits the peak current in the motor windings. With proper heat sinking, the controller is capable of operating in Current Limit indefinitely as long as the fault circuitry is not engaged. The fault circuitry will latch if a short circuit condition is detected. This occurs when the control detects a very fast rising current much higher than the maximum rated current limit (20Amps). A motor that fails with shorted windings or a direct short across the motor connection terminals on connector J5 usually causes this problem.
Care should be taken that the motor temperature does not exceed its design limits. A Negative Temperature Coefficient (NTC) resistor is mounted on the Power Output Stage heat sink. This device will shut down the Commutation and Control logic if the heat sink temperature exceeds approximately +105 to 110^{O}C. The control will automatically restart if the temperature goes below 95-100^{O}C. **Note: Always make sure power is off before attempting to work on the control or motor since it may be in thermal limit and can restart automatically once it falls below the restart temperature.** This feature is designed to protect the control from over heating and will not necessarily protect the motor. If the motor is rated at less than 20 Amps continuous it may overheat before the control in the event of an overload. It is useful to use an external speed control signal and use the on board potentiometer to adjust current limit to match the motors nameplate rating. Another method of protecting the motor is to use an external circuit that activates when the motor overheats. This circuit can be tied into the Output Enable to shut down the control.
Custom options are available that will not completely shut down the control. A couple of possibilities include reducing the PWM duty cycle so the motor draws less current or reducing the switching frequency to decrease losses in the control. These options can be added with custom software.

6.0 Application

Controller models that are ordered with AMETEK motors have been compensated to operate with those motors. In selecting the proper amplifier for any motor, several parameters are particularly important.

6.1 Maximum motor phase voltage- This parameter is jumper selectable by J2. Under no-load conditions, this voltage may be used to determine motor no-load speed. J2.1-2 for 9 to 18Vdc operation and J2.2-3 for 16 to 52Vdc operation.

6.2 PWM Frequency- The Controller has a nominal PWM frequency of 20 kHz. This value, combined with the motor inductance and maximum motor phase voltage, allows the user to calculate the ripple current in the motor.

6.3 Current Limiting- The Controller limits motor peak current to 20 Amperes when configured for internal speed command voltage with S1.3 on. (adjust with POT1). When the control is set up for external speed command voltage (S1.3 off), the current limit can be adjusted with POT1. This limiting feature, combined with the inductance of the motor, the maximum motor voltage, and the PWM frequency, determines the average current (torque) available. The stall or acceleration torque of a given motor is not simply the Amperes multiplied by the motor Kt. If the controller is held in current limit for a given amount of time, the controller will shut down. To restart, the controller power must be cycled. Note: The current limit can be pre-set to better fit the needs of the end user.
Note: Motor current is not equal to input current. Motor current is lower than input current when running at full voltage (100% trapezoid waveform). Motor current can be much higher than input current when the commanded speed is low (low PWM duty cycle) or when the control is in current limit.

6.4 Speed Control- The Controller implements a very simple PI loop. In applications with AMETEK motors, the loop is set to minimize overshoot based on the motor characteristics. If the user's application involves the addition of high inertial or frictional loads, a custom optimization may be necessary to reduce speed error or response time. For applications with high inertia loads, turning dipswitch S1.4 on can decrease the acceleration. Acceleration time is 10 seconds in this position and 1 second when S1.4 is off.
The overall acceleration time is from zero speed up to full speed.

6.5 Over Temperature- The controller is equipped with circuitry that will shut the controller down when the heat sink reaches a temperature of approximately 110°C. The controller power will resume operation when the heatsink temperature falls below 100°C.
Custom options are available that will not completely shut down the control. A couple of possibilities include reducing the PWM duty cycle so the motor draws less current or reducing the switching frequency to decrease losses in the control. These options can be added with custom software. **Note: Always make sure power is off before attempting to work on the control or motor since it may be in thermal limit and can restart automatically once it falls below the restart temperature.**

7.0 Troubleshooting

1) Unit Will Not Start

   a) DC Power not applied;

   b) Connector is miss-wired;

   c) Polarity of User Command Input is reversed;

   d) Motor is stalled, over-current condition exists;

   e) Power Output Stage heat sink temperature still exceeds +100^{O}C due to operating

point, ambient temperature, or both.

f) Output enable feature is active (J4-9)

g) Speed command voltage is zero or POT1 is fully counter-clockwise.

2) Unit Runs but Will Not Reach Required Speed

a) Motor or Controller is undersized for the application;

b) Internal pot is improperly adjusted;

d) Excessive friction on motor shaft;

e) Insufficient voltage at Speed Command Input;

f) Rotor Position Sensors or Motor Phases not properly connected.

g) Dipswitch S1.1 is set for improper electrical hall spacing

3) Unit Starts, Runs Briefly, then Stops.

a) Rotor Position Sensors or Motor Phases not properly connected.

b) Power Supply/Source is insufficient for load (Input Voltage sags).

c) Power Output Stage heat sink temperature still exceeded +100^{o}C due to operating point, ambient temperature, or both.

8.0 Thermal resistance of the Controls

Thermal testing was conducted in free space with no airflow across the control and no means of thermal conduction to another body. At 20 amperes (100% duty cycle) the control will radiate enough heat to allow it to function in a 50°C ambient in free space without tripping the thermal latch. The current rating of this control is based on RMS motor current, not input current. If the control is operating in PWM mode the motor current may be higher than input current. The control will operate at higher temperature in this situation since there are higher losses due to switching the power transistors. Operation at 20 motor Amps in PWM mode may require an additional heatsink. Ametek part number 5-7300 was designed to allow increased operating current in elevated ambient temperatures.

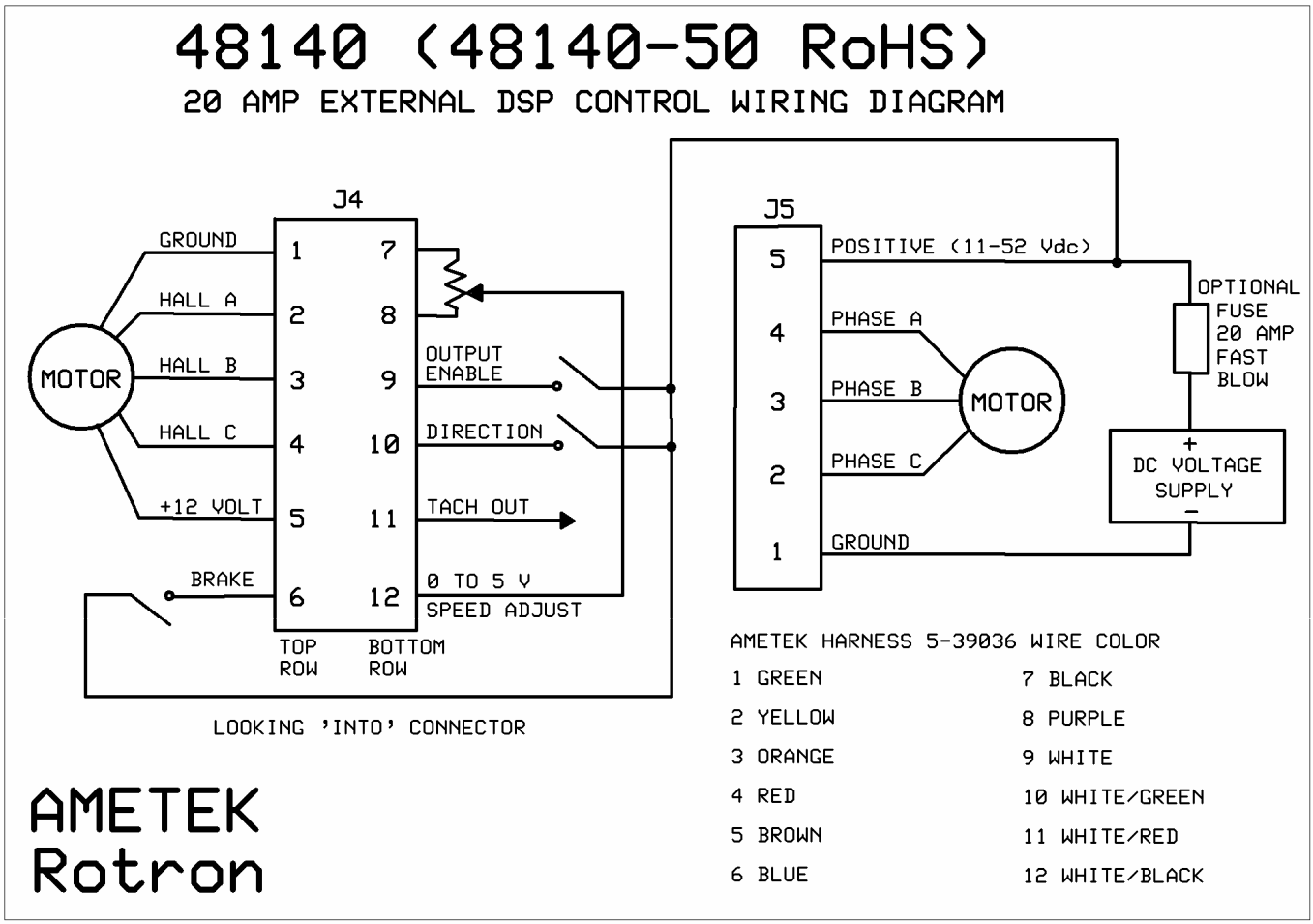
As a rule of thumb, the thermal resistance of the IMS (Insulated metal substrate) heat sink is 5°C/W. There are three sections that add to the conduction losses in the IMS material. First, there are the power MOSFETs. There are always two MOSFETs conducting at any one time. The power losses are calculated by I^2 * $Rds_{(on)}$ * thermal slope of the part. The case temperature of the MOSFETs will approximate the temperature of the IMS material. Another significant source of heating occurs when the control is operating in PWM mode. At 75% on time, the MOSFET's will be generating more than twice as much heat due to switching losses in comparison to conduction

losses. Therefor it is useful to design for maximum operation of the system such that the motor is operating at 100% on time. Second, the current sense resistors power drop can be calculated by (0.025 /4 resistors) * I^2. The third and final component is the generation of the logic voltage. This power drop can be calculated by (Vbuss – 12.3) * 0.05.

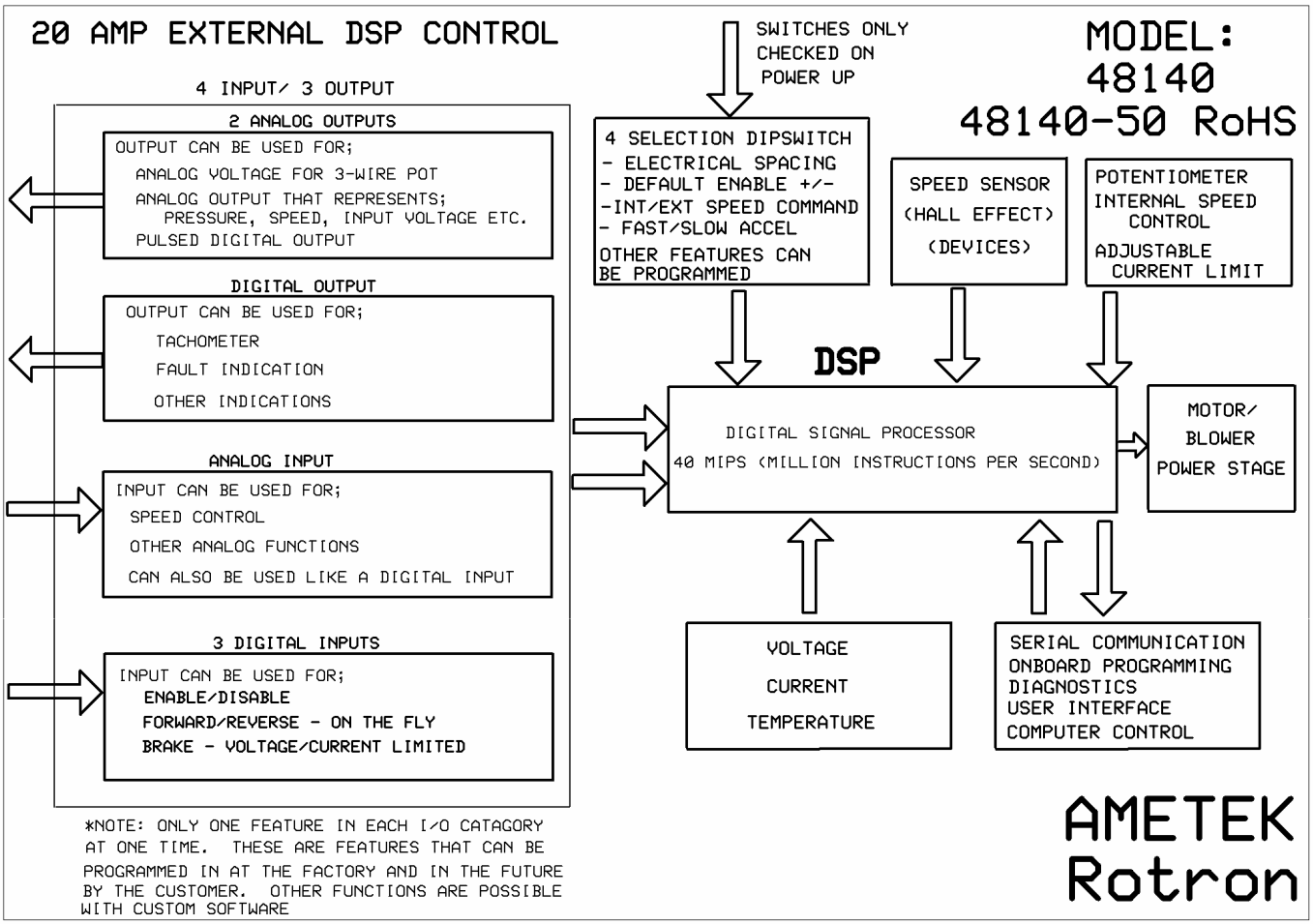
Note

All information presented is with the control floating in free space. The thermal model provided is for a point of reference only. Each application should be tested to ensure proper thermal management.

WIRING DIAGRAM



Overview of capabilities for custom software



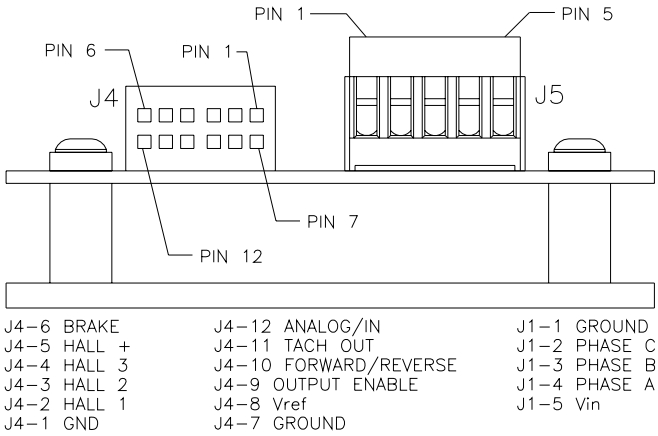
Specifications

Controller Model: 48140

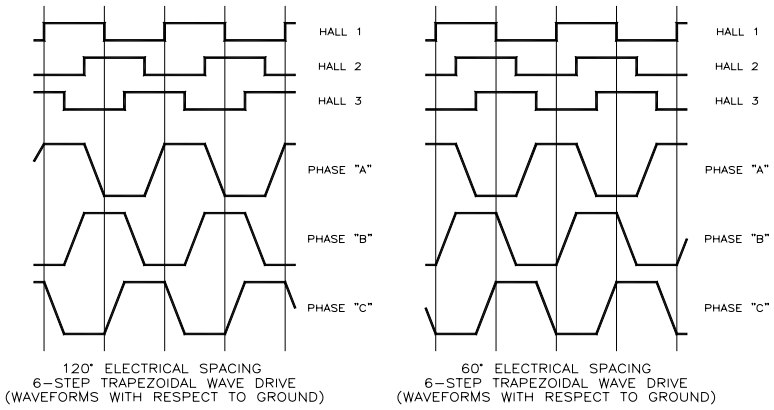
Description: 20A* Motor/Blower DSP Controller

Operating Parameters:
Input Voltage Range: 11-18 VDC and 16-52 VDC (Optional 60V)
Maximum Cont. Current: 20A* **Analog Speed Input:** 0-5VDC, 2K-20K Pot
Operating Temperature: -20°C to +50°C **Storage Temperature:** -40°C to +85°C
PWM Frequency: 20KHz **Thermal Trip**: 100°C (or programmable)

*Note: Max. Input Current at 100% on time, no PWM.



Connection Diagram



Commutation Diagram

Digital I/O

J4-8 – Output Default input enables braking

Control operates normally with no input or J4-6 connected to signal ground.
When J4-6 is connected to +12VDC*, the control will brake until the motor stops.

J4-8 – Output This output provides a +5VDC signal that can be used as the supply voltage for a 3-wire potentiometer (Used with input J4-12 for speed control)
Note: This pin will source 10mA maximum.

J4-9 – Input Default is Output Enable (OE)
S1.2 Off - If there is no input or it is connected to ground, the control will run.
When this input is connected to +12VDC*, the control will not operate.
S1.2 On - If S1.2 is ON, the control will operate when this input is connected to +12VDC* and will not operate if the input is connected to ground or left unconnected.

J4-10 – Input Default input determines direction of motor rotation (looking into shaft end of motor)
CCW – Counter Clockwise CW - Clockwise
CW is enabled when input is not connected or connected to signal ground.
CCW is enabled when input is connected to +12VDC*.

J4-11 – Output This output provides a +5VDC square-wave signal that indicates motor speed. Motor speed can be calculated from the following equation.
Fout (Hz) = (Motor RPM/120)(Motor Poles)

J4-12 – Input This input accepts a 0 to +5VDC signal to control motor speed. This input can also accept the wiper of a 3-wire potentiometer for speed control (the potentiometer is pins J4-8 (+5VDC) and J4-7 (Ground) also connected to supply.

NOTES:

1. Direction can be changed during operation.
   The control will decelerate at a controlled rate and reverse direction without cycling power.
2. High inertia loads cannot be braked too quickly. The control will measure bus voltage during braking and reduce the duty cycle if it exceeds a safe level.

*3. 12VDC used as logic high is default. This can be changed to other voltages including the input power (+16VDC to +52VDC).

Jumper Settings: ***Controller preset with J2 set for 16-52VDC operation.

J2 Position 1-2 for 11-18VDC operation.
*J2 Position 2-3 for 16-52VDC operation (closest position to terminal block J5).

CAUTION! Misplacement of jumper setting will destroy the control!

DIP Switch operation, S1.1-S1.4

Note: Controller preset with all DIP-Switches OFF

S1.1 OFF (default) – 60 degree electrical spacing
S1.1 ON - 120 degree electrical spacing (see commutation diagram above)

S1.2 OFF (default) – Control will operate with **J4-9** unconnected (or connected to signal ground).
S1.2 ON - Control will operate with **J4-9** connected to +12VDC* (see digital input 3 above)

S1.3 OFF (default) – External speed control input (**0-5VDC on J4-12**).
S1.3 ON - Internal speed control. Speed is increased by turning **POT1** CW.

S1.4 OFF (default) – Fast acceleration/deceleration (2 second ramp from stop to 100% duty cycle)
S1.4 ON - Slow acceleration/deceleration (10 second ramp)
(ramp rates can be customized at the factory)

Interface Connector J1:

J1 is used at the factory to program the DSP and provide diagnostic test and setup.
J1 can be used to update software or download custom software.

