Hybrid

Electric

Explore our Technologies

AC Motor Controller Gen5-S9, v1

Reference Manual

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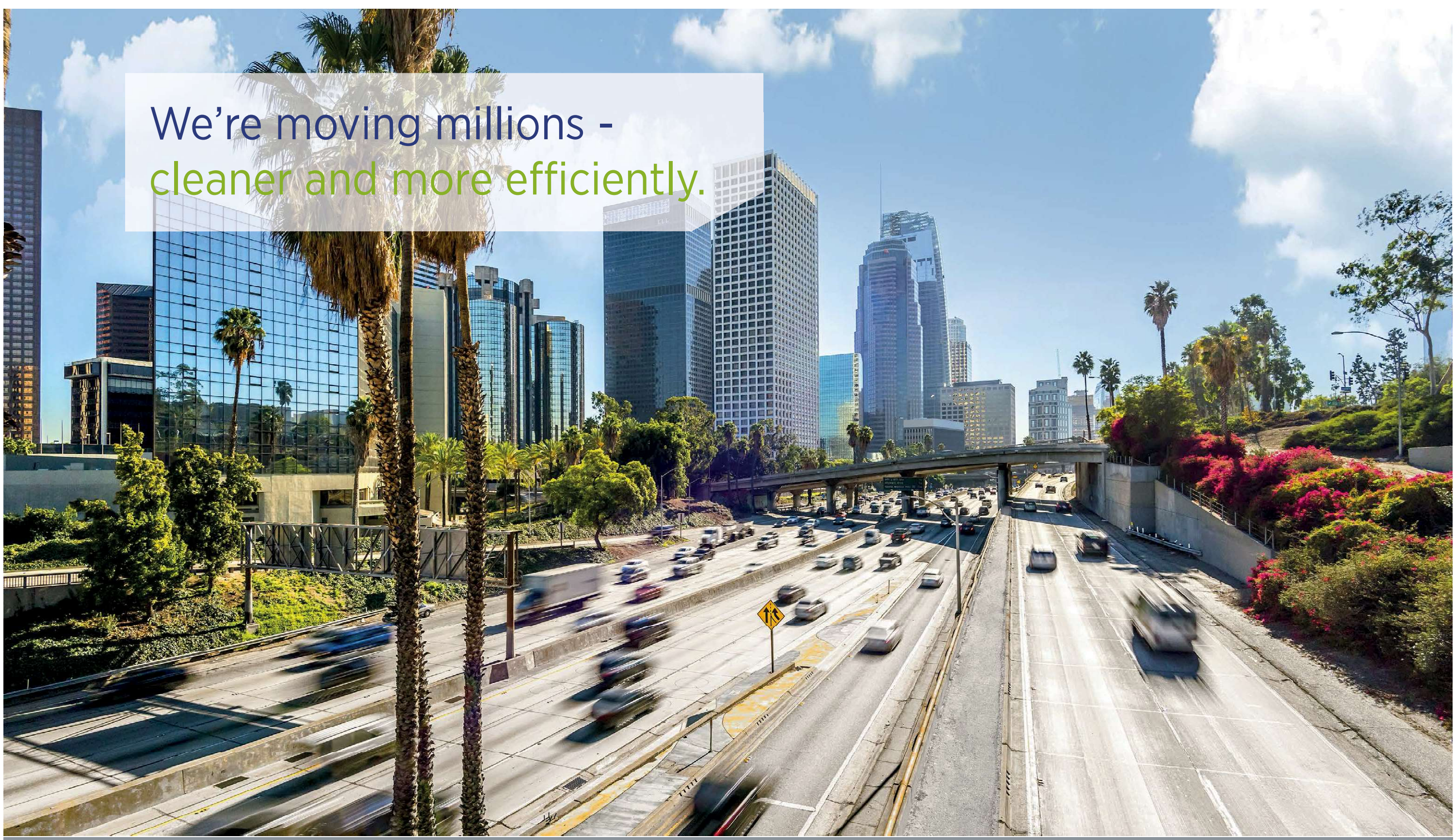
Contents 1 of 2

BorgWarner

Contents 2 of 2

Hybrid

Electric



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1

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2
Introduction

Reliably delivering what's needed today

There are few challenges as important today as creating solutions that support a cleaner, more energy-efficient world. This requires a commitment to constantly improve the transportation of people and things. We, at BorgWarner, made that commitment decades ago and have since been creating technologies to improve efficiency, emissions and performance in all types of vehicles.

Constantly pursuing what's next

Our proven track record has made us propulsion system leader for combustion, hybrid and electric vehicles. We uncover strong trends and use smart science and technology to address a future based on varying regulations, consumer demands and automaker requirements.

Product leadership that's changing the world

Our employees have earned trusted partnerships with customers and suppliers around the world. We leverage these relationships to gain a deeper understanding of the challenges at hand and then do what it takes to develop the next solution. Our strong operations and commercialization expertise result in high volume availability of competitive, efficient products that truly drive change.

BorgWarner enables the switch - to highly efficient electric drives.

Introduction

2.2 About BorgWarner's Technologies

Transforming vehicles to more fuel efficient, cleaner technologies requires a collaborative partner who understands the evolution of mechanical to electric systems. Our expertise in both provides the critical underpinnings of efficient and powerful propulsion. Integrating electronics into the mechanical system is the key to performance, packaging and cost. This is evidenced across a full line of our combustion, hybrid and EV products for light vehicles, medium & heavy duty vehicles as well as off-highway applications.

2.3 Purpose of this Manual

To support decision-makers, the first four chapters of this manual are intended to provide an overview of the Gen5-S9 motor control product, and where this product could be applied.

The installation instructions in this manual, which have been written for qualified automotive electrical and mechanical installation engineers, presents the basics of installing the Gen5-S9 motor controller. Guidance is provided to support engineers when configuring motor control systems, sizing a motor, and selecting system components, options and accessories. The installation instructions are housed in chapters five to eight.

Please pay special attention to the information relating to warnings, cautions and notes when they appear in the manual. For a full overview, please refer to section 5.1.

Custom Code and Comms support available on request.
Please contact us for further information.

Contact us at: motorcontrol@borgwarner.com

Introduction

2.4 Document Conventions

The following conventions are used within this document.

Convention	Description
	A **warning** is an instruction that draws attention to the risk of injury or death and tells you how to avoid the problem.
	A **caution** is an instruction that draws attention to the risk of damage to the product, process or surroundings.
	A **note** indicates important information that helps you make better use of your BorgWarner product.
Illustrations	Orthographic illustrations are drawn in third angle projection.
Units	SI units are used throughout.
Bold text	Used in procedures for names of interface elements, such as names of buttons, fields, and tabs. Also used to introduce a procedure.

Introduction

2.5 Our Controllers - An Overview

BorgWarner controllers are designed to control the following motors, in battery and generator-powered applications:

- 3-phase AC induction motors
- 3-phase permanent magnet AC (PMAC) motors, both surface and interior magnet

The controller adapts its output current to suit the loading conditions and the ambient temperature in which it is operating - temporarily shutting down if necessary. As a safety feature, the controller will protect itself if the low voltage circuits are incorrectly wired.

Signal wiring and power connections are designed to be as simple and straight forward as possible. Analog and digital signal inputs and outputs are provided for switches, sensors, contactors, hydraulic valves and CAN communications. The controller can be configured to share its I/O, share its results or take commands from other controllers or displays on the CAN bus.

Configuration and control of BorgWarner controllers is fully-customizable. For a bespoke solution, please contact us for further information.

3

About

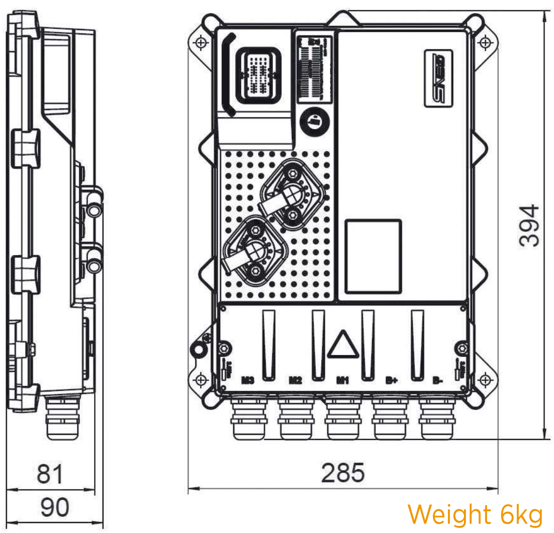
AC Motor Controller Gen5-S9

AC Motor Controller Gen5-S9

3.1 Overview of Specification

The Gen5 range of motor controllers utilise a highly-flexible control logic architecture to deliver a unique feature-rich set of functions and is well-matched to satisfy automotive, commercial and construction markets' electrification needs. The range of High Voltage High Power (HVHP) controllers is specifically aimed at vehicle OEMs and system integrators to offer them a compact, lightweight, robust and cost-effective, class-leading suite of solutions covering traction, hybridisation, power generation and sub-system electrification.

Dimensions



Weight 6kg

Intelligent I/O

The Gen5-S9 includes a fully-integrated set of inputs and outputs designed to handle a wide range of vehicle functions.
This eliminates the need for additional external I/O modules or vehicle controllers and connectors.

- All I/O protected to 40V
- 4 analog inputs 0 – 10V allowing for easy configuration of dual throttle and dual brake applications
- 2 PT1000/KTY84 ~~thermocouple~~ input
- 4 digital inputs
- 4 digital outputs PWM 2A (2 high side 2 low side)
- 3 programmable encoder power supplies (1x200mA 2x100mA voltage configurable)

Key Parameters

- Operating voltage range 128V to 450V, with derating after 420V
- Size 9
  - 450 Arms (1 min)
  - 200 Arms (1 hour+)
- Safety
  - Tested to EMC Reg. 10
  - Passive HVIL safety functionality
- Environmental
  - –40°C to +85°C operation, IP6K9K, ISO 16750
  - Coolant flow rate Water/Glycol 10l/minute de-rating starts 55°C
- Motors and Encoders
  - The Gen5-S9 architecture supports the majority of the industry standard motor and sensors types allowing a great deal of application flexibility, including resolver input AB, UVW and Sin/Cos encoder input

Versions to support ISO 26262:2011 ASIL C and electrical safety to ISO 6494 and IEC60664 available for OEM projects.

For futher information, please contact us:
motorcontrol@borgwarner.com

Smart Communications

Using 'custom code' functionality allows the communications protocols and data contained within the messages to be modified specifically for your application. For bespoke solutions, please contact us for further information.

Note: key parameters can vary, depending on controller set-up, environmental conditions and motor conditions

AC Motor Controller Gen5-S9

3.2 Compatible Motors

BorgWarner motor controllers can be used in many applications, such as; on-road four-wheel electric vehicles, off-road ATV, utility vehicles and burden carriers, hybrid vehicle systems and electrification of vehicle power train.

Our motor controllers will function with most AC Induction, PMAC SPM and IPM motors, but we recommended the High Voltage Hairpin, HVH250 family of BorgWarner Remy-branded motors.

For all other motors, please check with your supplier to ensure compatibility.

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3.3 Product Warranty

Please refer to the terms and conditions of sale or contract under which the Gen5-S9 was purchased for full details of the applicable warranty.

Notes:
Within the agreed warranty period and terms, credit will be given only after return and confirmation of BorgWarner liability. The customer is required to supply conditions during failure, and any other information required to verify the reported defect.

Do not attempt to open the controller.
Opening the controller may lead to risk of high voltage exposure and associated risks, including death.

There are no serviceable components. Opening the controller will invalidate the warranty.

Do not mechanically modify the controller in any way, as unexpected damage may occur. Mechanically modifying the controller will invalidate the warranty.

4
Performance

Performance

4.1 Motor Speed and Frequency

Overview of maximum motor speeds and frequency

Maximum Motor Speed

There are many factors influencing the maximum motor speed that can be controlled. Some of the key factors are:

- Number of magnetic poles
- Harmonic content of motor (any non-sinusoidal back emf)
- Encoder accuracy and noise
- 'Sensitivity' of motor (including inductance)
- Required tolerance of torque ripple

A typical range of achievable maximum motor frequency is 600Hz to 1000Hz, however frequencies above 1000Hz can sometimes be achieved if key factors are well managed.

An example of motor speeds and frequencies:

- 5 pole pair PMAC motor:
    - Applied frequency of 600Hz = motor speed of 7,200rpm
    - Applied frequency of 1000Hz = motor speed of 12,000rpm

As speed, and hence frequencies, become too high, degradation of the current control will occur.

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5

Electrical Ratings

Electrical Ratings

5.1 Warnings and Cautions

Electric vehicles can be dangerous. All testing, fault-finding and adjustments should be carried out by competent personnel. The vehicle manufacturer's manual should be consulted before any operation is attempted.

The battery or DC power source must be disconnected before replacing the controller. After the battery has been disconnected, wait until the internal capacitors are fully discharged (<1V) before handling the controller or working near exposed terminals. Please refer to the chart on page 59, which illustrates discharge time.

Never connect the controller to a battery with vent caps removed or a generator with an open fuel tank as an arc may occur. This is due to the controller internal capacitance when first connected. Gen5-S9 does not have any built-in pre-charge and so direct connection could result in very high in-rush currents and arcing across contacts in the supply path.

Do not attempt to open the controller. Opening the controller may lead to risk of high voltage exposure and associated risks, including death. Do not attempt to open the controller as there are no serviceable components. Opening the controller will invalidate the warranty.

Use cables of the appropriate rating and fuse them according to the applicable national vehicle and electrical codes.

Where appropriate, use of a suitable battery in-line contactor should be considered.

Electric vehicles are subject to national and international standards of construction and operation which must be observed. It is the responsibility of the vehicle manufacturer to identify the correct standards and ensure that their vehicle meets these standards. As a major electrical control component, the role of the motor controller should be carefully considered and relevant safety precautions taken. BorgWarner controllers have several features that can be configured to help the system integrator to meet vehicle safety standards.

The vehicle manufacturer must ensure that an appropriate controller configuration is set to ensure the vehicle remains in a safe condition, even in the event of a fault.

Electrical Ratings

5.2 DC Link Supply

The DC supply is connected through a main contactor to the terminals on the controller.

The Gen5-S9 inverter does not have high voltage pre-charge circuitry built in. Pre-charge must therefore be provided externally, on a system level. This is most typically provided by a battery pack and it's Battery Management System.

Nominal working voltage	350V
Operating voltage range	50-400V max output, 400-450V reduced output
Over-voltage hardware trip level	>475V, Software over-voltage trip level 460V. Permanent damage to the unit may occur above these voltages.
Current measurement accuracy	5%
DC link capacitance	640µF
Polarity protection	You must ensure that reverse polarity protection is provided external to the controller. For example, by control of the main line contractor.
Pre-charge	Must be controlled externally.
Ground fault protection	You must ensure that ground fault protection is provided externally to the controller. For example, by control of the main line contractor.

You must provide reverse polarity protection externally to the controller, for example, by control of the main contactor. Failure to do so will permanently damage the controller.

You must provide ground fault protection externally to the controller. If you fail to do this, dangerous voltages may be present that could lead to injury or death.

Electrical Ratings

5.2.1 Wire Size

When deciding on power cable diameter, consider cable length, grouping of cables, the maximum allowable temperature rise, and the temperature rating of the chosen cable.

Cable sizes between 35mm^2 and 70mm^2:

Average current (rms)	Cable size	
175A	35mm^2	AWG 2
200A	70mm^2	AWG 0

Table 1: average current for cable size

See figure 4 on page 24 for more information.
Consider cable temperature rises/ambient, based on your current.

5.2.2 Fuse Size

The DC Link supply must be fused to protect the vehicle wiring and the controller in the event of a fault. Use fast-blow fuses, rated appropriately.

For more information, refer to manufacturer's datasheets.

Electrical Ratings

5.3 Inverter (Motor Output)

The inverter connects to the motor. For example, on a motor with UVW terminals labelled, the terminals M1, M2, M3 on the controller would be connected to the terminals U, V, W (respectively).

Switching frequency	Range configurable between 2kHz and 12kHz range. We recommend 8kHz for most applications as it offers good thermal performance where high RPM is not required. Note that frequency can be set to adjust automatically based on the thermal requirements of the controller.
Protection: output current	Gradual reduction from peak to continuous rating over time, based on temperature.
Protection: short-circuit	■ Protected against any motor phase to B- or B+ during power-up. ■ Protected against motor phase to phase short circuits during operation. ■ On power-up and with drive current applied, the controller automatically detects that valid output loads are present. For example, an open/short circuit motor phase.

Repetitive short circuits may damage the controller.

5.3.1 Rating Conditions

For each test, four of the following five conditions are held at their nominal value and the remaining condition is varied. The conditions are:

1. DC link voltage: 300 volts DC
2. PWM switching frequency: 8kHz
3. Motor voltage: 65%
4. Ambient temperature: 45°C
5. Coolant: 45°C input temperature, 50/50 glycol/water mixture at 10L/min flow rate

All tests use a 50Hz AC waveform. Wire size is 50mm^2.

Electrical Ratings

5.3.2a Continuous Rating

Many external parameters effect the electrical rating of the controller, including the coolant temperature, ambient air temperature, the battery voltage, cable sizes and switching frequency.

These parameters feed into a complex algorithm used to deliver the maximum performance, while ensuring long-term reliability of the product. Below are a series of graphs designed to show how each of these parameters in isolation can cause de-rating to the electrical performance of the product.

In real life, the controller will be operating under a combination of these parameters, and it may be necessary to combine the information provided to understand the expected performance under your specific conditions.

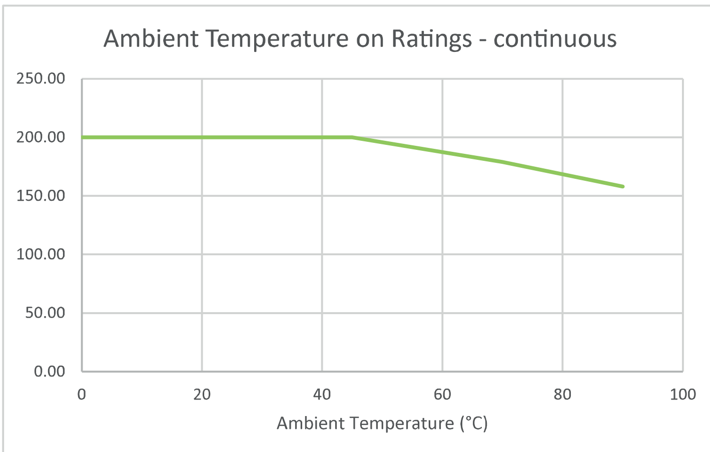

Figure 1: how ambient temperature affects ratings

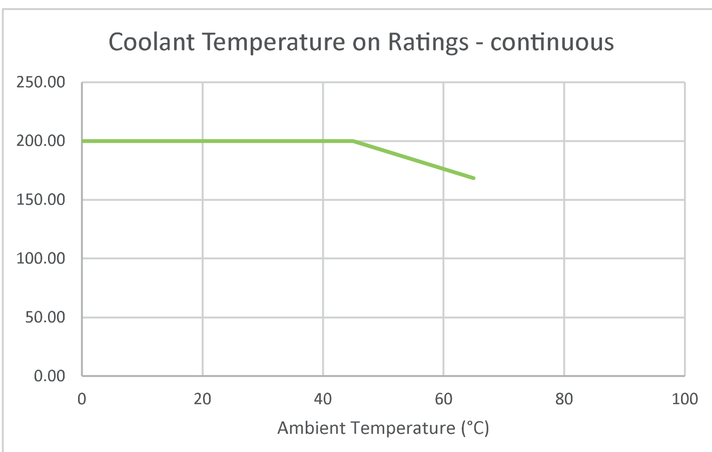

Figure 2: how coolant temperature affects ratings

Electrical Ratings

5.3.2b Continuous Rating

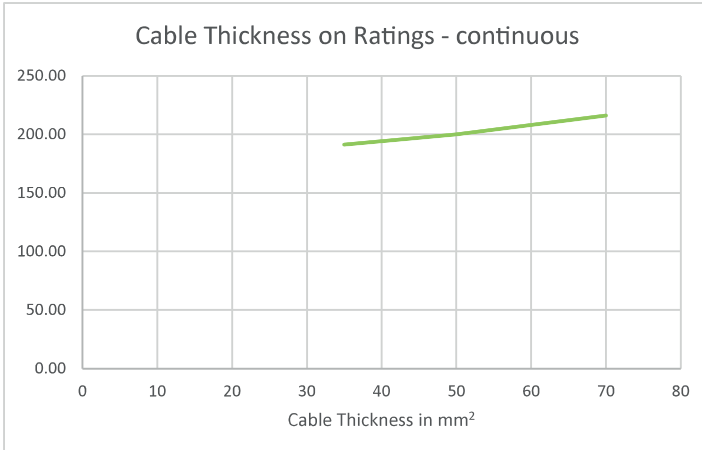

Figure 3: how cable thickness affects ratings

When deciding on power cable diameter, consider the cable length, grouping of cables, the maximum allowable temperature rise, and the temperature rating of the chosen cable.

5.3.3a Short-term Overload

Short-term overload is affected by switching **frequency**, **coolant flow rate and temperature** and **DC Link**.

The following graphs outline how these factors affect ratings.

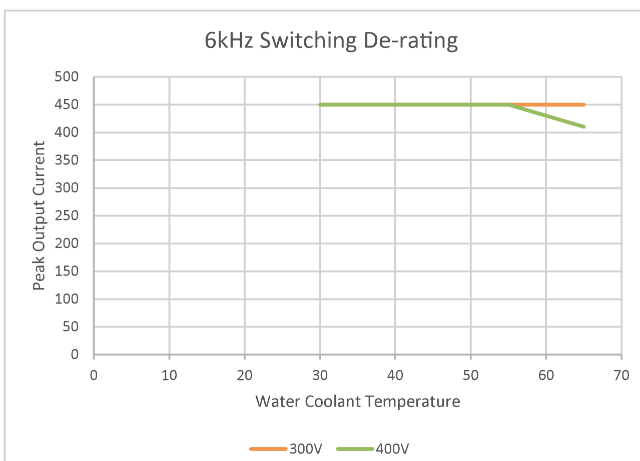

Figure 4: 6kHz switching de-rating

Electrical Ratings

5.3.3b Short-term Overload

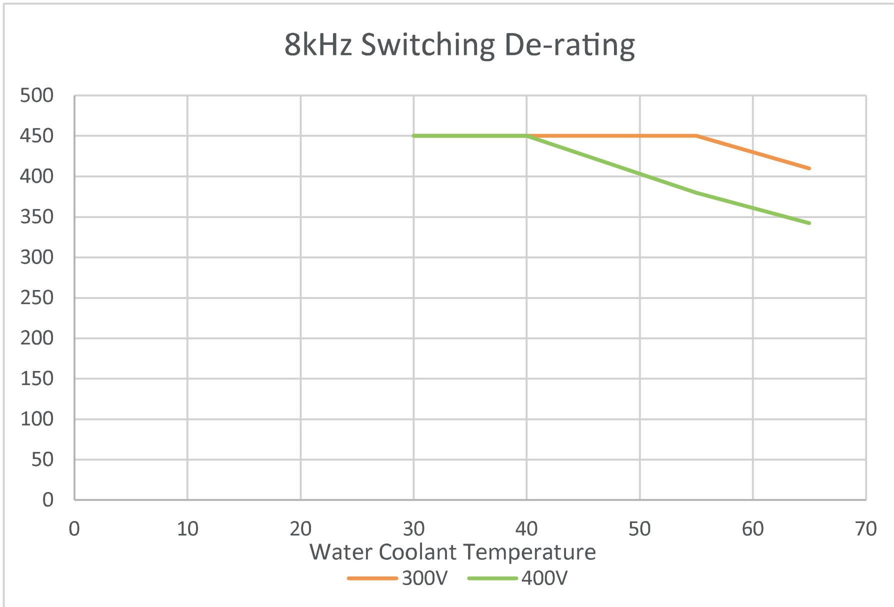

Figure 5: 8kHz switching de-rating

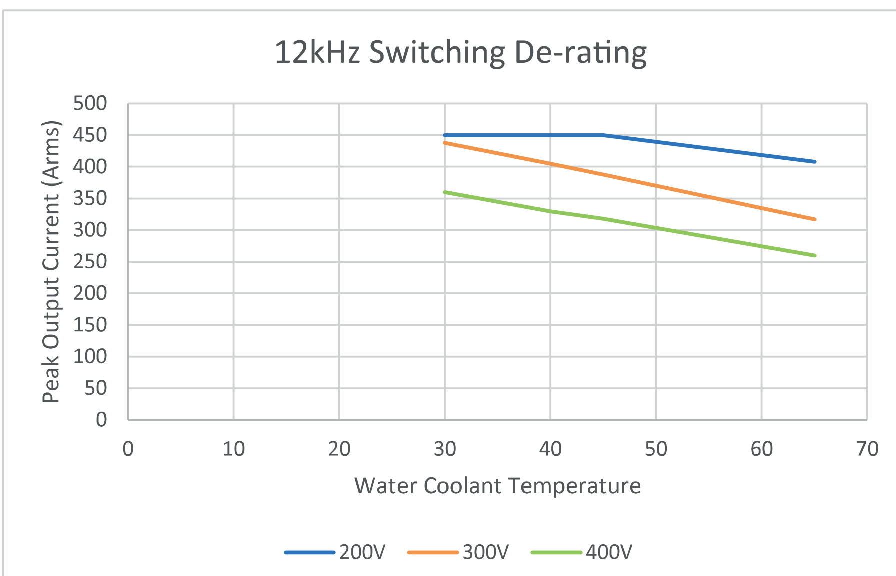

Figure 6: 12kHz switching de-rating

Electrical Ratings

5.3.3c Short-term Overload

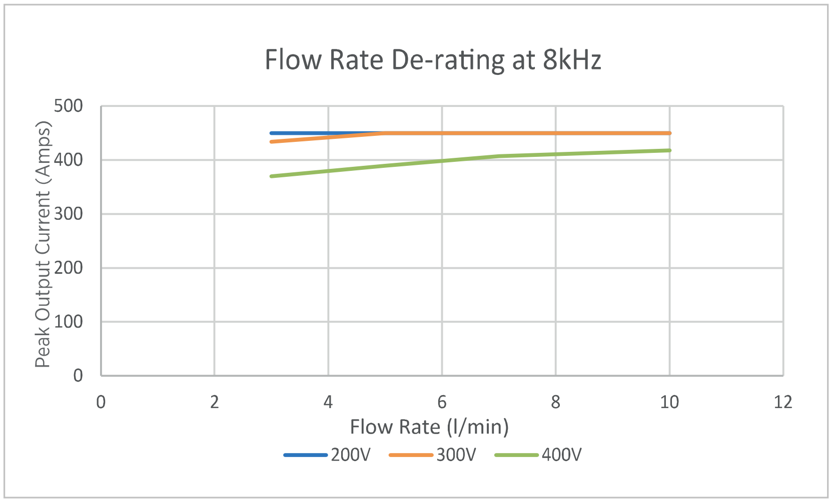

Figure 7: 8kHz how flow rate affects ratings

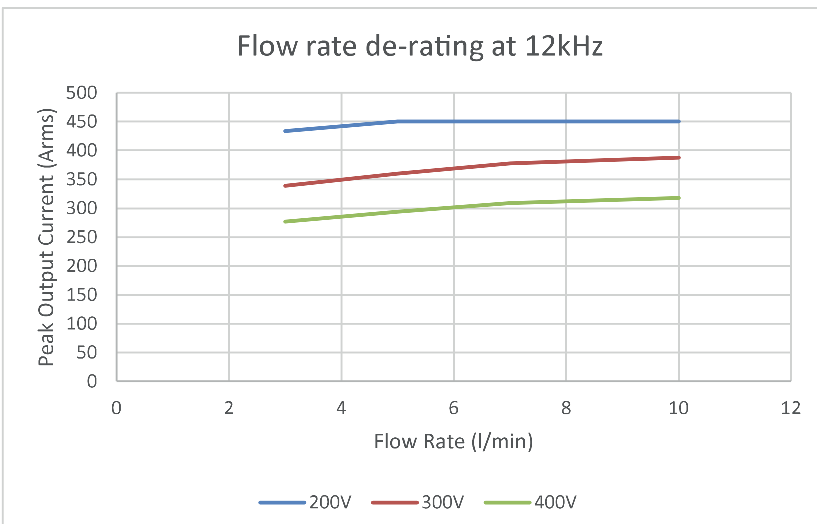

Figure 8 12kHz how flow rate affects ratings

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Electrical Ratings

5.3.3d Short-term Overload

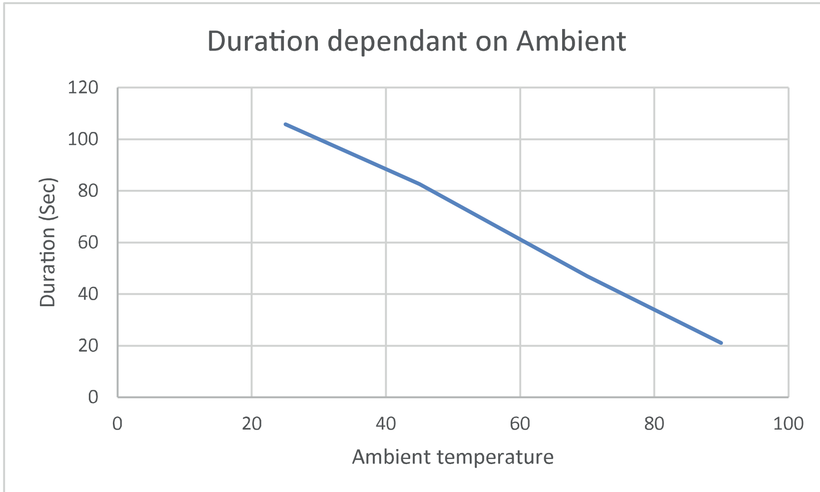


Figure 9: Duration dependant on ambient

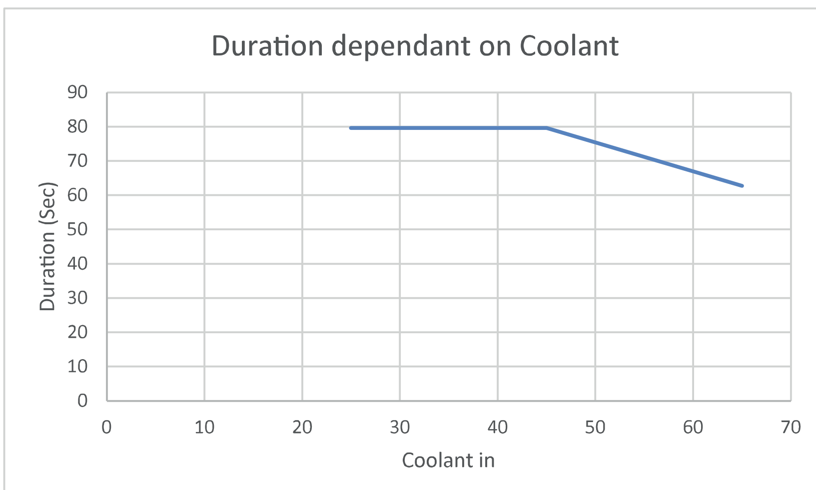


Figure 10: Duration dependant on coolant

Electrical Ratings

5.3.3e Short-term Overload

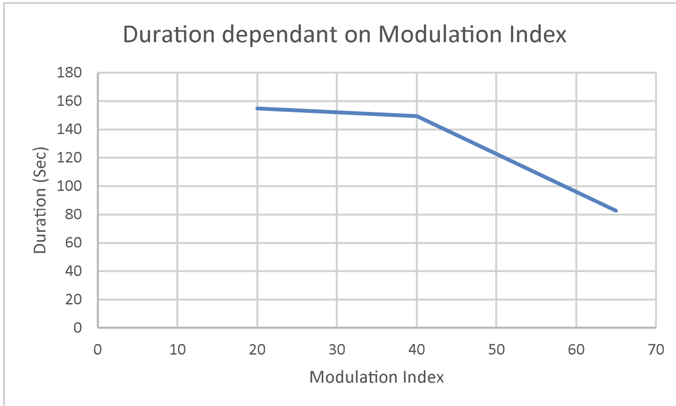


Figure 11: Duration dependant on modulation index

5.3.4 Overload Duration

When running from cold (at the respective ambient and coolant temperatures), the times highlighted in the graphs above represents the duration at 450A - before the inverter cuts back. In some cases, to achieve the 450A, the switching frequency is reduced due to junction temperature limits.

5.3.5 Effect of Multiple Conditions on Ratings

It can be difficult to determine the effect of multiple conditions varying from nominal. One approach is to use the minimum of each condition. This can work reasonably well when operating at conditions more limiting than nominal, but tends to be more pessimistic than necessary when operating at conditions less limiting than normal.

6

Wiring

Wiring

6.1a Signal Connector

Mating connector	Molex 64320-1311 (left) or 64320-3311 (right)
Integrity	IP67/IP6K9K
Pin labels	**A1** to **M4** and are marked on the connector.
Required pins	CMC 0.5mm Sq Crimp Terminal Molex 64322-1039 and CMC 0.5-1.0mm Sq Crimp Terminal Molex 64323-1029. **Please refer to the Molex website to select the most up-to-date, appropriate pins.**

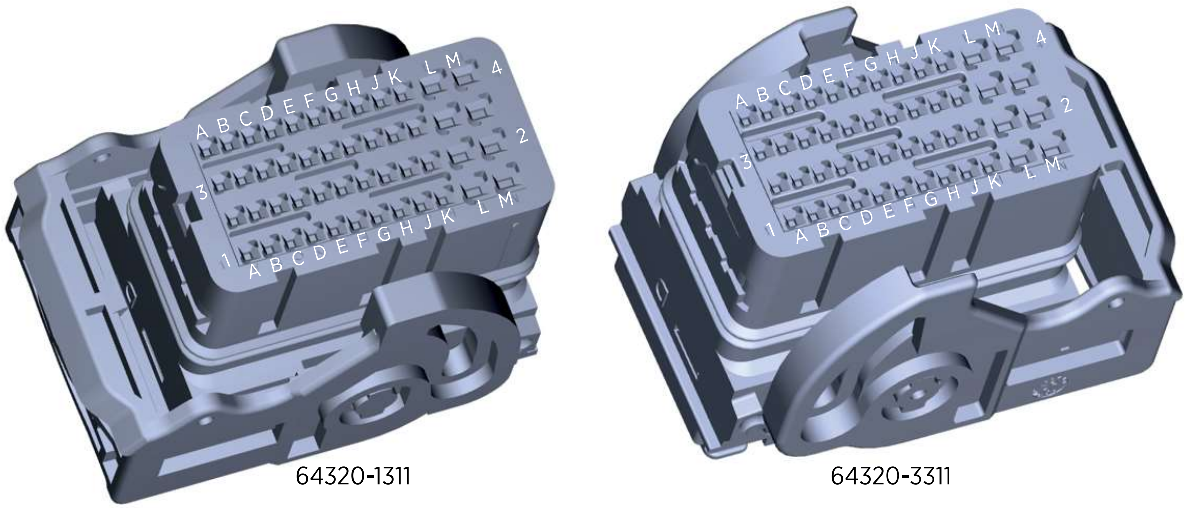


Figure 12: mating connector

Wiring

6.1b Signal Connector

	4	3	2	1
A	No connection	Din 1	CAN1 H	Encoder Supply (Enc Supply)
B	Encoder Gnd (Enc Gnd)	Resolver Excitation - (Enc-)	Din 2	Resolver Excitation + (Enc+)
C	No connection	CAN Gnd	CAN1 L	CAN1 Termination Resistor (CAN Res)
D	No connection	Din 4	Din 3	User Supply 1
E	User Supply 2	Resolver Cos	Encoder U (Enc U)	Analog In 1 (Ain 1)
F	Analog In 2 (Ain 2)	Resolver Cos Low (CosLo)	Uart Tx	EncoderA / Sin (Enc A, Enc Sin)
G	HVIL A	Thermistor TH2	Ain Gnd	Thermistor TH1
H	HVIL B	Resolver Sin	Uart Rx	Encoder V (Enc V)
J	Analog In 3 (Ain 3)	Resolver Sin low (SinLo)	Encoder B / Cos (Enc B, Enc Cos)	Ignition Switch (KL15)
K	Dout 4 Source	Dout 3 Source	Analog In 4 (Ain 4)	Encoder W (Enc W)
L	Control 0V (KL31)	Dout 1 Sink	Dout Common	12-24V supply (KL30)
M	Control 0V (KL31)	No connection	Dout 2 Sink	12-24V supply (KL30)

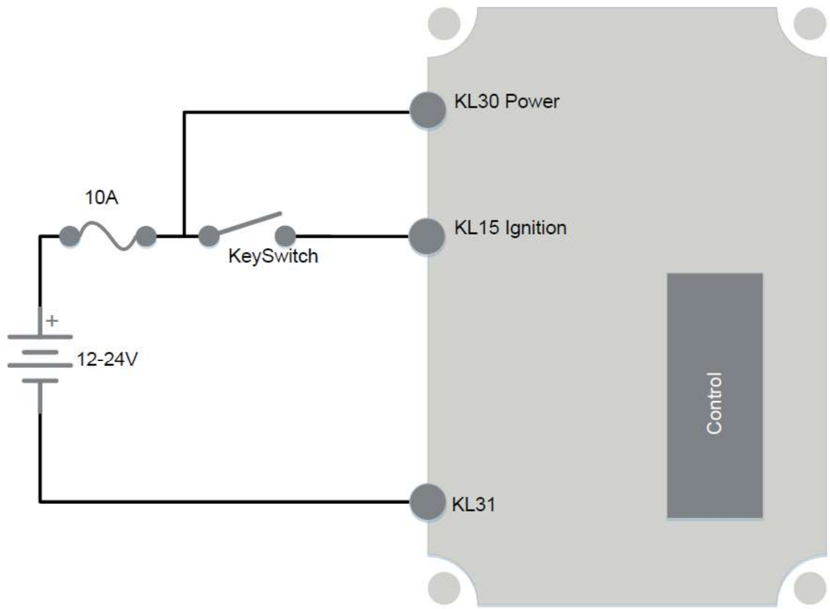
Table 2: signal connector

Wiring

6.2 KL30 Control Supply

The controller has one logic power input.

The figure shows a suggested schematic connection.



PIN IDs:

L1/M1: KL30
J1: KL15
L4/M4: KL31

Figure 13: KL30 schematic connection

KL30 is connected directly to the power supply.

Absolute maximum voltage	36V
Capacitance	10µF (before inrush)
Peak inrush current	< 10A @ 25°C
Protected against reverse voltage connection	Yes
Nominal working voltage	12-24V
Signal power	Supplied between KL30 and KL31 (the signal ground)
Standby power consumption	12V <150µA. 24V <450µA
Wire size, recommended	0.6mm^2 / AWG20
Working voltage limits	8-32V ISO16750-2 Class B (12V System)/Class F (24V System)

Wiring

6.3 KL15 Ignition Switch

The controller has one ignition switch input.

The figure shows a suggested schematic connection. The key switch provides voltage to KL15.

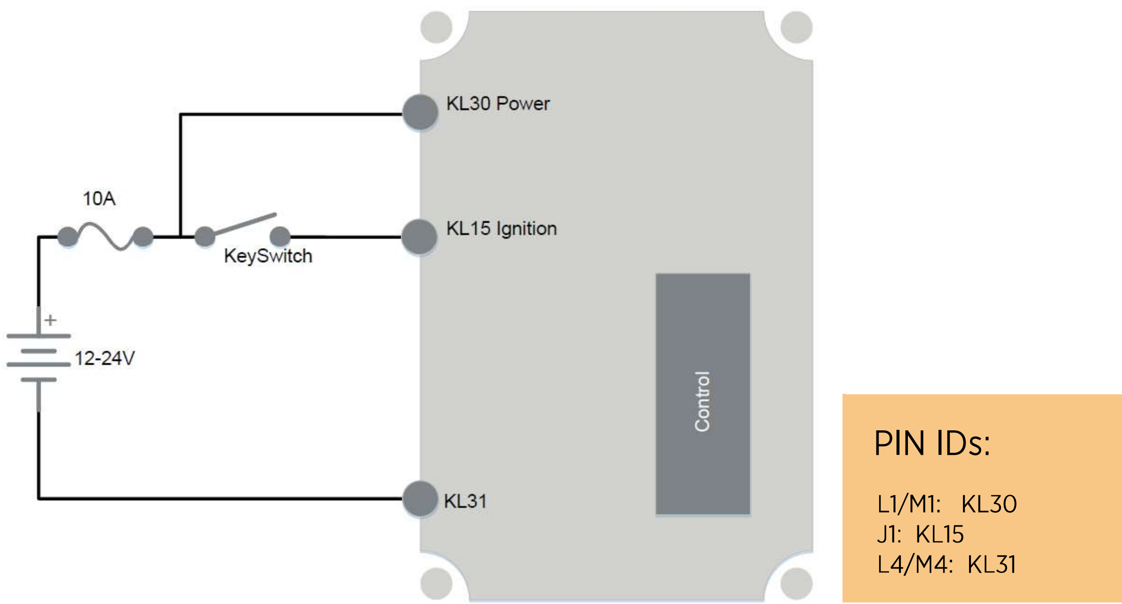


Figure 14: KL15 schematic connection

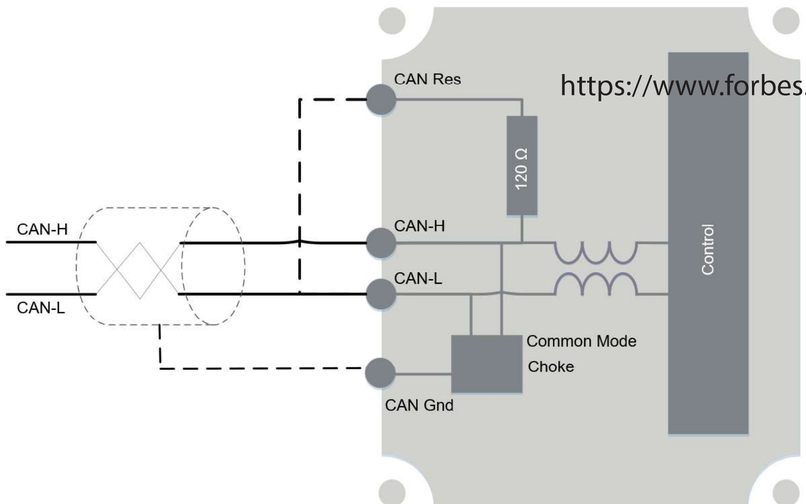
Absolute maximum voltage	36V
Maximum current consumption	10mA
Minimum voltage to start	8V
Nominal working voltage	12-24V
Wire size, recommended	0.6mm^2 / AWG20

Wiring

6.4 CAN Interface

A CAN1 channel is used to communicate with the controller.

https://www.forbes.com/sites/sap/2018/09/06/seven-reasor



PIN IDs:

A2: CAN High
C2: CAN Low
C1: CAN Res
C3: CAN Gnd

Figure 15: CAN schematic connection

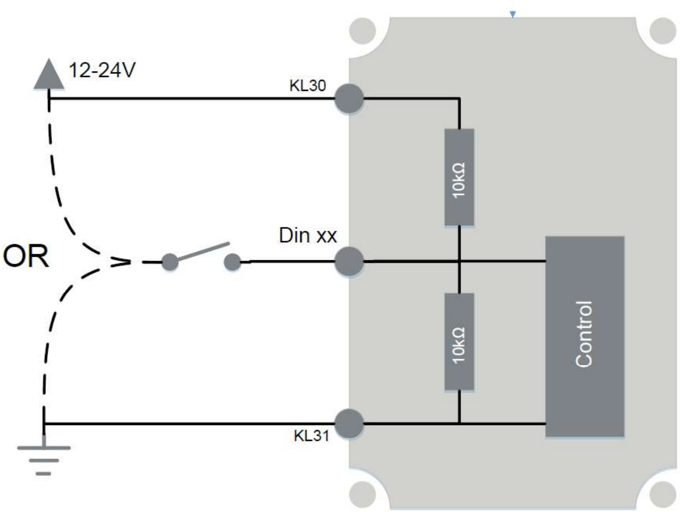
Absolute maximum voltage	36V transient, 24V continuous
Built-in 120Ω termination resistor, selectable through wiring	See CAN schematic connection diagram
CAN Revision	We support both standard (2.0A and 2.0B compatible) and extended CAN frames (2.0B compatible). Configuration is via CANOpen, while ProCAN supports J1939 message semantics. Bitrates up to 1Mbit are supported.
ESD protected	Yes
Maximum common mode signal	± 40V
Wire size, recommended	0.6mm^2 / AWG20

Wiring

6.5 Input - Digital

The controller has four identical digital inputs - these can only be accessed by custom code, or I-protocol.

The figure shows a simplified schematic of the internal controller circuit and an example of how the circuit can be used. The digital signal is connected between DIn x (the digital input) and KL31 (the signal ground / active low) or KL30 (signal power / active high) depending on desired configuration.



PIN IDs:

L1/M1: KL30
L4/M4: KL31

A3: Din 1
B2: Din 2
D2: Din 3
D3: Din 4

Figure 16: input digital connection

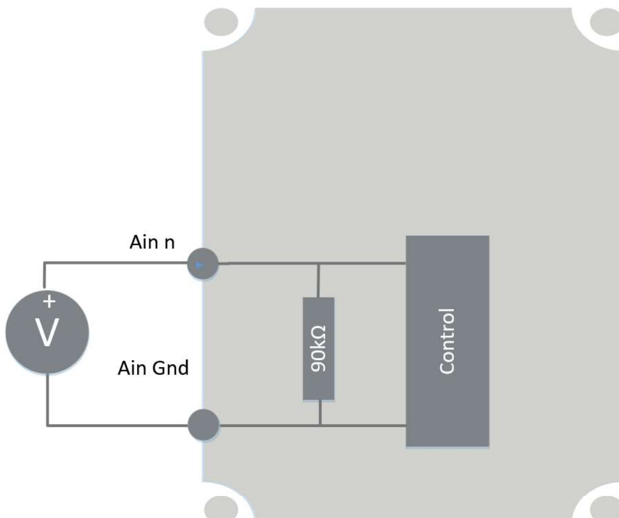
Absolute maximum input voltage	36V (continuous)
Configurable to be active hi or active low	Yes
Input impedance	5kΩ
Quiescent level	50% of KL30
Threshold level	User configurable up to 36V
Wire size, recommended	0.6mm^2 / AWG20

Wiring

6.6 Input - Analog

The controller has four identical analog inputs.

The figure shows a simplified schematic of the internal controller circuit and an example of how the circuit can be used. The analog signal is connected between Ain x (the analog input) and Ain Gnd (the signal ground).



PIN IDs:

E1: Ain 1
F4: Ain 2
J4: Ain 3
K2: Ain 4
G2: Ain Gnd

Figure 17: input analog connection

Absolute maximum input voltage	36V (continuous)
Accuracy	5%
Bandwidth	127Hz
Input resistance	90kΩ
Input voltage	0 to 10V
Resolution	10 bit
Wire size, recommended	0.6mm^2 / AWG20

To preserve analog signal accuracy, use good wiring practice, especially to the Ain Gnd signal. This ground is also used for the sourcing digital out.

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6.7 Input - Temperature

The controller has two identical temperature sensor inputs, typically used for motor temperature measurement, and can be used to ensure improved reliability and operation of the motor and controller.

The figure shows a simplified schematic of the internal controller circuit and an example of how the circuit can be used. The temperature sensor is connected between TIn x (the sensor input) and S 0V (the signal ground).

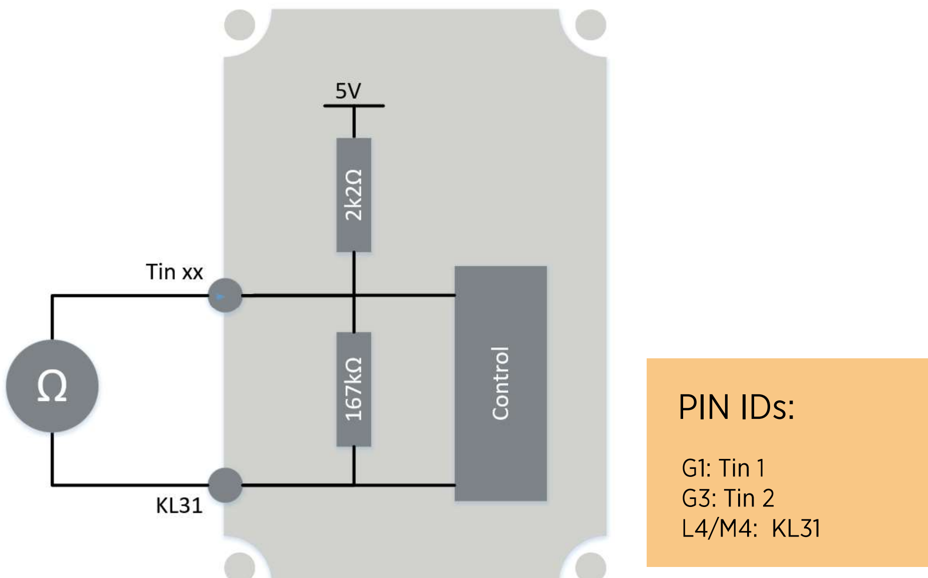


Figure 18: temperature sensor schematic connection

Absolute maximum input voltage	36V (continuous)
Accuracy: 10% from 330Ω to 1000Ω	When configured with a KTY84: @20°C ± 5°C; @200°C ± 5°C, Typical When configured with a PT1000: @20°C ± 6°C; @200°C ± 6°C, Typical
Internal excitation for the thermistor	5V with 2k2Ω pull-up resistor (the calibration takes into account the internal resistors)
Wire size, recommended	0.6mm^2 / AWG20

Wiring

6.8a Input - Sin-Cos Encoder

The controller has one Sin-Cos encoder input. The pins are shared with the A-B encoder input. Sin-Cos encoders are one of several motor speed/position sensors supported by the controller.

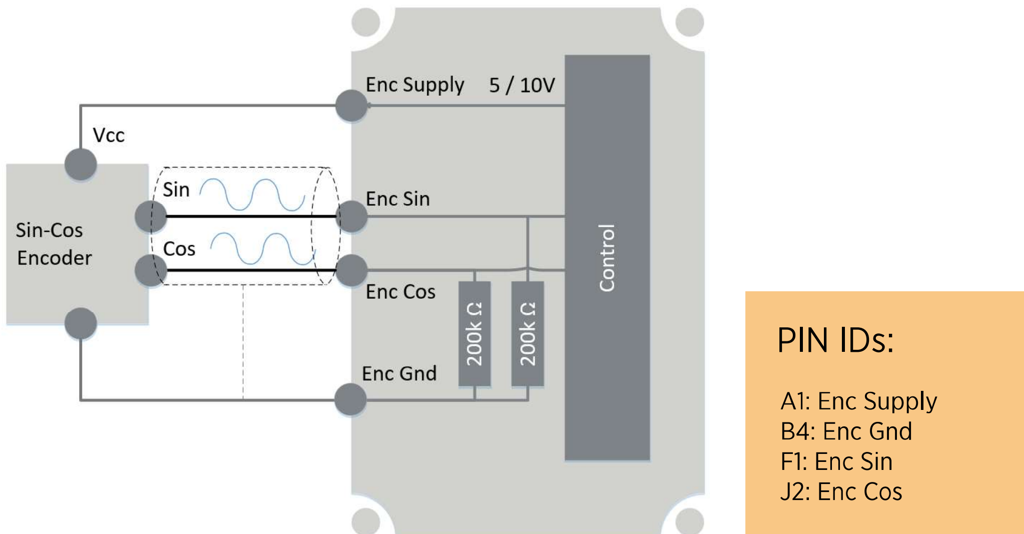


Figure 19: sin-cos speed sensor schematic connection

Absolute maximum input voltage	36V (continuous)
Current measurement accuracy	5%
Input impedance	200kΩ
Input pins	Shared with the A-B Encoder
Input voltage	0-5V
Maximum frequency	1.2kHz
Voltage	Selectable 5/10V supply. Sin-cos encoder is supplied from a dedicated encoder supply. The 0-5V encoder output phases are connected to *Enc-Sin* and *Enc-Cos* and the ground to *Encoder Gnd* (the signal ground). ⚠ To avoid any permanent damage to any external sensors connected to this supply, please ensure the correct output voltage is set before connecting to sensor.
Wire size, recommended	0.6mm^2 / AWG20 screened cable

Wiring

6.8b Input - Sin-Cos Encoder

Pole Pairs

The controller can control motors with sin-cos sensors that produce multiple sin and cosine waves per mechanical rotation. However, the number of pole pairs in the motor must be an integer multiple of the number of sin-cos waves per rotation (itself an integer only).

Examples:

An encoder that produces	Can be used with motors with
1 wave per rotation	1 pole pair, 2 pole pairs, 3 pole pairs, etc.
3 waves per rotation	3 pole pairs, 6 pole pairs, 9 pole pairs, etc.
5 waves per rotation	5 pole pairs, 10 pole pairs, 15 pole pairs, etc.

Wiring

6.9a AB Encoder

The controller has one A-B encoder input. The pins are shared with the Sin-Cos encoder input.

The A-B Encoder is one of several motor speed/position sensors supported by the controller.

- Four-wire connection provided for open-collector quadrature pulse encoder devices.
- One of several motor speed/position sensors supported by the controller. Supplied from a dedicated encoder with a selectable 5/10V supply. Phases are connected to *Enc-A* and *Enc-B* and the ground to *Encoder Gnd* (the signal ground).

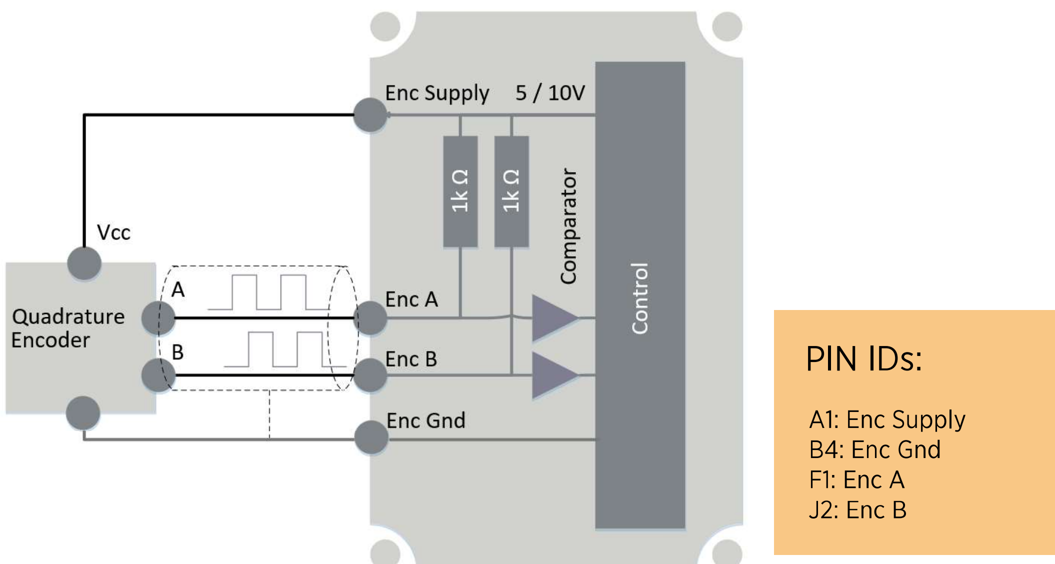


Figure 20: AB Encoder sensor schematic connection

Wiring

6.9b AB Encoder

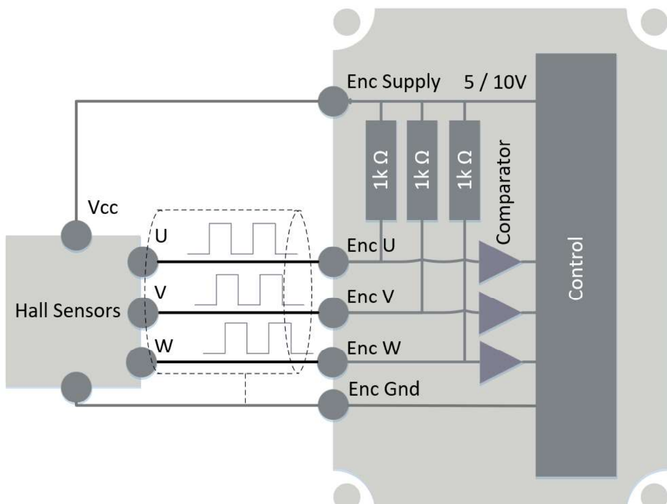
Absolute maximum input voltage	36V
Filter	<5µs A hardware circuit cleans the signal: a glitch filter removes very short pulses and a comparator with hysteresis provides a definite hi & low. The inputs are shared with the Sin-Cos Encoder
Hi/Low threshold	50% of Encoder supply (2.5 or 5V)
Hysteresis	300mV
Maximum Frequency	50kHz. For a pulses per revolution (ppr) encoder, the maximum readable motor speed is 50,000 x 60 / (ppr/2). For example: 256 pulses per evolution, maximum readable speed is ~11,700 RPM
Voltage	Selectable 5/10V To avoid any permanent damage to any external sensors connected to this supply, please ensure the correct output voltage is set before connecting to sensor.
Wire size, recommended	$0.6mm^2$ / AWG20 screened cable

Wiring

6.10 Input - UVW Encoder

The controller has one set of U-V-W Hall sensor inputs.

The UVW encoder is one of several motor speed/position sensors supported by the controller. A UVW input (Hall Sensors in diagram) is supplied from a dedicated encoder with a selectable 5/10V supply. The UVW input (Hall Sensors in diagram) signals to Enc-U, Enc-V and Enc-W and the ground to Encoder Gnd (the signal ground).



PIN IDs:

A1: Enc Supply
B4: Enc Gnd
E2: Enc U
H1: Enc V
K1: Enc W

Figure 21: UVW speed sensor schematic connection

Absolute maximum input voltage	36V
Filter	< 5µs. A hardware circuit cleans the signal: a glitch filter removes very short pulses and a comparator with hysteresis provides a definite hi & low.
Hi/low threshold	50% of Encoder supply (2.5 or 5V)
Hysteresis	300mV
Maximum frequency	1.2kHz
Selectable voltage	5/10V To avoid any permanent damage to any external sensors connected to this supply, please ensure the correct output voltage is set before connecting to sensor.
Wire size, recommended	0.6mm^2 / AWG20 screened cable

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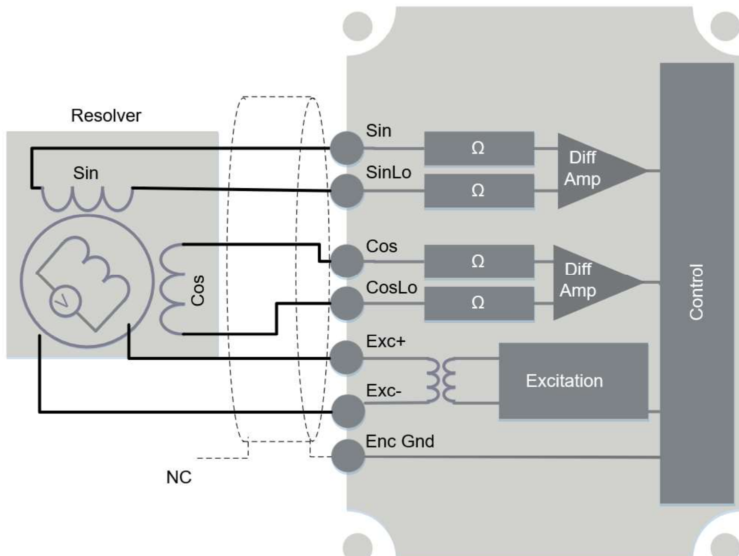
Wiring

6.11a Input - Resolver

The controller supports one resolver.

The resolver is one of several motor speed/position sensors supported by the controller.



PIN IDs:

B1: Exc +
B3: Exc -
H3: Sin High
J3: Sin Low
E3: Cos High
F3: Cos Low
B4: Enc Gnd

Figure 22: wiring connection

Accuracy	1 electrical degree
Common mode impedance	21kΩ
Differential mode impedance	24kΩ
Excitation	Excitation frequency: 10kHz Maximum output voltage: 3.5Vrms Maximum output current: 50mA Isolated
Resolver gain range	0.2 to 0.7
Resolver voltage input	1.5Vp-p
Wire size, recommended	0.6mm^2 / AWG20. Differential pairs should be twisted-pair. Shield connected to signal ground.

6.11b Input - Resolver

Pole Pairs

The controller can control motors with multiple pole-pair resolvers, that is, returning multiple sine and cosine waves per mechanical rotation. However, the number of pole pairs in the motor must be an integer multiple of the number of resolver pole pairs.

Examples:

Encoder	Can be used with motors with
Single pole pair	1 pole pair, 2 pole pairs, 3 pole pairs, etc.
3 pole pair	3 pole pairs, 6 pole pairs, 9 pole pairs, etc.
5 pole pair	5 pole pairs, 10 pole pairs, 15 pole pairs, etc.

6.12 Output - Low Side Driver (1A PWM capable)

The PWM output pins on this module are capable of sinking a maximum of 1A

The figure shows a simplified schematic of the internal controller circuit and an example of how the circuit can be used. The load is connected between Dout Common and Dout. Connecting directly to KL30 is not recommended . Inductive loads may incorporate a recirculating diode, although it is not required when connected as recommended. (Note the internal controller diode.)

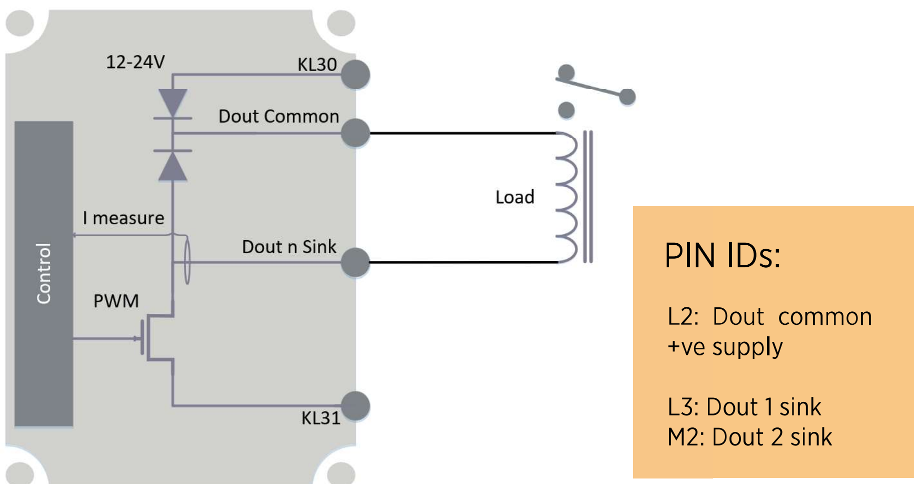


Figure 23: output LSD (1A PWM capable)

Current measurement accuracy	± 0.2A
Maximum capacitive load	100nF
Maximum output current	1A continuous
Maximum output voltage	KL30
Protected against	Battery reverse polarity connection and overload
PWM frequency	16kHz (fixed)
Wire size, recommended	1.5mm^2 / AWG16

Do not use contactors that have built-in economiser circuits. The internal circuits are not compatible with the controller and may cause a malfunction or damage. The current software has limited protection of low side drivers. Use the over-current trip with caution as it is slow to prevent damage in all cases.

6.13 Output - Low Side Driver (3A PWM capable)

The PWM output pins on this module are capable of sinking a maximum of 3A

The figure shows a simplified schematic of the internal controller circuit and an example of how the circuit can be used. The load is connected between Dout Common and Dout. Connecting directly to KL30 is not recommended . Inductive loads may incorporate a recirculating diode, although it is not required when connected as recommended. (Note the internal controller diode.)

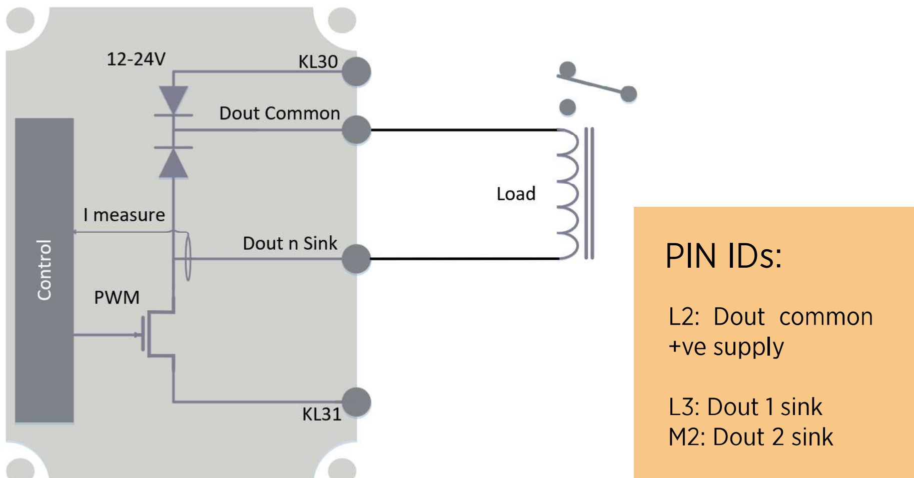


Figure 24: output LSD (3A PWM capable)

Current measurement accuracy	± 0.2A
Maximum capacitive load	100nF
Maximum output current	3A continuous
Maximum output voltage	KL30
Protected against	Battery reverse polarity connection and overload
PWM frequency	16kHz
Wire size, recommended	1.5mm^2 / AWG16

Do not use contactors which have built-in economiser circuits. The internal circuits are not compatible with the controller and may cause malfunction or damage. The current software has limited protection of low side drivers. Use the over-current trip with caution as it is slow to prevent damage in all cases.

6.14 Output - High Side Driver

The controller has two identical digital outputs which source current.

The figure shows a simplified schematic of the internal controller circuit and an example of how the circuit can be used.

- The load is connected between *S 0V* (ground reference for signals) and *Dout*.
- Inductive loads should incorporate a recirculating diode, although it is not required with low inductance loads, such as a signal relay.

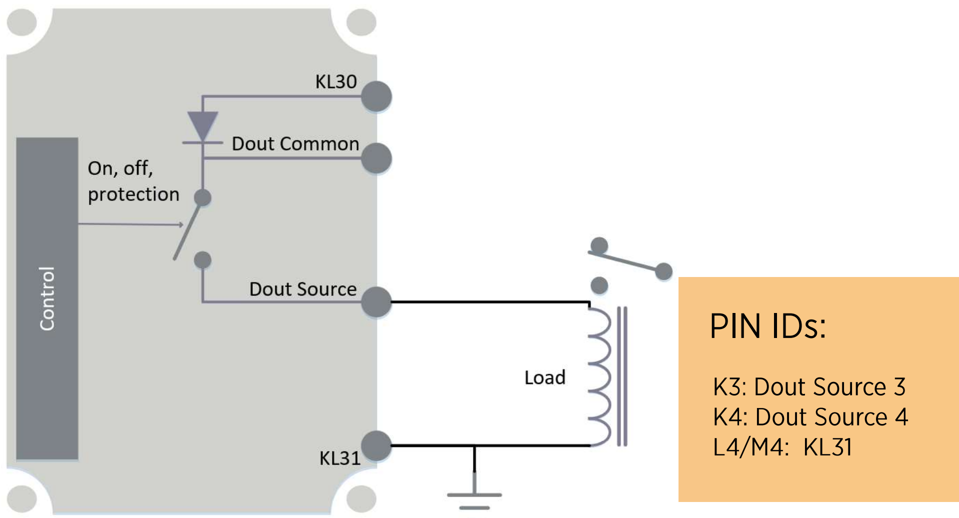


Figure 25: high side driver connection

Maximum capacitive load	1µF
Maximum output current	2A continuous
Maximum output voltage	KL30
Protected against	Battery reverse polarity connection and overload
Wire size, recommended	1.5mm^2 / AWG16

Wiring

6.15a HVIL

The controller has a High Voltage Interlock (HVIL) circuit, which becomes effective when housed in a vehicle system.

The High Voltage Interlock Circuit (HVIL) protects against exposed high voltage. HVIL-A and HVIL-B form a loop. The HVIL is an internally monitored electrical loop that detects when the cable cover is removed. To detect the loop status change, you can use one of the following methods:

- Use an external device to independently monitor the electrical HVIL status
- Configure Gen5-S9 to report on the status of the HVIL over CAN

The software will report the status of the current (flowing or not), but no action will be taken by the inverter.

All work must be carried out by a competent, qualified engineer, and failure to comply with this advice may lead to risk of high voltage exposure and associated risks, including death.

If action is required when the cover is removed, then this action must be triggered externally to the Gen5-S9 controller. The external system can intervene either physically (for example, by opening line contactors feeding power to the Gen5-S9), or by sending an appropriate CAN message to the Gen5-S9 (for example, by requesting a reduction of torque to 0, or by requesting the disabling of the power frame). For other HVIL status change action using the Gen5-S9 Custom Code feature, consult Custom-code help pages in the Gen5-S9 interface Documentation Drawer. This loop should be part of the high voltage enable in the DC supply circuit.

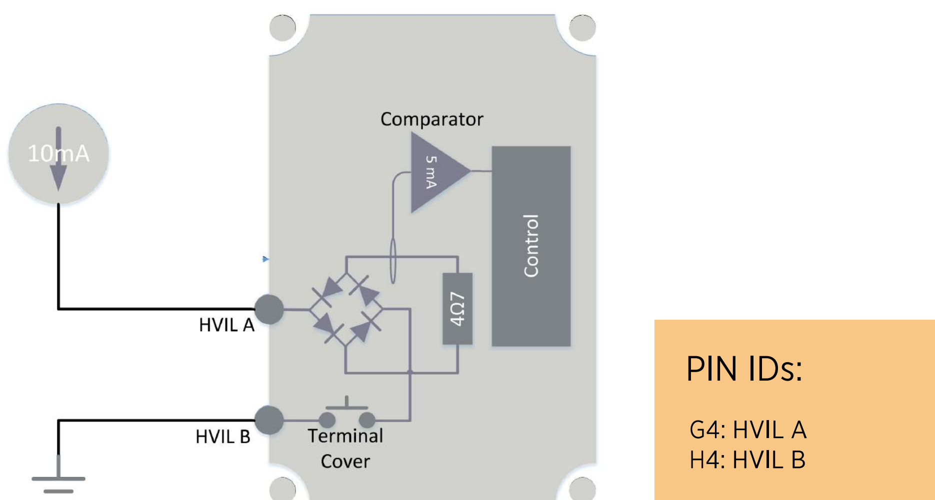


Figure 26: HVIL schematic connection

Wiring

6.15b HVIL

Absolute maximum input current	100mA
Galvanic isolation from other circuits	Yes
Maximum voltage drop at 100mA	2.5V
Maximum common mode input voltage	100V
Maximum current guaranteed to be detected as off	3mA
Minimum current guaranteed to be detected as on	5mA
Wire size, recommended	$0.6mm^2$ / AWG20

Wiring

6.16 Supply - Encoder

The controller has a single supply to be used with encoders.

The figure shows a simplified schematic of the internal controller circuit and an example of how another circuit can be used. The encoder is connected between Encoder Vcc and Encoder Gnd.

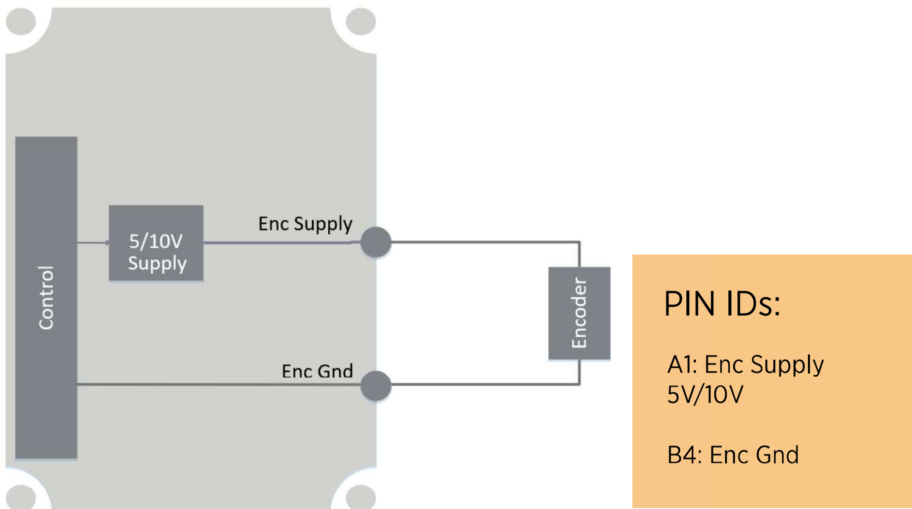


Figure 27: supply encoder connection

Voltage output accuracy	5%
Deviation over temperature	1%
Droop overload	1%
Dynamic response	<10% deviation, 10-90% load
Maximum capacitive load	100µF
Maximum output current	200mA continuous
Protected against	Reverse battery connection and overload
Voltage	Either 5V out or 10V out. Configured via a voltage current unit message. ⚠ To avoid any permanent damage to any external sensors connected to this supply, please ensure the correct output voltage is set before connecting to sensor.
Wire size, recommended	0.6mm^2 / AWG20

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Wiring

6.17 Supply - Sensors

The controller has two identical, independent sensor output supplies.

The figure shows a simplified schematic of the internal controller circuit and an example of how the circuit can be used. The sensor is connected between KL31 (ground reference for signals) and User Supply n.

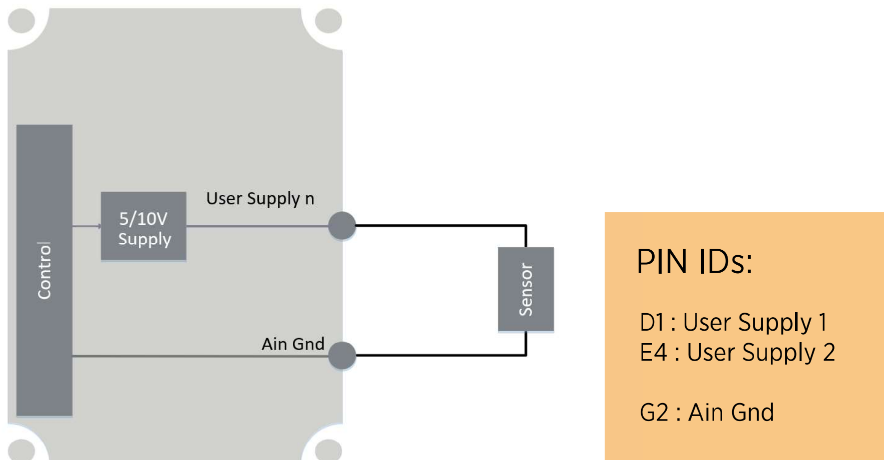

Figure 28: supply sensor connection

Voltage output accuracy	5%
Deviation over temperature	1%
Droop overload	1%
Maximum capacitive load	100µF
Maximum output current	100mA continuous
Protected against	Reverse battery connection and overload
Voltage	Either 5V out or 10V out. Configured via a voltage current unit message. ⚠ To avoid any permanent damage to any external sensors connected to this supply, please ensure the correct output voltage is set before connecting to sensor.
Wire size, recommended	0.6mm^2 / AWG20

6.18 Isolation

Electrical isolation of the Gen5-S9 connections are rated as follows:

- Power terminals to case: 600V OV cat 2 – Production Flash test 2.3kV DC – Impulse level 4kV
- Power terminals to control terminals: 600V OV cat 3 – Production Flash test 2.3kV DC – Impulse level 6kV
- Control terminals and CAN bus to case: 100V

7

How to Install the Controller

How to Install the Controller

7.1 Mounting

This section assumes you are familiar with the EMC guidelines.

7.1.1 Mounting Hole Pattern

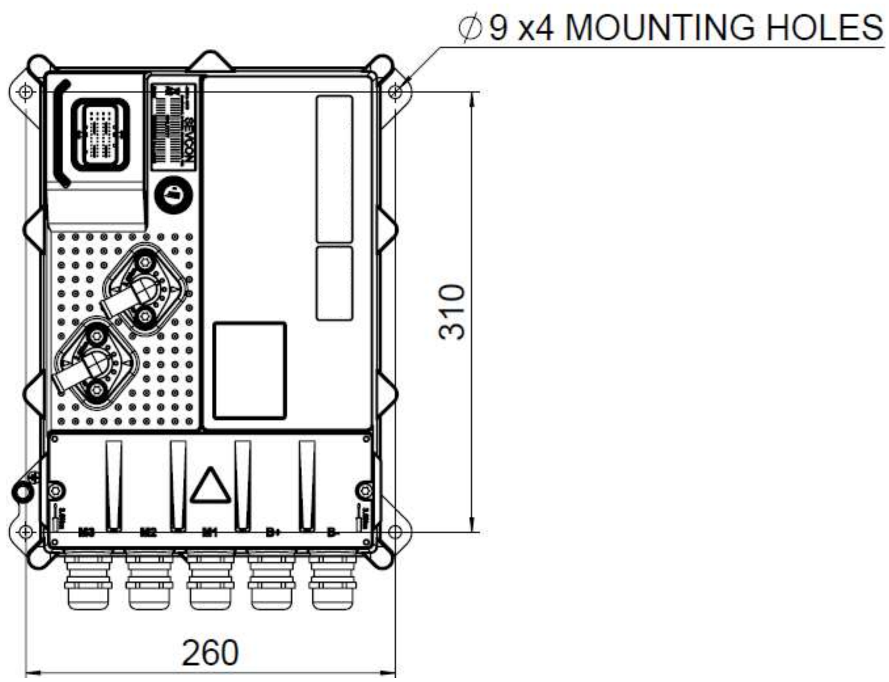

Figure 29: mounting hole pattern

Mounting procedure:

1. Position the controller over the mounting surface and ensure the mounting holes are aligned.
2. Fit spring washers over the bolts.
3. Utilising the spring washers prepared in step 2, insert bolts through the mounting holes and loosely secure the nuts.
4. Firstly, fasten one of the numb and bolt pairs to the recommended torque.
5. Fasten the nut and bolt pair that is diagonally opposite to the pair in step 4 - to the recommended torque.
6. Fasten the remaining nut and bolt pairs to the recommended torque.

*Note: If an alternative mounting method is adopted, for example using screws and threaded holes, please adjust the mounting procedure and torque value accordingly.

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How to Install the Controller

7.1.2 Mounting Location

Electrical power terminals under the terminal cover on the controller present an electric shock hazard. All work must be carried out by a competent, qualified engineer, and failure to comply with this advice may lead to risk of high voltage exposure and associated risks, including death. High currents can also present a burn hazard. You must ensure that the electrical terminals of the controller are protected against access by unauthorised personnel.

When choosing the mounting location for the controller, consider the following guidelines:

1. Do not mount the controller on the outside of a vehicle where it would be assessable to unauthorised personnel.
2. Do not mount the controller where it may be susceptible to damage due to minor collisions or impact from road debris.
3. Although the controller has a high degree of ingress protection, avoid mounting the controller in locations where it may be submerged in water or subjected to long term exposure to jets of water.
4. The controller can be mounted in any orientation.
5. The inverter should not be used as a stressed member.
6. Co-planarity of mounting points: <0.2mm. Failure to comply with this flatness specification can cause deformation of the enclosure and damage to the product.
7. Take note of thermal and EMC considerations.

7.1.3 Equipment Required for Mounting

- 4 x M8 socket cap head bolts, nuts and spring washers. Bolts need to be long enough to pass through 7mm of Gen5-S9 mounting lugs and your mounting surface thickness.
- T hand-socket wrench or Allen key.

Recommended torque setting for the above mounting arrangement: 11Nm

7.2 Cooling Requirements

7.2.1 Cooling Considerations

To get the maximum performance from the controller:

- Keep the controller away from other heat-generating devices on the vehicle.
- Maintain its ambient operating temperature below the specified maximum.
- Maximum allowable coolant pressure of 1.0bar.
- Published ratings are based on a 50/50 water-glycol mixture. The mix you use may vary, depending on the application you are working on.

For information about flow rate, see Inverter section, 5.3.

7.2.2 Connecting Coolant Hoses

To optimize coolant hose routing within the vehicle, you can adjust the coolant fitting's angle, to support a range of cable options:

1. Remove the X2 M5 screws.
2. Lift the spigot away from the seal.
3. Rotate the spigot to the desired angle.
4. Refit the spigot ensuring the seal is correctly located in the groove.
5. Tighten the X2 M5 screws. The torque setting is 3.0Nm ± 0.2Nm

For information about flow rate, see Inverter section.

Coolant spigot outer diameter: 13mm (14.2mm over lip/bulge).
Hoses should be provided with mechanical fixing within 200mm of the fitting.

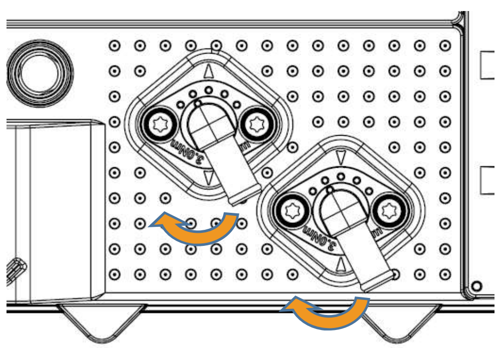

Figure 30: connecting coolant hoses

Coolant flow direction is shown with arrow heads marked on the case (next to the coolant ports). Failure to comply with this will reduce performance and may damage the product.

7.3 Earth Connection

It is essential that the chassis earth connection on the enclosure is connected to the vehicle or machine chassis using a short cable.

- The controller is supplied with an M6 hex-head screw for this purpose.
- The protective chassis cable must be minimum 50% cross-sectional area of the power cables, terminated at the controller end with a suitable M6 ring terminal.
- The screw is supplied with a flat washer and spring washer, which should all be refitted, and the screw tightened to 5Nm ± 0.5Nm.
- The protective earth connection should have a maximum resistance of 0.1Ω when measured at 20A.

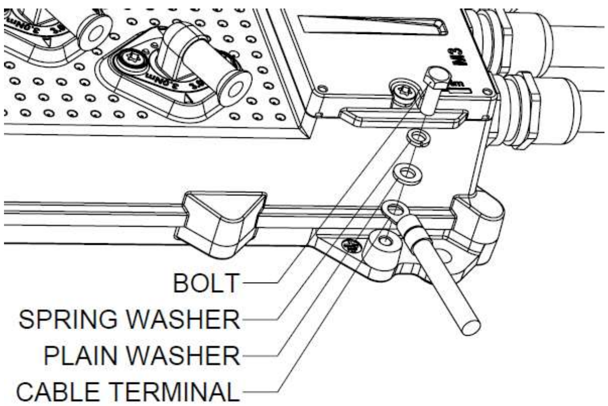

Figure 31: earth connection

Failure to provide a correctly sized protective earth connection may lead to risk of high voltage exposure and associated risks, including death, as well as non-compliance with international electrical safety regulations.

High voltage cable shields should be regarded as EMC shields and are not a substitute for the protective earth connection described above.

How to Install the Controller

7.4 Power Cables

Use the following tools and materials:

- Screened power cables sized to suit the controller and application
- Power cabling must have an orange coloured outer sheath, to comply with automotive regulations
- M8 crimp ring lugs
- Heat-shrink sleeving
- Copper tape
- Crimp tool
- M8 wrench

Note: Cables carrying high AC currents are subject to alternating forces and may require support in the cable harness to avoid long-term fatigue.

7.4.1 Wire Size

When deciding on power cable diameter, consider cable length, grouping of cables, the maximum allowable temperature rise, and the temperature rating of the chosen cable. Refer to table 1 in section 5.2.1 and bullet points in section 7.4.4 for more information.

7.4.2 Recommended Torque

Cable terminals should be secured by tightening the socket screws to 11Nm ± 2Nm.

⚠ Coolant flow direction is shown with arrow heads marked on the case (next to the coolant ports). Failure to comply with this will reduce performance and may damage the product.

How to Install the Controller

7.4.3 To Attach a Terminal Lug to the Power Cable

Procedure to connect a cable:

Ensure voltage is fully-discharged, before removing cover. Failure to do so may lead to risk of high voltage exposure and associated risks, including death.

1. Ensure the chosen terminal lug will fit through the cable gland with an ID of approx. 18mm.
2. Cut back the outer sheath and screen 40mm.
3. Cut back the inner insulation 21mm.
4. Cut back the outer sheath 65mm.
5. Crimp the terminal lug.
6. Fit the copper tape over the screen.
7. Fit the heat shrink sleeve over the lug and inner insulation.

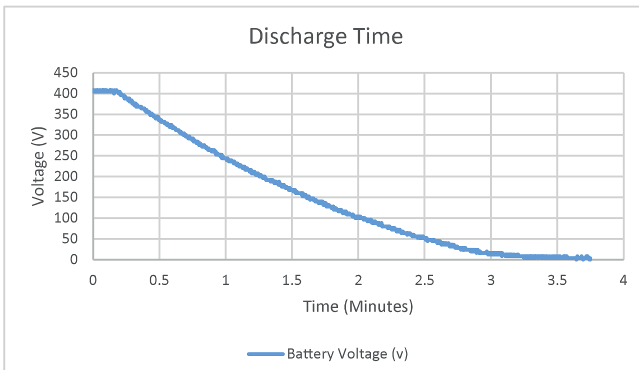

Figure 32a: discharge time

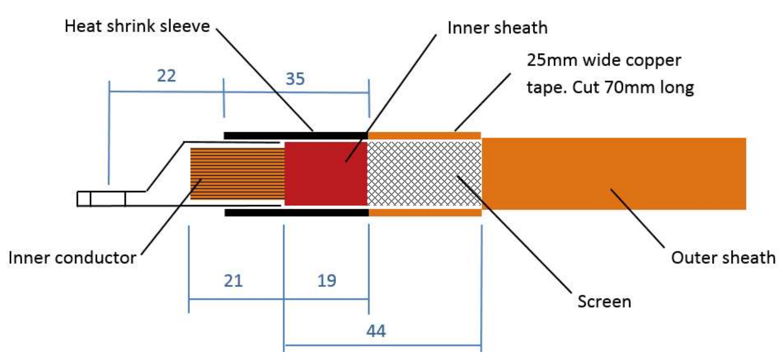

Figure 32b: cable connection

Ensure there are no loose conductor strands or screen mesh braid exposed, as debris could fall into the unit and cause a PCB short circuit. The cable must be properly prepared with heat-shrink sleeve and copper tape, as instructed.

How to Install the Controller

7.4.4 To Attach Cables

Keep the following in mind:

- The cable glandes accept cables with outer diameters of Ø10mm ~ Ø18mm.
- Keep cable runs short.
- Minimize current loops by keeping positive and negative cables as close together as possible.
- Connect your power cables using the bolts supplied. They are sized to clamp one ring lug thickness. Use a longer bolt if you are fastening more than one ring lug. You need thread engagement of at least 10mm and the maximum penetration is 15mm.

To feed the cable through the cable gland:

1. While feeding a cable through a cable gland, loosen the cap first.
2. When it is completely undone, immediately tighten it back for about 1 or 2 threads engagement. Then push the cable through the gland with the cap retained.
3. Once the terminal is secured, the cap can be tightened.
4. During the entire installation, DO NOT separate the cap from the rest of the gland structure. This is to prevent any inner components dropping out. If inner components are missing or not aligned properly while reinserting, the gland could have a leaking problem.

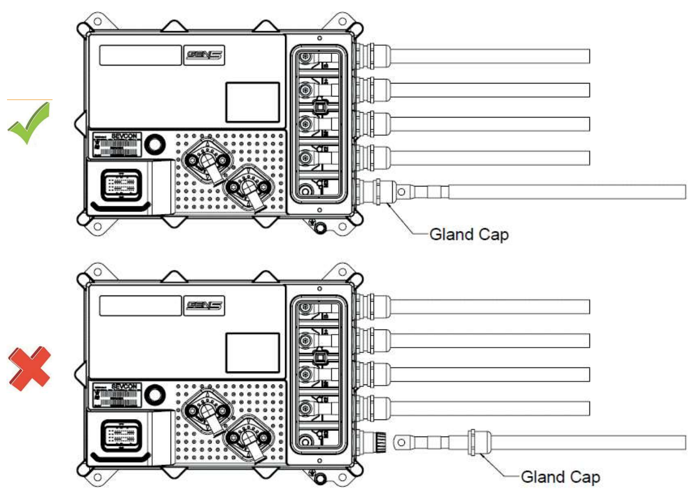

Figure 33: feeding cables

If you use a bolt that is too long, damage to the terminal and overheating of the connection may occur. If you use a bolt that is too short and there is not enough thread engagement, you may damage the threads.

How to Install the Controller

7.4.5 Using Screened Cables & Metal Screened Cable Glands

1. Ensure that all high voltage power cables are electrically isolated from the cable glands on the controller.
2. Ensure the cable screen is electrically isolated from the live inner conductor and the cable termination. Under no circumstances should any of the cable screens be connected to any power terminal or live conductor.
3. The metal cable gland cap should be tightened to the gland body to a torque of 15Nm ± 1.0 Nm.
4. Once the unit is fitted, ensure the first 70mm exposed cables are straight, that is, no bending, and in line with the cable gland as much as possible. This is to achieve optimum sealing performance at the gland and cable interface.

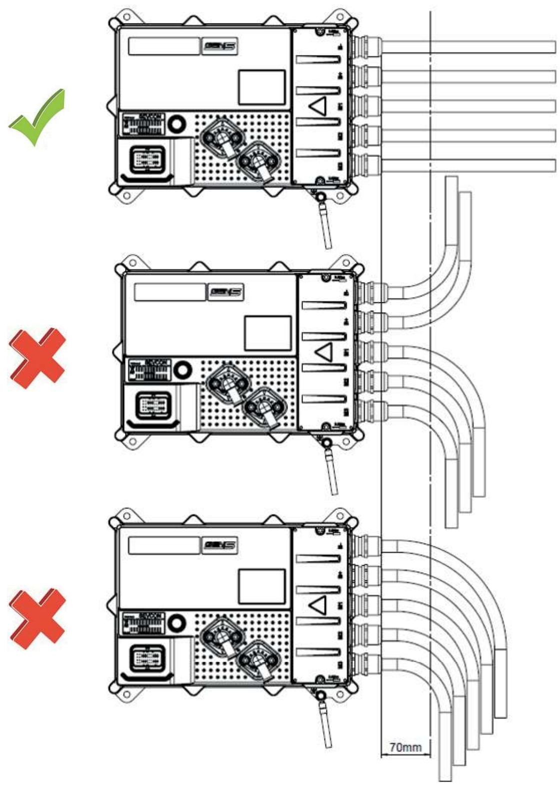

Figure 34: 70mm of cables left straight

When using metal cable glands, ensure that the spring contact fingers within the gland connect to the cable screen. There should be at least 8mm of inner insulator between the end of the screen and the cable lug.

How to Install the Controller

7.4.6 Fitting the terminal cover

1. Ensure the lid seal is correctly positioned. The HVIL plug must be correctly aligned with the socket.
2. Position the cover ensuring it sits flat against the seal.
3. Fit the X2 M5 screws (provided) to a torque setting of 3.0Nm ± 0.3Nm.

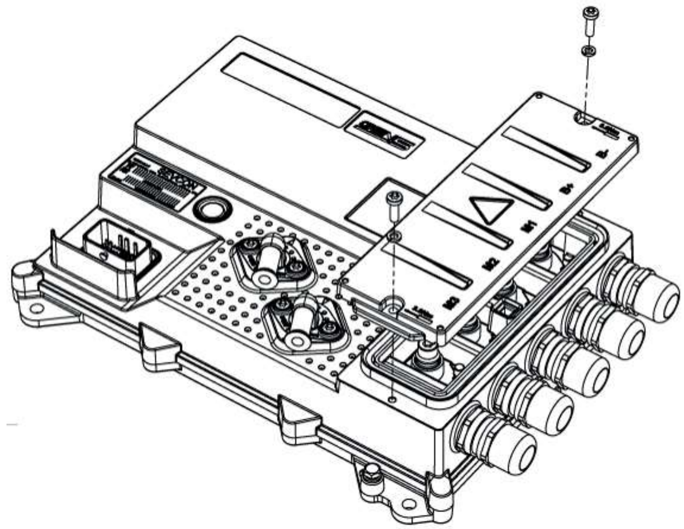

Figure 35: fitting terminal cover

8

Safety, Regulations, and Standards

Safety, Regulations and Standards

8.1 Compliance

8.1.1 ISO 16750 Compliance Summary

For standards satisfied, please see below.

The coding system (B/E, L, H, I and Z) defines which parts/tests the MCU complies with, depending on the vehicle mounting location.

Standard section	ISO16750 code	Parameter	Description	Comments
ISO16750-2	B/E	US_MIN 8V/10V US_MAX 16V/32V	MCU supply voltage limits. The MCU must be able to perform in class A conditions and throughout the operating temperature range defined in ISO16750-4 within the supply voltage limits.	As the MCU is a dual 12V/24V product, code A (12V) and code E (24V) have been defined. The worst case supply voltage will be used in tests.
ISO16750-3	L	See ISO16750-3 Table 25	Mechanical test requirements.	Mechanical tests conducted and their levels are determined by this code. For details, see ISO16750-3 Table 25.
ISO16750-4	H	TMIN -40°C TMAX 90°C	MCU operating temperature range. The MCU must be able to perform in class A conditions throughout this operating temperature range.	The MCU will operate in this range so long as the coolant is at a maximum temperature of 85°C. The MCU output capability will de-rate at higher temperatures; this is still deemed to be class A operation.
ISO16750-4	I	See ISO16750-4 Table 4	Climatic test requirements.	Climatic tests conducted and their levels are determined by this code. For details, see ISO16750-4 Table 4.
ISO16750-5	A/Z	See ISO16750-5 Table 1	Chemical test requirements.	Chemical tests conducted and their levels are determined by this code. For details, see ISO16750-5 Table 1.

Safety, Regulations and Standards

8.1.2a Test Requirements for the MCU and Compliance Status

Standard	Section	Test	Status
ISO 16750-2	4.2	DC Supply Voltage.	Compliant - Class A
ISO 16750-2	4.4	Over-voltage	Compliant - Class C
ISO 16750-2	4.2	Superimposed Alternating Voltage	Compliant - Class A
ISO 16750-2	4.5	Slow Decrease and Increase	Compliant - Class A/D
ISO 16750-2	4.6.1	Momentary Drop in Supply	Compliant - Class B
ISO 16750-2	4.6.2	Reset Behaviour at Voltage Drop	Compliant - Class C
ISO 16750-2	4.6.3	Starting Profile	Compliant - Class A
ISO 16750-2	4.6.4	Load Dump	Compliant - Class C
ISO 16750-2	4.7	Reverse Voltage	Compliant - Class A
ISO 16750-2	4.9.1	OC Single Line Interruptions	Non-Compliant[1]
ISO 16750-2	4.9.2	OC Multiple Line Interruptions	Compliant - Class C
ISO 16750-2	4.10.2	SC Signal Circuits	Non-Compliant[1]
ISO 16750-2	4.10.3	SC Load Circuits	Non-Compliant[1]
ISO 16750-2	4.11	Withstand Voltage	Compliant - Class C
ISO 16750-2	4.12	Insulation Resistance	Compliant - >10MΩ
ISO 16750-3	4.1.2.7	Random Vibration - Test VII	Compliant - Class A
ISO 16750-3	4.2.2	Mechanical Shock - Rigid	Non-Compliant[4]
ISO 16750-3	4.3	Free-fall	Non-Compliant[2]
ISO 16750-4	5.1.1.1	Low Temperature Storage Test	Compliant - Class C
ISO 16750-4	5.1.1.2	Low Temperature Operation Test	Compliant - Class A
ISO 16750-4	5.1.2.1	High Temperature Storage Test	Compliant - Class C
ISO 16750-4	5.1.2.2	High Temperature Operation Test	Compliant - Class A
ISO 16750-4	5.2	Temperature Step Test	Compliant - Class A

continued on page 65...

8.1.2b Test Requirements for the MCU and Compliance Status

...continued from page 64

Standard	Section	Test	Status
ISO 16750-4	5.3.1	Temperature Cycling	Compliant - Class A
ISO 16750-4	5.3.2	Rapid Temperature Change	Compliant - Class C
ISO 16750-4	5.4.3	Submersion Test	Compliant - Class A
ISO 16750-4	5.6.2.3	Composite Temperature/Humidity Cyclic Test	Compliant - Class A
ISO 16750-4	5.6.2.4	Dewing Test	Compliant - Class B
ISO 16750-4	5.7	Damp Heat Steady State	Compliant - Class A
ISO 16750-4	5.5.1	Salt Spray Corrosion Test	Compliant - Class C
ISO 16750-4	5.5.2	Salt Leakage and Function Test	Compliant - Class A
ISO 16750-4	5.8	Corrosion Test with Flow of Mixed Gases	Compliant - Class C
ISO 16750-5	4	Chemicals - Various	TBC - Class[3]

Notes

1. MCU requires a user power recycle because current software does not allow recovery from certain faults. Additionally the current software does not support protection of low side drivers.

2. DC link capacitor pins breaking; however, there was no significant indentation made to the MCU, hence the non-compliance result.

3. Chemical tests were successfully carried out on prototype units; however, these were machined and not off-tool.

4. Break in track near fastener, hence the non-compliance result.

Safety, Regulations and Standards

8.1.3 REG10 Compliance Summary

For standards satisfied, please see below

Standard	Section	Test	Status
UNECE REG10	6.5 and 6.6	Radiated Emissions	Compliant
UNECE REG10	6.8	Radiated Immunity	Compliant
UNECE REG10	6.9	Transient Disturbances - Immunity	Compliant
UNECE REG10	6.7	Transient Disturbances - Conducted	Compliant

8.1.4 IP Compliance Summary

The MCU has an IP rating of IP6K9K as well as IP67.

Standard	Test	Status
UNECE REG10	Submersion	Compliant
UNECE REG10	Steam	Compliant

Figures and Tables Index

Figures

Tables

Paving the way for a cleaner, more energy-efficient world.

BorgWarner Inc.
3850 Hamlin Rd
Auburn Hills, MI 48326
USA

For additional BorgWarner information:
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