Hybrid Electric

Explore Our Technologies

AC Motor Controller

Dragon 8

Reference Manual V1.7

Document no: 177/52705

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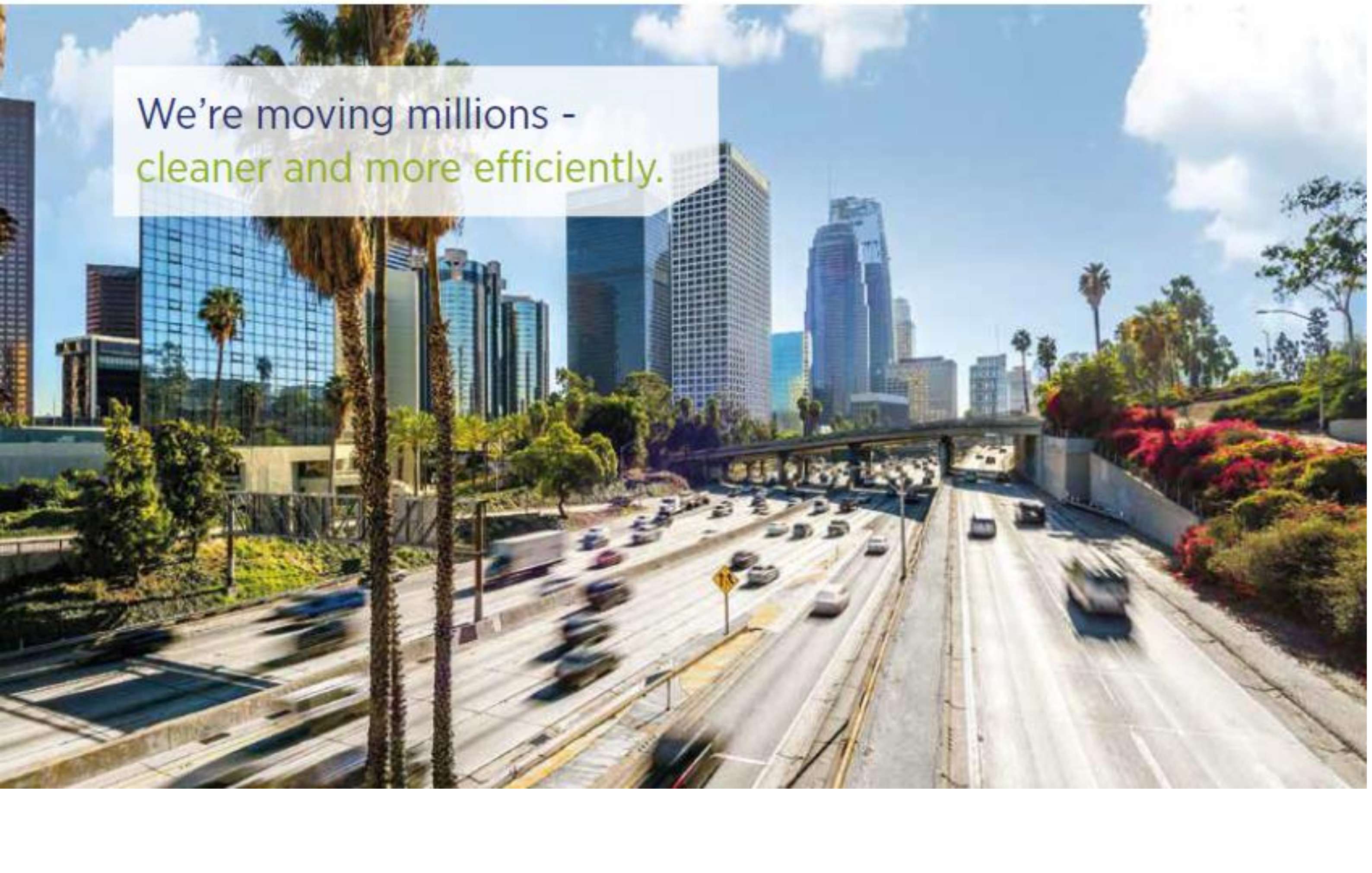
Hybrid Electric



Chapter 1: Legal Disclaimer

Chapter 1 - Legal Disclaimer

Trademarks

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No warranties and pre-presentations

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Licenses

No license to the BorgWarner's intellectual property or the intellectual property of third parties has been granted by this manual.

Important safety information

Electric vehicles (and their component parts such as motors, controllers and batteries) can be dangerous and cause severe damage to property and individuals if not handled correctly. All testing, fault-finding and parameter adjustment should be carried out by competent personnel. Incorrect parameter configuration or wiring can lead to an unsafe or dangerous system.

When setting up a new vehicle configuration, the vehicle should be immobilized with drive wheels raised on axle stands until the basic driver controls have been configured and the driver is able to stop the vehicle safely. Before this point, it is possible for full torque to be output from the motor, regardless of the driver demands.

Chapter 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

Chapter 2 - Introduction

2.1 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.

2.2 Purpose of this Manual

The first four chapters of this manual are intended to provide an overview of the Dragon 8 motor control product, and where this product could be applied.

The installation instructions in this manual, which have been written for qualified electrical and mechanical installation engineers, presents the basics of installing the Dragon 8 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.

2.2.1 The version of the manual

This version of the Dragon8 manual replaces all previous versions. BorgWarner has made every effort to ensure this document is complete and accurate at the time of printing. In accordance with our policy of continuing product improvement, all data in this document is subject to change or correction without prior notice.

2.2.2 Scope of this manual

The Application Reference Manual provides important information on configuring motor control systems using Dragon8 controllers as well as details on sizing and selecting system components, options and accessories.

This version of the manual applies to all controllers with BorgWarner part number:

635D94201 - 96V Dragon8 AC CONTROLLER

2.2.3 Related documents

The following documents are available from BorgWarner:

- DVT software user manual
- The Object Dictionary providing important information about CANopen communication with Dragon8 (integrated in DVT software)
- Application Notes for specific configuration:
    - H-Protocol
    - I-protocol
    - HVLP + D8 Line Contactor and Pre-Charge configuration
    - HVLP + D8 Mapping J1939 Items to VehApp
    - HVLP + D8 Motor Temperature Sensor configuration
    - HVLP + D8 + Gen5 Encoder configuration
    - HVLP + D8 Torque Conditioner
    - Vehicle EMC recommendations

2.3 Product identification label

If you have a customized product your unique identifier will appear at the end of the Type number. When discussing technical issues with BorgWarner always have your product's Type number, Part number and Serial number available.

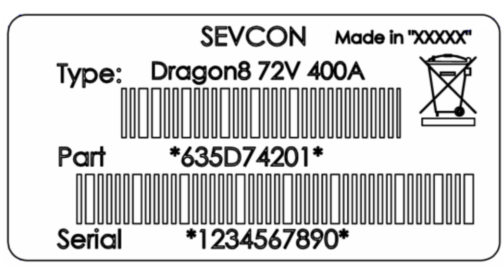


Figure 1 – Typical product Identification label

2.4 Sales and Technical support

BorgWarner is a major OEM focused business; however, we have an extensive authorized distributor network who can provide you with technical or commercial support. Please find the details of your nearest distributor through the following link https://www.borgwarner.com/aftermarket/controllers-converters/distributor-search

For direct customers of BorgWarner please contact one of the following BorgWarner offices for assistance:

- North America Office:
    - BorgWarner Southborough Inc. (US.drives.sales@borgwarner.com)
- European Office (+ Rest of World):
    - BorgWarner Systems Lugo S.r.l. (drives.sales@borgwarner.com)

2.5 Document Conventions

The following conventions are used within this document. Special attention must be paid to the information presented in Warnings, Cautions and Notes when they appear in this manual. Examples of the style and purpose of each are shown below:

Convention	Description
	**A WARNING indicates a hazard with a high level of risk, which if not avoided, will result in death or serious injury.**
	**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.**

Table 1 – Manual Conventions

2.6 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.

Chapter 3: About the Dragon8

Chapter 3 - About the Dragon8

3.1 Overview of Specification

BorgWarner Dragon8 controllers are designed to control 3-phase AC induction motors and Permanent Magnet AC (PMAC) motors in battery and generator powered applications.

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). It will also protect itself if the low voltage circuits are incorrectly wired.

Signal wiring and power connections have been 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. This I/O can be mapped to the CANbus for control by an external VCU.

Configuration and control of Dragon8 is fully customizable using the latest version of BorgWarner's DVT, a Windows based configuration software tool.

The state of the controller can be viewed by the integrated LED and can be presented via a signal to a dashboard mounted light for example.

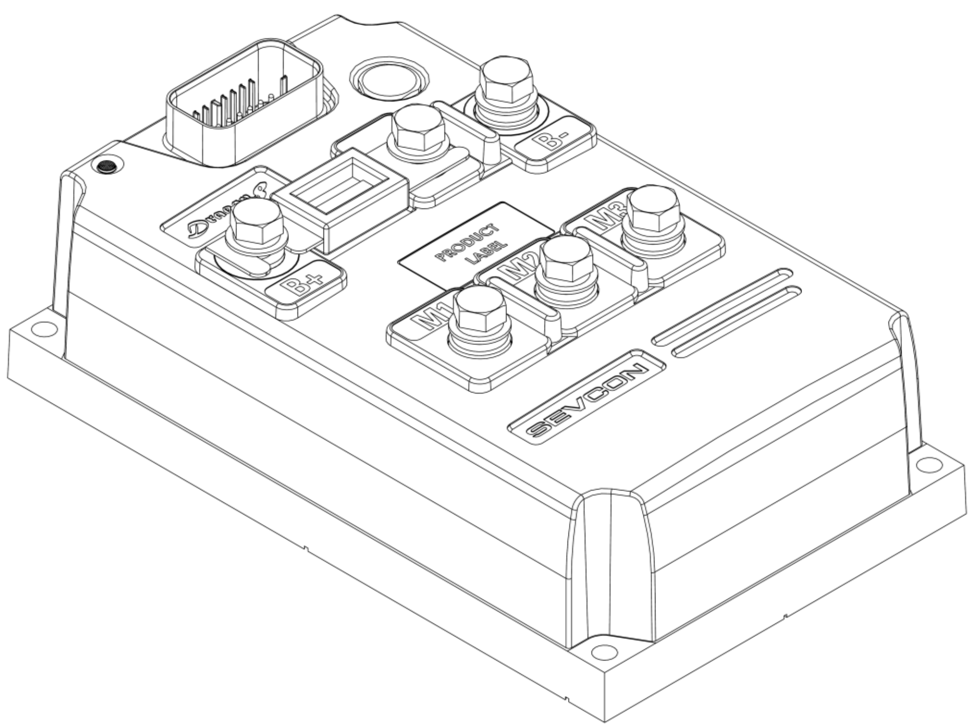


Figure 2 – Mechanical package

3.2 Standard features and capabilities

3.2.1 Intended use of the Dragon8

The Dragon8 motor controller can be used in many applications, such as:

- On-road 4-wheel EV
- 2-wheel electric motorcycle and scooter
- Off road ATV
- Utility vehicles and burden carriers
- Hybrid vehicle systems

3.2.2 Available accessories

The following accessories are available from BorgWarner:

- DC-DC converters
- Contactors
- Fuses
- DVT - PC based configuration tool

3.3 Principles of operation

3.3.1 Functional description

The main function of Dragon8 is to control the power flow to an AC electric motor - PMAC (SPM and IPM) or Induction. Measured phase currents and current demands are used as part of a closed-loop control system to calculate the necessary voltage demands for each phase of the motor. Voltage demands are then converted into PWM demands for each phase.

3.3.2 Internal subsystems

The electrical circuit blocks within Dragon8 have the following functions: -

- Control power supplies – these convert a 12V or 24V nominal supply into the voltage required for the control logic
- Control logic – software runs on microprocessor circuits with input and output circuits for analogue and digital inputs, motor encoder, CANbus and digital outputs.
- Isolated measurement circuits – voltage and current feedback are sent to the control logic. Over-current and over-voltage conditions are also detected.
- Gate drives – isolated low power signals from the control logic drive the inverter power stage devices. Output short circuits detected by these circuits are fed back to the control logic.
- Inverter power stage – this converts the DC battery supply into AC to power the motor.

See the following section for more details.

NOTE: The high voltage power circuits are fully isolated from the logic control and CAN circuits. All the required power supplies and control signals for the high voltage system are isolated from the low voltage system

NOTE: All the control inputs and outputs such as the analogue inputs, digital inputs and motor encoder are referenced to the 12V / 24V logic circuit ground. The CANbus is connected to the control circuit ground

CAUTION Do not connect the high voltage circuit to the 12V / 24V logic circuits directly. If you do this the isolation barrier will be bypassed. This could cause high voltages to be present on circuits which do not have protection against accidental contact

3.3.3 Power conversion section

The power conversion section of Dragon8 employs a 6-switch MOSFET bridge. Excellent electrical and thermal efficiency is achieved by:

- Minimization of thermal resistances
- Use of the latest MOSFET technology
- Internal thermal protection (if temperatures are excessive, switching frequency and output torque may be reduced)
- Overcurrent protection using device characteristics
- Internal measurement of output current
- Overvoltage trip in the event of regenerative braking raising battery voltage to unsafe levels

3.3.4 Interfaces

In addition to its motor control functions, Dragon8 offers many other functions designed to interface with electric systems. A variety of digital and analog input sources are supported.

On/off control of contactors is provided by Dragon8. All I/O on the Dragon8 controller is protected against short-circuit to the control logic positive and negative logic supply.

Dragon8 connectivity and interoperability with other system devices (for example A VCU) using a CANbus, the CANopen protocol, BorgWarner’s H-protocol (providing J1939 compatibility) and BorgWarner’s I-protocol is provided. In addition to in-service operation, the CANopen protocol allows the controller to be commissioned using the BorgWarner DVT tool.

3.3.5 General operation

The Dragon8 controller functions as a motor control and I/O slave, as shown in **Figure 3**. It can also function as a vehicle master using the internal TracApp functionality, see **Figure 4**.

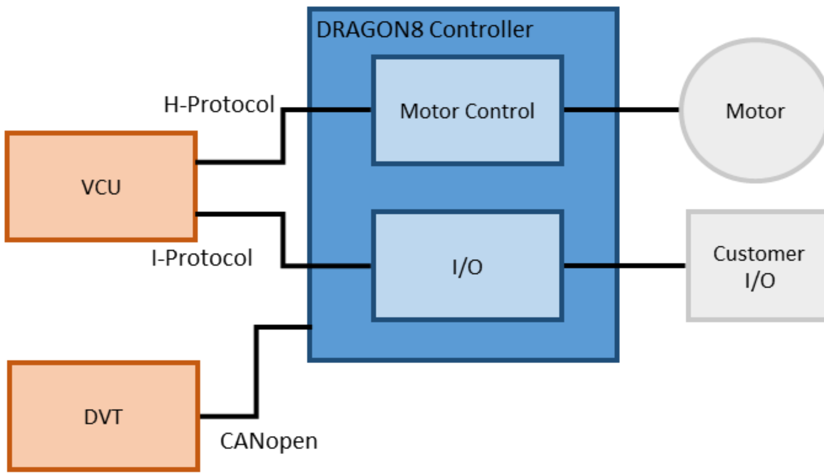


Figure 3 – Dragon8 Controller – Slave

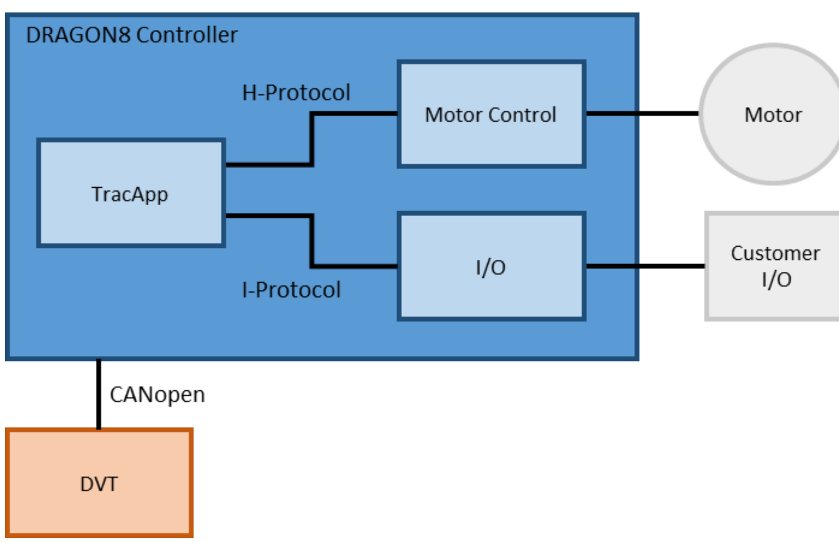


Figure 4 – Dragon8 Controller – Traction

The H-protocol allows the VCU to control the state, torque demand, drive/braking torque limits, forward/reverse speed limits and discharge/recharge current limits to be controlled. Refer to the H-protocol application note for more information.

I/O control is managed using the I-Protocol. Refer to the I-Protocol application note for more information.

3.4 Safety and protective functions

3.4.1 General

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

WARNING The battery or generator must be disconnected before replacing the controller. After the battery has been disconnected, wait for the internal capacitors to discharge to less than 60V before handling the controller or working near exposed terminals.

WARNING Hazardous voltages may remain on the controller internally and on exposed power terminals after the main battery power connections and keyswitch power supplies have been removed if the controller is connected to a rotating permanent magnet motor

Controller discharge profile is shown on page 56 for controller discharge times

WARNING Hazardous voltages may remain on the controller internally and on exposed power terminals after the main battery power connections and keyswitch power supplies have been removed if the controller is connected to a rotating permanent magnet motor

WARNING Never connect the controller to a battery with vent caps removed or a generator with an open fuel tank as an arc may occur due to the controller internal capacitance when first connected

WARNING Do not attempt to open the controller as there are no serviceable components. Opening the controller will invalidate the warranty

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

CAUTION Where appropriate, use of a suitable line contactor should be considered.

CAUTION 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 Dragon8 motor controller should be carefully considered and relevant safety precautions taken. The Dragon8 has several features which can be configured to help the system integrator to meet vehicle safety standards. BorgWarner accepts no responsibility for incorrect application of their products.

3.4.2 On-Highway Vehicles

This applies to all on-highway vehicles, such as cars, motorcycles, buses and trucks.

WARNING The installer must ensure an appropriate controller configuration is set to ensure that the vehicle remains in a safe condition, even in the event of a fault. The vehicle designer must ensure that the entire vehicle system complies with all international standards

3.5 Product warranty

Please refer to the terms and conditions of sale or contract under which the Dragon8 was purchased for full details of the applicable warranty.

Chapter 4: Specifications

Chapter 4 - Specification

4.1 Electrical

4.1.1 Input voltage – control supply

Nominal working voltage:	12V to 24V
Working voltage limits:	8V to 36V
Input protection:	Input protected against reverse connection of battery

Table 2 – Input voltage - control supply

4.1.2 Input voltage – DC Link supply

Nominal working voltage:	48V to 96V
Working voltage limits:	24V to 135V dc
Non-operational overvoltage limit:	145V dc
Input protection:	User must ensure that reverse polarity protection is provided external to the controller, for example by control of the main line contactor.
Surge protection	The Dragon8 controller requires external DC-Link pre-charge circuit to minimize inrush current.
Ground fault detection	User must ensure that ground fault protection is provided external to the controller, for example by control of the main line contactor.

Table 3 – Input voltage - traction supply

4.1.3 Motor Output protection

Output current:	Reduced automatically from peak to continuous rating depending on the time a peak load is applied to the controller. Reduced automatically if the controller or motor is operated outside normal temperature range.
Short-circuit:	Protected against any motor phase to B- or B+ at power-up. Protected against any motor phase to another motor phase at any time during operation. At switch-on the Dragon8 determines if valid output loads are present before applying drive current.

Table 4 – Motor output protection

CAUTION Repetitive short circuits may eventually damage the controller.

4.1.4 Output ratings*

Voltage	1-hour current	Peak current (2 mins)	Boost current (10s)
96V	110Arms	325Arms	480Arms

Table 5 – Output Ratings

* Based on 25C ambient

4.1.5 CAN interface

CAN protocol:	H-protocol and I-protocol are supported J1939 compatible Physical layer uses ISO11898-2.
Baud rates supported:	1 Mbits/s (default), 500 kbits/s, 250 kbits/s, 125 kbits/s, 100 kbits/s and 50 kbits/s.

Table 6 – CAN interface

4.1.6 Control inputs and outputs

Digital inputs:	3 digital switch inputs (software configurable polarity). Active low inputs < 2V, active high inputs > Vb – 2 V Current ~ 2mA when active
Analog inputs:	2 general purpose inputs which can be used for 2-wire potentiometers or dual throttle type devices: • 0 to 10V input • 10-bit resolution • Input resistance > 50kΩ All analog inputs can also be used as digital inputs.

Motor thermistor input	A motor thermistor (e.g. KTY84) can be connected between the analogue input and control 0V
	• Internal excitation for the thermistor
	• When configured with a KTY84:
	  ○ -40°C to +200°C measurement range
	  ○ ±5°C accuracy
	• Configurable to use a user defined characteristic.

Digital high side outputs	2 short circuit protected active high outputs. On / off control of the output only (equal to the logic supply voltage), no PWM voltage or current regulation Continuous source current = 2A
Analogue supply outputs	2 short circuit protected supply outputs: • 5V, 200mA max • 10V, 200mA max
Motor commutation sensor inputs:	Quadrature AB encoder signal inputs are provided for control of induction motors UVW digital position sensor or sin-cos analogue position sensor or resolver inputs are provided for control of permanent magnet synchronous motors.

Resolver excitation	Two outputs, Exc+ and Exc-, provide a fixed 10kHz excitation to a speed feedback resolver. Each output is 4V max pk-pk, 100mA, protected against short-circuit. Consult the ‘Resolver’ section in the System Design section of this document for important information about resolver feedback.

Table 7 – Control inputs and outputs

4.1.7 Isolation

Power terminals to the case:	2000V ac
Power terminals to control terminals	2500V ac
Control terminals and CAN bus to the case	2000V ac

Table 8 – Isolation

4.1.8 Regulatory compliance

The controller is designed to meet -

Safety regulations	EN 60664 Insulation coordination for low voltage equipment ISO 6469 Electrically propelled vehicles Safety specifications UNECE Reg 100 Electric vehicles - Construction & safety
EMC regulations	UNECE reg 10 approval of vehicles with regard to electromagnetic compatibility

Table 9 – Regulatory compliance

4.2 Mechanical

4.2.1 Operating environment

Operating ambient temperature:	-30°C to +25°C no current derating -40°C to -30°C and +25°C to +85°C with derating
Non-operational ambient temperature:	-40°C to +85°C (can be stored for up to 12 months in this ambient range)
Humidity:	3% to 95% at 40°C
Ingress of dust and water:	Signal connector fitted: IP66 rated Signal connector not fitted: IP42 rated

Table 10 – Operating environment (Dragon8)

4.2.2 Shock and vibration

Thermal shock	EN60068-2-14, Test Na
Repetitive shock:	50 g peak 3 orthogonal axes, 3+ and 3- in each axis, 11 ms pulse width
Drop test:	BS EN 60068-2-32:1993 Test Ed: Free fall, appendix B, Table 1
Bump:	40 g peak, 6 ms, 1000 bumps in each axis repetition rate 1 to 3 Hz.
Vibration:	3 g, 5 Hz to 500 Hz
Random vibration:	20 Hz to 500 Hz, acceleration spectral density 0.05 g^2/Hz (equivalent to 4.9 g_{rms})

Table 11 – Shock and Vibration

4.2.3 Weight

Weight (without fixings):	2kg

Table 12 – Weight

4.2.4 Dimensions

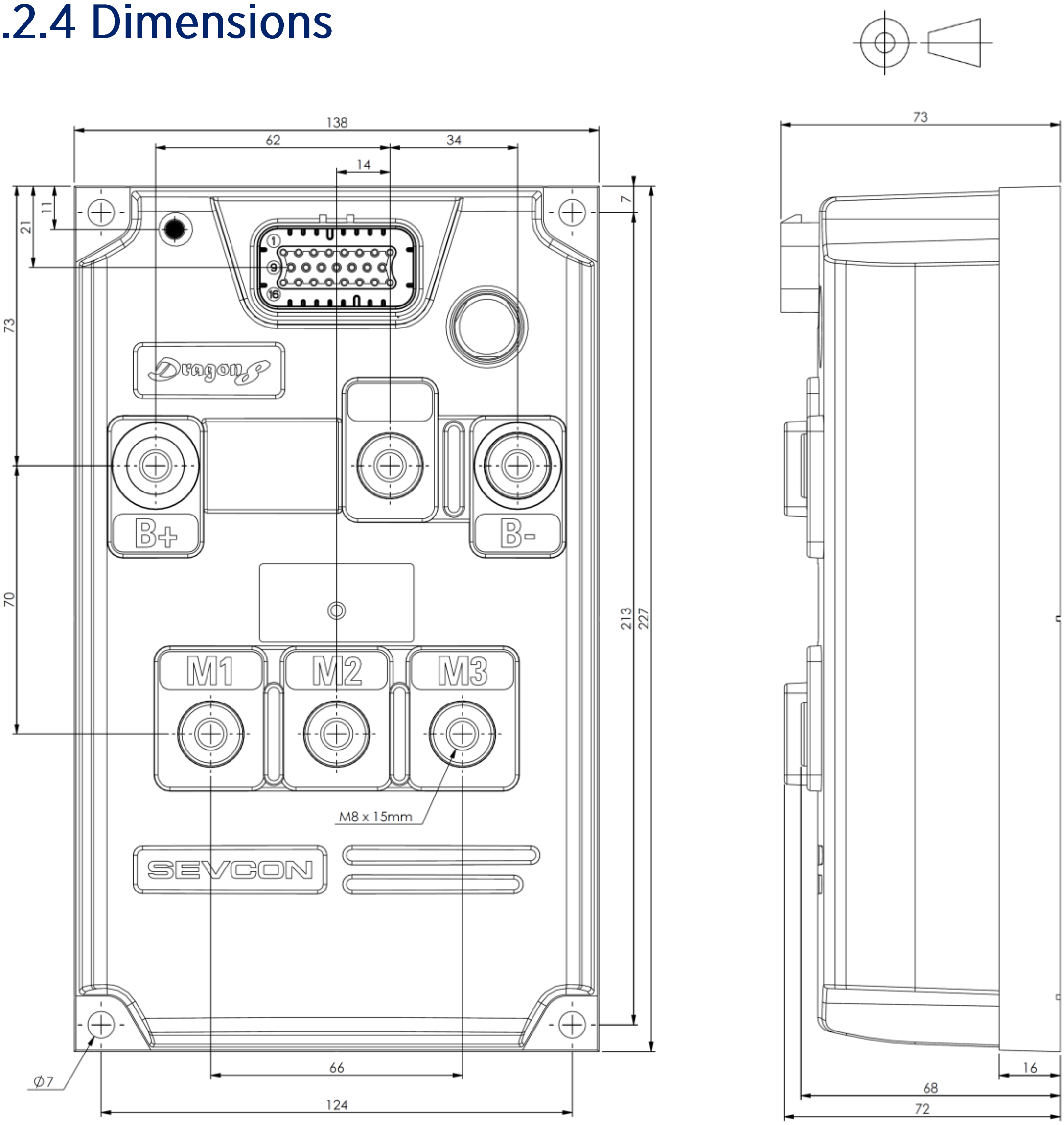


Figure 5 – Dragon8 drawing and dimensions

Chapter 5: Installation

Chapter 5 - Installation

5.1 Mounting Dragon8

5.1.1 Location

The mounting location for the controller should be chosen with care taking into account the following considerations: -

- Do not mount the controller on the outside of a vehicle where it would be accessible to unauthorized personnel (for the purposes of UL, the controller enclosure is not considered to be the 'ultimate enclosure' and as such it should be sited within another enclosure).
- Do not mount the controller where it may be susceptible to damage due to minor collisions, impact from road debris, or chemical contamination (see 'Protection from chemical contamination' below).
- Although the controller has a high degree of ingress protection, the electrical power terminals are exposed. Avoid mounting the controller in locations where it may be submerged in water, exposed to jets of water, or exposed to potentially conductive contamination and/or debris.
- Blocking the breather vent (see below) may lead to damage to the controller housing or allow water ingress

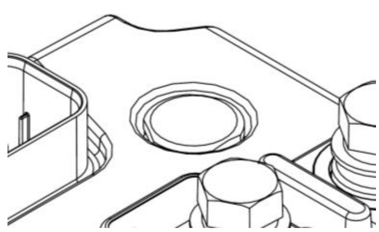


Figure 6 – Breather Vent location

5.1.2 Protection and Chemical Contamination

The covers of Dragon8 controllers are designed for good all-round protection of the electronics. However, the controller should be sited so that it cannot come into contact with significant quantities of industrial chemicals. The following have shown to be damaging to Dragon8 covers:

- Most esters (contained in 'bio' hydraulic fluid such as Shell Naturelle HF-E)
- Most industrial alcohols (contained in some contact grease such as Electrolube CG53A)

WARNING Electrical terminals on the controller present an electric shock hazard. High currents can also present a burn hazard. You must ensure that the electrical terminals of the controller are protected against access by unauthorized personnel

5.1.3 Orientation

The controller can be mounted in any orientation.

5.1.4 Clearance for LED Access

If you want an operator of your vehicle to be able to view the onboard LED, it is advisable to consider the line of sight to the LED.

5.1.5 Mounting Hole Pattern

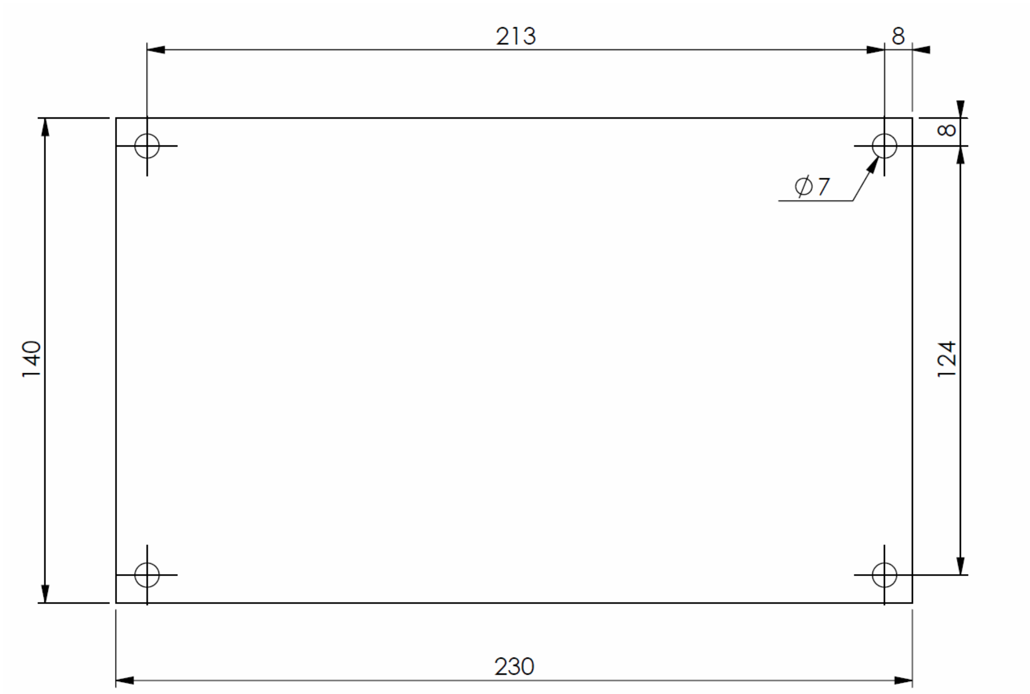


Figure 7 – Mounting Hole Pattern

Minimum flatness of mounting surfaces: 0.2mm

CAUTION Failure to comply with this flatness specification can cause poor product performance or deformation of the base and damage to the product.

5.1.6 Equipment Required

- 4 x M6 socket cap head screws and spring washers. Screws need to be long enough to pass through 16-18mm of Dragon8 base plate and penetrate the mounting surface a minimum of 8mm. If through bolting to a panel then nuts and additional washers will be required and the screws need to penetrate at least 1 thread turn through nuts.
- Socket wrench or Allen key
- Thermal grease
- Recommended torque setting: 10 Nm ± 2 Nm

5.1.7 Thermal Grease Application

It is recommended that a thermal interface material or thermal paste is used between the controller and the mounting face. Spread a layer of thermal grease (such as Dow Corning 340 or Novagard G641) as described below, before bolting to your mounting surface.

- Thermal compound should be applied with a hard, rubber inking roller of appropriate size to ensure an even spread of thermal compound.
- The most appropriate thickness will look white, but with a greyish color still showing through from the controller base or vehicle mounting face material. It should be noted that too little thermal compound will not fill all gaps left by the flatness mismatch of the contact surfaces. Too much thermal compound may prevent the gap from closing up when tightening.
- It is recommended that thermal compound is applied to both the Controller base and the vehicle/panel/boost plate surfaces.
- The controller should then be placed onto the vehicle/panel/heatsink.
- It is important that the two surfaces are then rubbed together in order to help transfer the thermal compound between the two surfaces.
- The entire assembly is then bolted together at all mounting holes.

An example of a good thermal compound spreading can be seen in Figure 8:

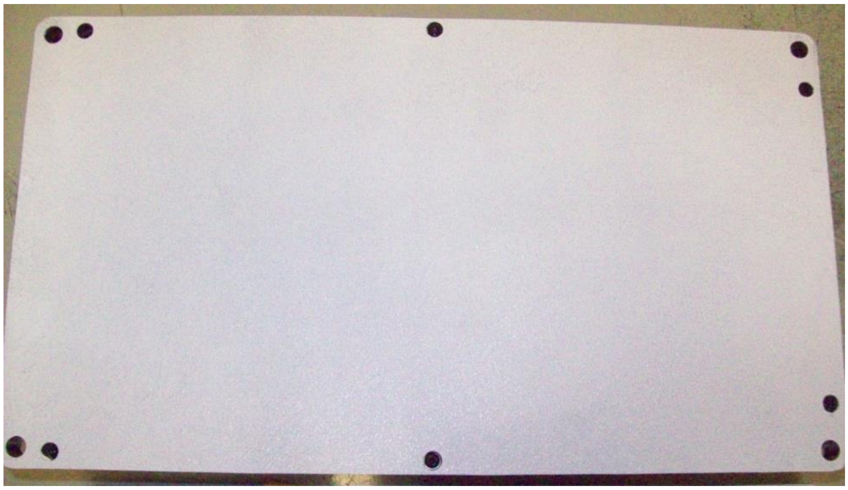


Figure 8 – Thermal compound spreading.

The effectiveness of the spreading technique can be checked by removing the controller and inspecting the paste residue left on the mounting faces. On a well applied paste application, the controller will be difficult to remove and a rippled surface will be left on the paste surface as shown (magnified) below:

Figure 9 – Example of thermal paste residue on mounting plate

5.2 Dragon8 Cooling requirements

To ensure you get the maximum performance from your Dragon8 controller:

- Keep it away from other heat generating devices on the vehicle
- Maintain its ambient operating temperature below the specified maximum, see table 12.

To obtain maximum performance, it is important to keep the Dragon8 base plate within the operating temperature range. To do this, mount Dragon8 to a surface capable of conducting away the waste heat. Finned heatsinks are considerably better at doing this than flat plates. For example, a finned heatsink used at BorgWarner has a footprint of 330mm x 200mm and thermal resistance of 0.3°C/W, whereas a plate approximately 420 mm x 270 mm x 9.5 mm will give approximately the same thermal performance (0.3°C/W).

In BorgWarner's experience, the thermal resistance of the stand-alone Dragon8 packages and achievable thermal resistances to ambient using conductive heatsinking are as shown in the table below. These are given as a guide: actual performance in an application must be verified.

Thermal resistance without additional heatsinking (°C/W)	Thermal resistance achievable with finned heatsink (°C/W)	Dimension of finned heatsink (W x L)
0.6	0.3	330mm x 200mm

Table 13 – Thermal resistance with/without heatsink

Cooling performance is affected by mounting surface flatness and the thermal transfer between mounting surface and Dragon8. Ensure your application of thermal grease is effective and your mounting surface meets the flatness figures as described in the 'Mounting' section above.

5.2.1 Dragon8 – Air Cooling

Optimum performance will be achieved when mounted in a ventilated location with a minimum of 1m/s airflow.

5.3 EMC guidelines

The following guidelines are intended to help vehicle manufacturers to meet the requirements for Electromagnetic Compatibility. Any high-speed switch is capable of generating harmonics at frequencies that are many multiples of its basic operating frequency. It is the objective of a good installation to minimize, contain or absorb the resultant emissions. All wiring is capable of acting as a receiving or transmitting antenna. Arrange wiring to take maximum advantage of the structural metal work inherent in most vehicles. Link vehicle metalwork with conductive braids.

5.3.1 General measures

5.3.1.1 Power cables

Use shielded power cable for all connections to the motor and the battery. Where cables pass through metal enclosures, such as at the motor and battery; use metal cable glands to connect the cable shield to the enclosure, ensuring that the various enclosures are linked with conductive braid to the vehicle chassis.

Route all cable within the vehicle framework and keep as low in the structure as is practical - a cable run within a main chassis member is better shielded from the environment than one routed through or adjacent to an overhead guard. Keep cables short to minimize emitting and receiving surfaces. Shielding by the structure may not always be sufficient - cables run through metal shrouds may be required to contain emissions.

Parallel runs of cables in common circuits can serve to cancel emissions - the battery positive and negative cables following similar paths is an example. Tie all cables into a fixed layout and do not deviate from the approved layout in production vehicles. A re-routed battery cable could negate any approvals obtained.

The cable manufacturer’s recommendations for minimum bend radius should always be followed.

Good practice when routing cables is to keep power cables at least 300mm from the signal cables.

5.3.1.2 Signal cables

Keep all wiring harnesses short and route wiring close to vehicle metalwork. Keep all signal wires clear of power cables and consider the use of shielded cable. Keep control wiring clear of power cables when carrying analogue information - for example, accelerator wiring and speed feedback. Tie all wiring securely and ensure it always follows the same layout.

5.3.2 Measures required for specific signals

5.3.2.1 High voltage battery/generator power cables

Cables should be as short as possible. Minimize the loop area of the B+ and B- wiring. A common mode ferrite choke may be required. Shielded cables may be required in some applications.

5.3.2.2 Motor power cables

Cables should be as short as possible. Minimize the loop area of the M1 M2 M3 wiring. A common mode ferrite choke may be required. Shielded cables may be required in some applications.

5.3.2.3 Motor encoder connection, types AB, UVW, Sin-Cos and Resolver

- The encoder cable must be as short as possible.
- A multi-core shielded cable should be used.
- The inner cores should be used for the encoder supply and encoder ground and the AB or UVW or Sin-Cos signals.
- For resolver, separate twisted pair shielded cables should be used for the primary excitation and the sine and cosine secondary signals.
- The cable shield should be connected to the control 0V.
- Ensure that the shield does not connect the motor chassis back to the encoder ground terminal. This is to avoid motor power cable current returning through the encoder cable shield.

5.3.2.4 CANbus

A multi-core shielded cable should be used. The inner cores must be twisted pairs. The twisted pair should be used for CANH and CANL. Ensure that there is a common ground connection for all nodes on the CAN bus. If there is a node on the bus which is galvanically isolated from the Dragon8 controller then the CAN ground on this node must be connected to the Dragon8 controller control 0V. The cable shield should be connected to the control 0V terminal at the Dragon8 controller

5.3.3 Additional measures

Where it has not been possible to meet the required EMC specifications using the standard measures listed above it may be necessary to use one or more of the following measures: -

- Use of shielded cable for all control connections
- Use of a Faraday cage around the controller and motor
- Addition of an LC filter on the keyswitch supply
- A common mode ferrite choke for all the small signal connections will attenuate common mode emissions

5.3.4 Problems to avoid

CAUTION EMC is a complex subject and on a typical vehicle there are many potential radiators and receivers. Measures taken on a vehicle to improve EMC can unintentionally make the situation worse

- Beware of devices that are connected to the small signal wiring which have a significant (>10nF) capacitance to vehicle chassis. The capacitance to vehicle chassis can cause currents to flow out of the Dragon8 controller along the signal wiring to the device and back to the controller via the vehicle chassis.
- When using shielded cable beware of generating ground loops in which currents may be induced or which may cause noise currents to flow via unintended paths.

5.4 Typical System

5.4.1 Wiring diagram

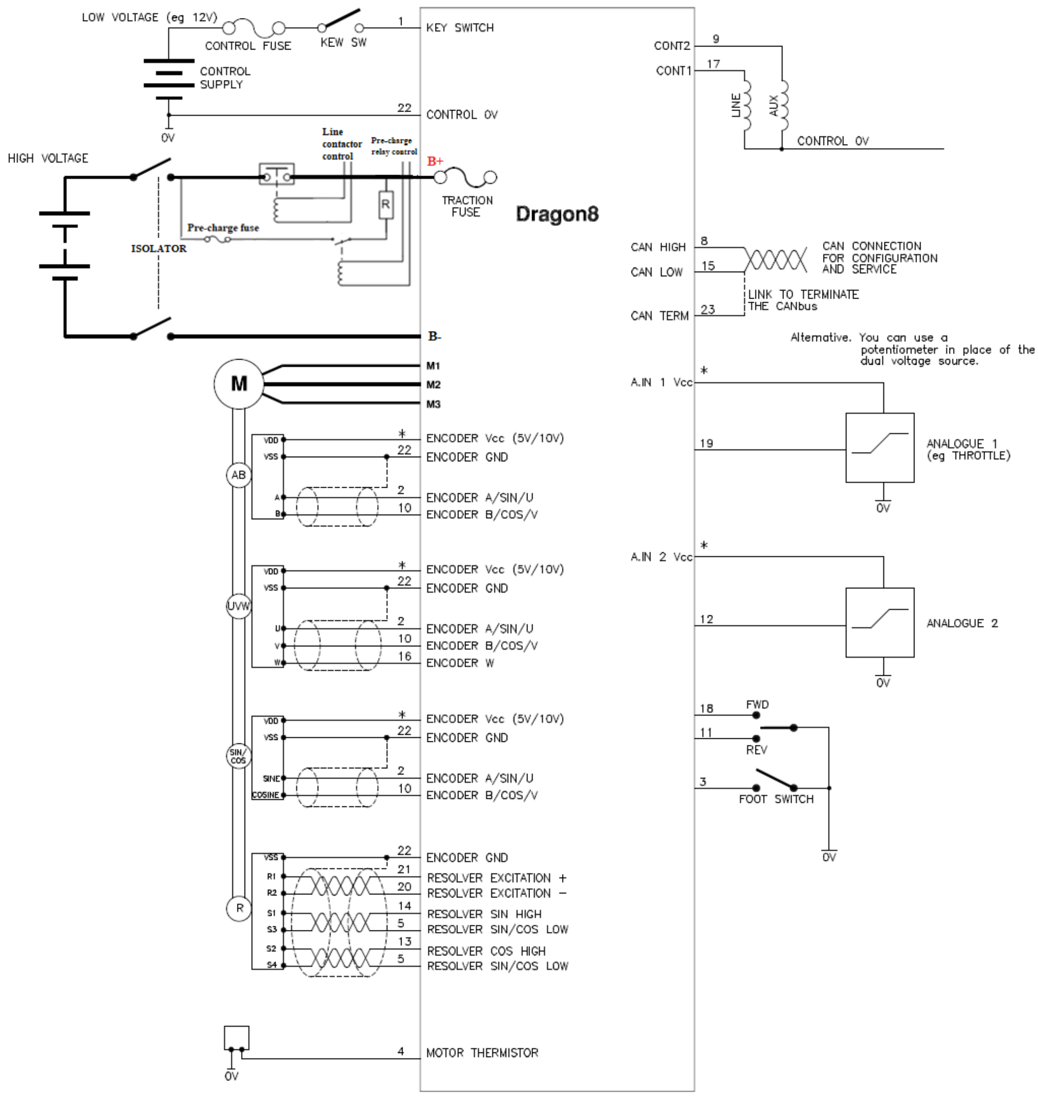


Figure 10 – Wiring Diagram

* pin 7 (5V or pin 6 (10V)

Encoder input signals AB / UVW can be configured as additional digital inputs if not used for an encoder.

Encoder input signals Sin-Cos can be configured as additional analogue inputs if not used for an encoder.

5.4.2 Signal wiring

Assemble your wiring harness using wire types recommended below. The use of shielded twisted pair cables is recommended for the encoder and CANbus wiring.

Pin	Name	Type	What to connect	Maximum rating	Comment
1	Key Switch KL15 / KL30	Power	From “dead” side of key switch via suitable fuse	V = 12V or 24V (Nominal) I = 1A maximum plus current required for digital outputs (5A total)	This input supplies power to the logic circuits within the controller. The unit cannot operate without a “Key switch” supply.
2	Encoder A / U / Sin	Encoder	Encoder: A if using AB or U if using UVW or Sin if using SinCos or Analogue input Ain4 or Analogue as digital input Din7		Shielded cable should be used for encoder connections. Only one encoder type can be configured at a time.
3	Digital Input 3	Digital	From digital switch input 3	Type B V = Vb See **Table 15**	See **Table 15** In a basic configuration this is usually the footswitch (FS1).
4	Motor Thermistor Input	Analog	Either from a thermistor device inside the motor or Ain3	V = 5 V (via 2.2 kΩ internal pull-up resistor)	Mapped to a user configurable table to program the resistance / temperature profile for the thermistor. Connect the other lead of the thermistor to the Logic 0V terminal of the Dragon8 controller. Can alternatively be used as an additional analogue input
5	Resolver Sin / Cos low	Analog	Resolver type encoder	6V peak to peak from resolver	Shielded cable should be used for encoder connections. Only one encoder type can be configured at a time.

6	10V supply output	Power	10V supply output	I = 200mA V = 10V	This output can be used to power transducers or similar devices at 10V and up to 200mA.
7	5V supply output	Power	5V supply output	I = 200mA V = 5V	This output can be used to power transducers or similar devices at 5V and up to 200mA.
8	CAN High	Comms	CAN bus high signal	V = 5V	Maximum bus speed 1 Mbits/sec. Note that the CANbus signals are referenced to Control 0V (pin 22).
9	Contactor 2 output	Output	To the switched high side of contactor or valve coil.	2.0A max output	This output provides high side voltage control to the load.
10	Encoder B / V / Cos	Encoder	Encoder: B if using AB or V if using UVW or Cos if using SinCos or Analogue input Ain5 or Analogue as digital input Din8		Shielded cable should be used for encoder connections. Only one encoder type can be configured at a time
11	Digital Input 2	Digital	From digital switch input 2	Type A V = Vb See **Table 15**	See **Table 15** In a basic configuration this is usually the reverse direction switch
12	Analogue Input 2	Analog	From potentiometer 2 wiper	V= 10V Zin = 50kΩ	Suitable for potentiometers in the range 500Ω to 10 kΩ, or a voltage-output device. For example, 0 to 5 V or 0 to 10 V. Ensure that at least 0.5V margin exists between the maximum valid throttle and the wire-off threshold
13	Resolver Cos High	Analog	Resolver type encoder	6V peak to peak from resolver	Shielded, twisted pair cable should be used for all resolver connections. Only one encoder type can be configured at a time.

14	Resolver Sin High	Analog	Resolver type encoder	6V peak to peak from resolver	Shielded, twisted pair cable should be used for all resolver connections. Only one encoder type can be configured at a time.
15	CAN Low	Comms	CAN bus low signal	V = 5 V	Maximum bus speed 1 Mbits/sec. Note that the CANbus signals are referenced to Control 0V (pin 22).
16	Encoder W	Encoder	Encoder: W if using UVW Digital input DIn6	0 - 5V from encoder.	Shielded cable should be used for encoder connections. Only one encoder type can be configured at a time
17	Contactor 1 output	Output	To the switched high side of contactor or valve coil.	2.0A max output	This output provides high side voltage control to the load.
18	Digital Input 1	Digital	From digital switch input 1.	Type A V = Vb See **Table 15**	See **Table 15** In a basic configuration this is usually the forward direction switch
19	Analogue Input 1	Analog	From potentiometer 2 wiper	V= 10V Zin = 50kΩ	Suitable for potentiometers in the range 500Ω to 10kΩ, or voltage-output device. For example, 0 to 5V or 0 to 10V. Ensure that at least 0.5V margin exists between the maximum valid throttle and the wire-off threshold
20	Resolver Excitation low	Analog	Resolver type encoder	10kHz 10V pk-pk (max)	Shielded, twisted pair cable should be used for all resolver connections. Only one encoder type can be configured at a time
21	Resolver Excitation High	Analog	Resolver type encoder	10kHz 10V pk-pk (max)	Shielded, twisted pair cable should be used for all resolver connections. Only one encoder type can be configured at a time

22	Control 0V	Power	Logic Power supply ground connection	0V	
23	CAN Termination	Comms	To terminate the CANbus for this node, link this pin to pin 15. This connects an internal 120Ω termination resistor across the CANbus.		Make the connection only if the controller is physically at one end of the CANbus network

Table 14 – I/O Pin allocation

Keep signal wires away from power cables to avoid electrical interference.

5.4.3 Signal wire size

Use wire between 0.5 mm² (20 AWG) and 1.5 mm² (16 AWG) for all signal wiring. Single twisted pair cable is readily available in 0.5 mm² (20 AWG).

5.4.4 Digital input configuration

Digital inputs can be configured as either active-high (switched to Keyswitch (KL15/30)) or active-low (switched to Control 0V). This configuration applies to all dedicated digital input switches (1 to 3) i.e. all must be active-high or all active-low. See section Digital inputs (page 72) for more details.

Three digital input types are used by the Dragon8:

Digital Input Type	Resistance to Keyswitch	Resistance to Control 0V
A	10kΩ	12.56kΩ
B	12kΩ	10.56kΩ
C	*	*

Table 15 – Impedance at Digital Input Pins

* Type C digital inputs are coupled via a blocking diode and are pulled up to an internal 5V source via a 1kΩ resistor.

When a switch is open the digital input pin sits at 0.5 x Vb (type A), 0.46 x Vb (type B) and 4.5V (type C).

5.4.5 CANbus termination

If your system has more than one CAN node, connect the nodes in a ‘daisy chain’ arrangement and terminate the connections of the two end nodes of the CANbus with a 120Ω resistor. If the end node is a Dragon8, link pins 15 and 23 on the customer connector; a 120Ω resistor is built into the controller.

If you have a single node system, the termination resistor should be connected so that the bus operates correctly when configuration tools (such as DVT) are used.

5.4.6 Signal connections

Signal connections are made to Dragon8 via a 23-way AMPSeal connector, Tyco P/N 770680-1. Which uses the followings terminals Tyco P/N 770854-1 (for 0.5 mm^2 – 1.25mm^2 wire size).

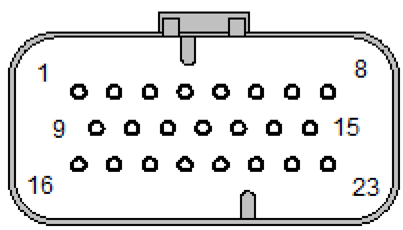


Figure 11 – AMPSeal Connector Pin Numbering

Gently push the connector housing onto the mating half of the Dragon8. Never force a connector. Mating ends are keyed to prevent incorrect insertion.

Inserting contacts into connector housing pierces the sealing diaphragm and forms a seal around the wire. If a contact is inserted and subsequently removed, it must be re-sealed with appropriate hardware (available from Tyco 770678-1) to maintain IP rating.

Tyco strain relief 776464-1 is recommended (especially for applications where the connector is not fully populated) to reduce chance of ingress through the connector body.

NOTE: Please see Tyco Application Specification 114-16016 and Instruction sheet 408-3229 before assembling the AMPSeal connector

5.5 Connecting power cables

See also the section on EMC Guidelines.

5.5.1 Battery and motor connections

CAUTION Cables carrying high currents are subject to mechanical forces and may require support in the cable harness to avoid long-term fatigue

CAUTION Terminal connections may degrade with multiple screw insertion/torque cycles leading to terminal overheating. Controllers are typically rated for 5 installation cycles

Equipment required:

- 6-off M8x16mm screws, flat washers and spring washers
- Cables sized to suit the controller and application (see table below)
- M8 crimp ring lugs
- Crimp tool
- Suitable torque wrench and socket

Torque setting: 11 Nm ± 2 Nm

CAUTION If you use an incorrect torque, poor electrical connection or damage to the terminal may occur leading to overheating of the terminal

Consider cable routing before making connections.

- Keep cable runs short. Battery cable run should be less than 3m. Battery cable lengths greater than 3m will risk damage to the integrated battery switch.
- Minimize current loops by keeping positive and negative cables as close together as possible.
- Route cables away from the LED if you intend to make this visible under normal operating conditions.

Connect your power cables using the correct screws and **USE THE CORRECT TORQUE**. The recommended screws are sized to clamp one ring lug thickness. Use a longer screw if you are fastening more than one ring lug. You need thread engagement of at least 10 mm and the maximum penetration is 15 mm.

CAUTION If you use a screw which is too long, damage to the terminal and overheating of the connection may occur. If you use a screw which is too short and there isn’t enough thread engagement you may damage the threads

CAUTION ‘Bottoming out’ a screw in the terminal marked ‘B+’ will damage the cover leading to liquid ingress

5.6 On-board fuse mounting

You can mount your main input protection fuse directly onto the controller body as shown below. Connect the battery positive cable to the B+ terminal. Connecting to the other end of the fuse will connect battery voltage to the controller but will leave your installation without a fuse unless a fuse is located elsewhere in the system. The B+ terminal is a dummy terminal to allow fuse connection only and has no internal connection.

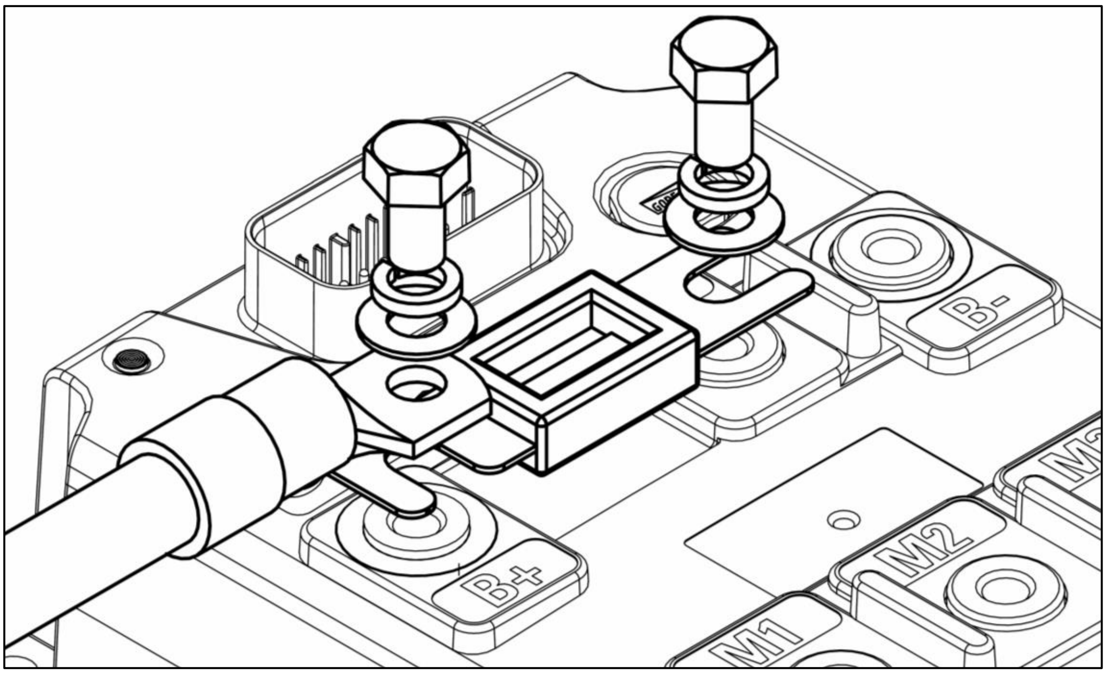


Figure 12 – On-board fuse mounting

Fuse rating and selection

On-board fuse dimensions are in accordance with DIN43560/1. The fuse rating should be selected based on the application and should not be greater than 500A for the 96V controller.

5.6.1 Line contactor and pre-charge

The Dragon8 controller (635D94201) does **NOT** have an integrated pre-charge circuit or reverse battery connection protection for the DC power connections. An external line contactor and pre-charge is required. The Dragon8 has 2 digital outputs (same voltage as supplied to KL15/KL30) that can be mapped to control the external pre-charge relay and line contactor. Further information will be found in Chapter 6 under ‘Main contactor and pre-charge circuit’.

Chapter 6: System Design

Chapter 6 - System Design

6.1 Auxiliary components

6.1.1 Main Contactor and Pre-charge circuit

The Dragon8 96V controller does not offer any internal pre-charge function. Pre-charge must be done externally to the unit. If battery isolation is required for the application, an external device must be used to isolate the Dragon8 from the vehicle battery.

It is recommended that the pre-charge circuit is connected as shown in Figure 13. The circuit is intended to operate in the following manner: -

- At start-up K1 must be energized, the controller DC bus voltage should be monitored and should have reached 90% of the battery voltage within 5 seconds.
- If the DC bus voltage is more than 90% of battery voltage the main contactor K2 can now be closed. If the DC bus voltage is too low, this indicates a fault has occurred and K1 should be de-energized.

At shut-down K1 and K2 may be de-energized simultaneously.

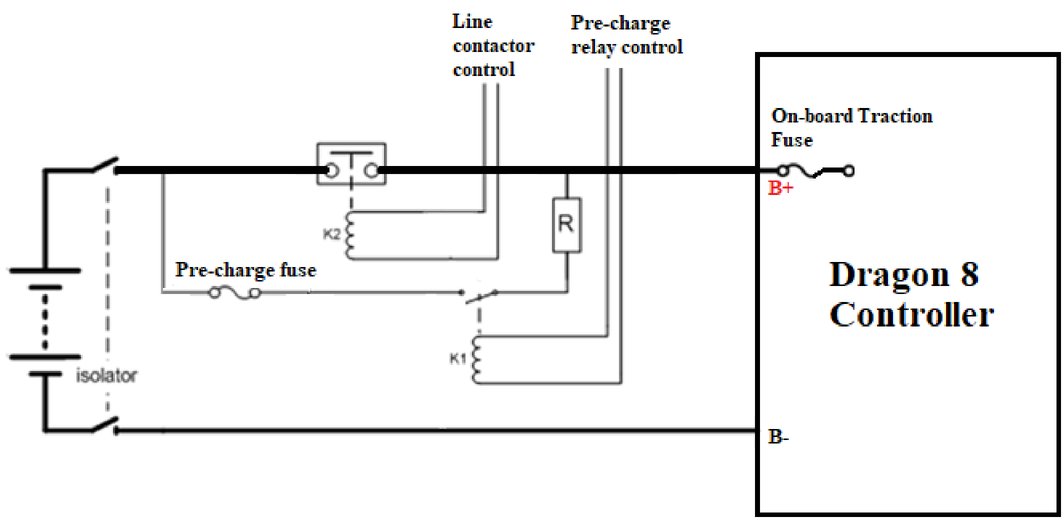


Figure 13 – Line contactor and pre-charge wiring diagram

Components required for the pre-charge circuit are listed in Table 16.

Name	Function	Required specification	Comment
F1	Pre-charge fuse	10A 150V DC Slow blow preferred	
K1	Pre-charge contactor / relay	Single pole 150V DC 5A	
K2	Main line contactor	Single pole >150V DC >500A	Must be interlocked so that K2 can only close if K1 is energized.
R1	Pre-charge resistor	Resistance 33Ω to 100Ω Pulse voltage 150V Energy pulse 100J Power 25W	Must be overload protected with thermal cut out and/or fuse

Table 16 – Pre-charge Components

WARNING Failure to use a capacitor pre-charge circuit may damage the controller and line contactor

A switchable resistor can be used to limit pre-charge inrush current. System voltage and other requirements should be used to determine the resistance and power values. The line contactor should close only after the controller has reached 90% of the battery voltage. The system should not remain in pre-charge for more than 5 seconds.

WARNING The internal DC capacitor bank will remain charged at a hazardous voltage for several minutes after power has been removed

Note that, if you use the built-in contactor drivers (digital outputs) for the pre-charge relay and main line contactor, the coil specification must fall within the working limits of the Dragon 8. Please refer to Table 14.

6.1.2 Digital Outputs from Dragon8

The digital outputs can provide up to 2A each and may be used for various purposes (e.g. lamps, relays, contactors). But users should be aware that these outputs are powered from KL15/KL30 (keyswitch supply). Therefore, any contactors driven by those outputs will immediately open after keyswitch power is removed – even if the motor is still turning.

See Figure 14 for a circuit diagram showing the internal components.

The digital outputs are short circuit and thermally protected. An internal snubber circuit protects the system from flyback voltage when de-energizing an inductive load. Do not connect an external flyback diode in parallel with the load, as this will defeat the reverse battery (keyswitch) protection of the Dragon8.

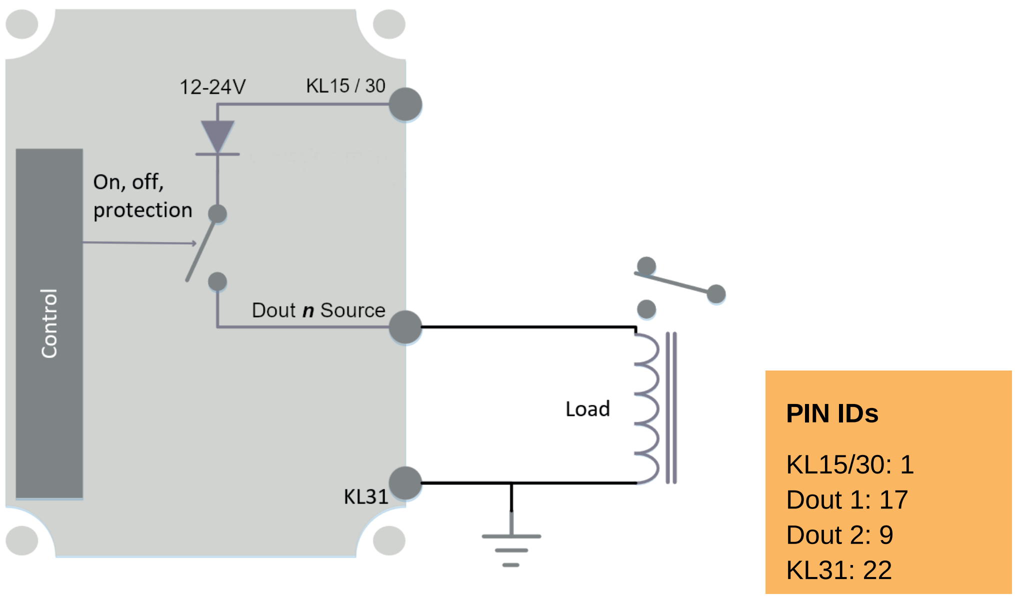


Figure 14 – Digital Output Schematic

Note the following:

- Digital outputs are ON/OFF only, there is no PWM function
- The load is referenced to the Control 0V (logic ground)
- The load must not have (and do not fit) a parallel diode, as this would bypass the reverse battery (logic) protection

6.1.3 Key switch fuse

Use a fuse rated for the sum of the current required for the digital outputs plus 2A for internal circuits.

6.1.4 Motor speed sensor (AB encoder)

A 4-wire connection is provided for open-collector quadrature pulse encoder devices. These types of encoder are optimized for accurate speed measurement, required for efficient control of induction motors.

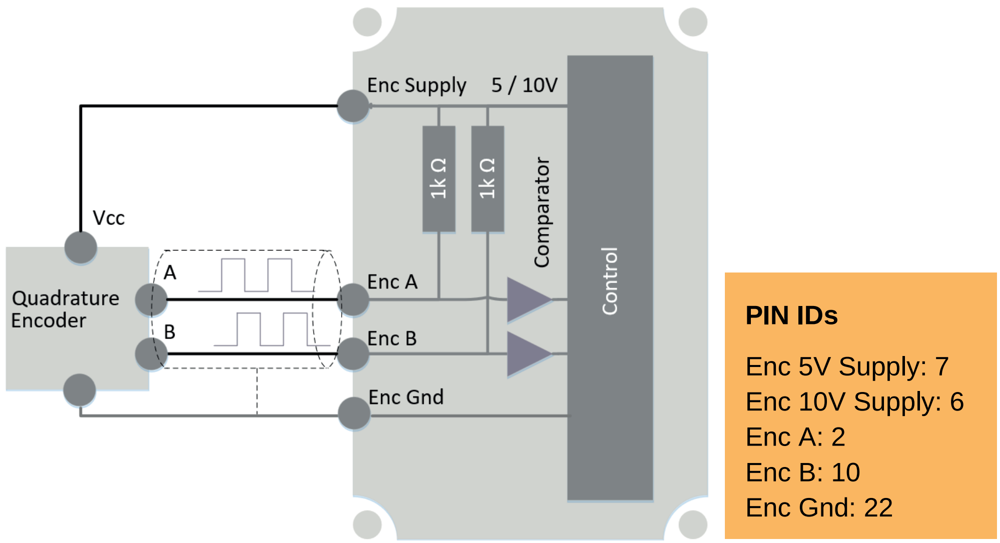


Figure 15 – Sample wiring for an AB quadrature speed encoder

* Encoder supply may be connected to pin6 (+10V) or pin7 (+5V)

The number of encoder pulses per revolutions (**n**) and the maximum motor speed (**N**) are related to, and limited by, the maximum frequency of the encoder signal (**f**$_{max}$).

$$f_{max}(Hz) = \frac{n(per\ rev) \times N(rpm)}{60}$$

with **f**$_{max}$ limited to 200 kHz, and

$$N_{max}(rpm) = \frac{20000(rpm)}{(p/2)}$$

Please refer to page 70 for information on entering encoder settings.

6.1.5 Motor commutation sensor (UVW / sin-cos / resolver)

Commutation sensors are designed to measure the absolute position of the rotor shaft within the motor, rather than its rotational speed. Rotor position information is used for control of permanent magnet motors, as it allows the controller to energize the motor phases appropriately based on the measured position of the magnets on the rotor.

6.1.5.1 UVW Commutation Sensors

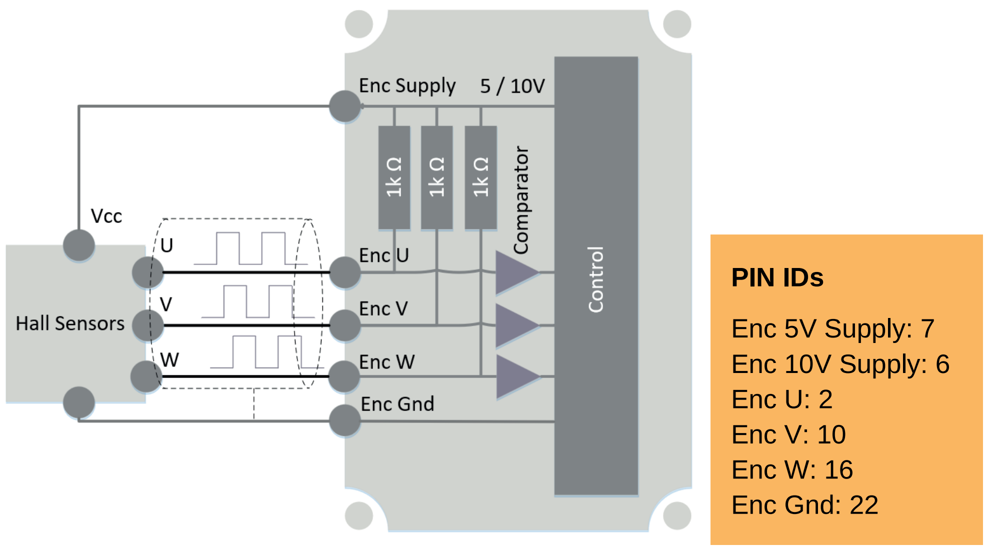


Figure 16 – Sample wiring for a UVW commutation sensor

* Encoder supply may be connected to pin6 (+10V) or pin7 (+5V)

3 digital inputs are provided for UVW encoders, with options of a 5V (pin7) or 10V (pin6) power supply. The encoder should provide one pulse on each UVW channel per electrical cycle of the motor, and each pulse should be 120° out of phase with the others and have a 50% duty cycle.

Figure 17 shows an example pulse train for the U, V and W inputs.

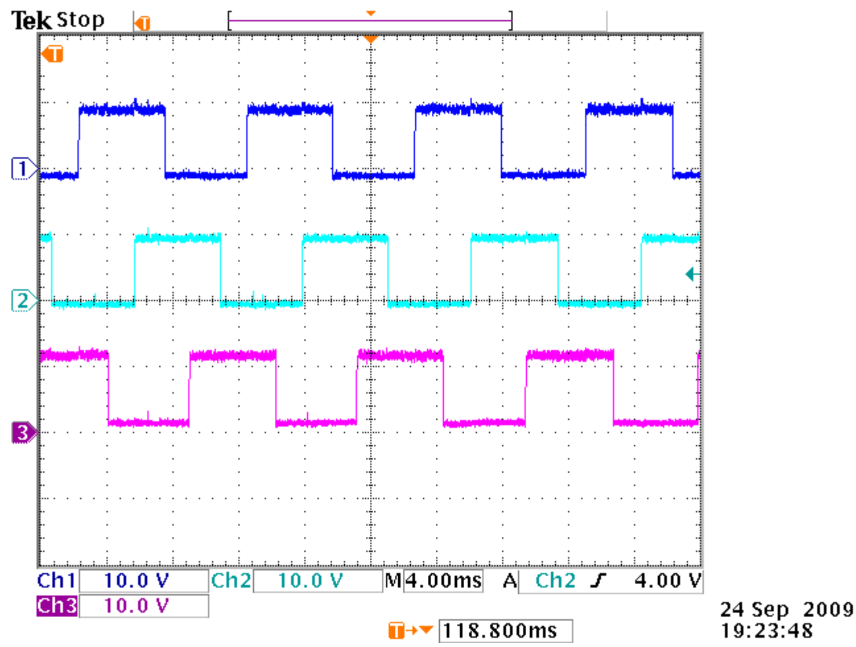


Figure 17 – Example pulse train from a UVW commutation sensor

6.1.5.2 Sin-Cos Commutation Sensor

Analogue sin-cos encoders generate a number of sin and cosine waves per mechanical rotation of the motor.

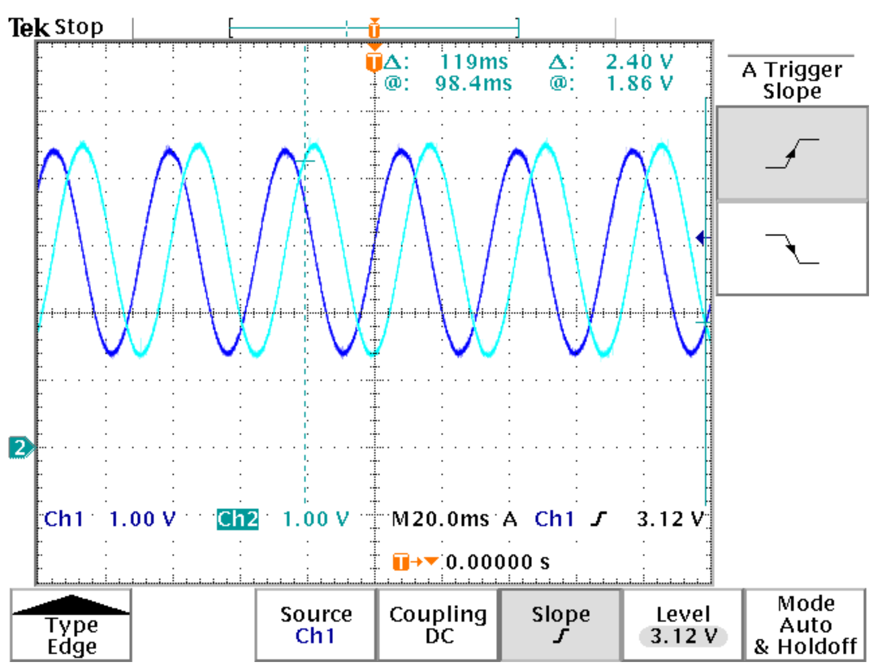


Figure 18 – Example of signals from a sin-cos position sensor

BorgWarner

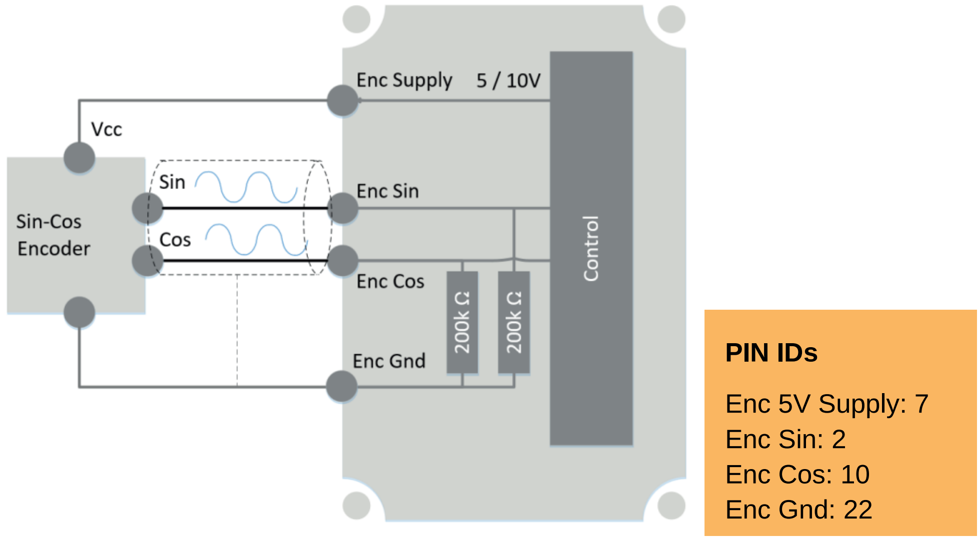


Figure 19 – Sample wiring for a sin-cos commutation sensor

Sin-cos encoders are typically powered by a +5V supply. Therefore, it is important that the sin-cos encoder supply is connected to pins 7 and 22.

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

For example:

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

6.1.5.3 Resolver

The resolver is a position feedback device which requires a sinusoidal excitation (provided by the Dragon8 controller). The position feedback consists of two pairs of signals: a resolver sine pair and a resolver cosine pair (Figure 20). These signals consist of the excitation frequency modulated by the sin or cosine (respectively) of the rotor position.

The following issues are important when selecting a resolver: mechanical, environmental and electrical specification.

- Mechanical specification includes e.g. material; dimensions; max speed; max angular acceleration; rotor moment of inertia; resistance to shock; resistance to vibration; permitted axial offset; permitted radial runout (deviation from true circle) of motor shaft.
- Environmental specification includes: max operating temperature (including self-heating); IP rating.

- Electrical specification includes: number of pole pairs (p); transformer ratio (Rt); angular error tolerance; residual voltage; recommended input voltage; recommended operating frequency; maximum primary current.

Regarding mechanical and environmental specification, the user must select a resolver appropriate to the environment of the application.

Regarding electrical specification, the following features are required of a resolver to work with the Dragon8:

- Transformer ratio = 0.2 to 0.6
- Excitation frequency = 10kHz
- Excitation voltage = 5Vrms nominal (a resolver specified to 5Vrms or higher will be acceptable)

The controller is able to control motors with multiple pole-pair resolvers (i.e. returning multiple sin and cosine waves per mechanical rotation). However, it is required that the number of pole pairs in the motor is an integer multiple of the number of resolver pole pairs.

For example:

- A single pole pair encoder can be used with motors that have 1 pole pair, 2 pole pairs, 3 pole pairs, etc.
- A 3-pole pair encoder can be used with motors that have 3 pole pairs, 6 pole pairs, 9 pole pairs, etc.
- A 5-pole pair encoder can be used with motors that have 5 pole pairs, 10 pole pairs, 15 pole pairs, etc.

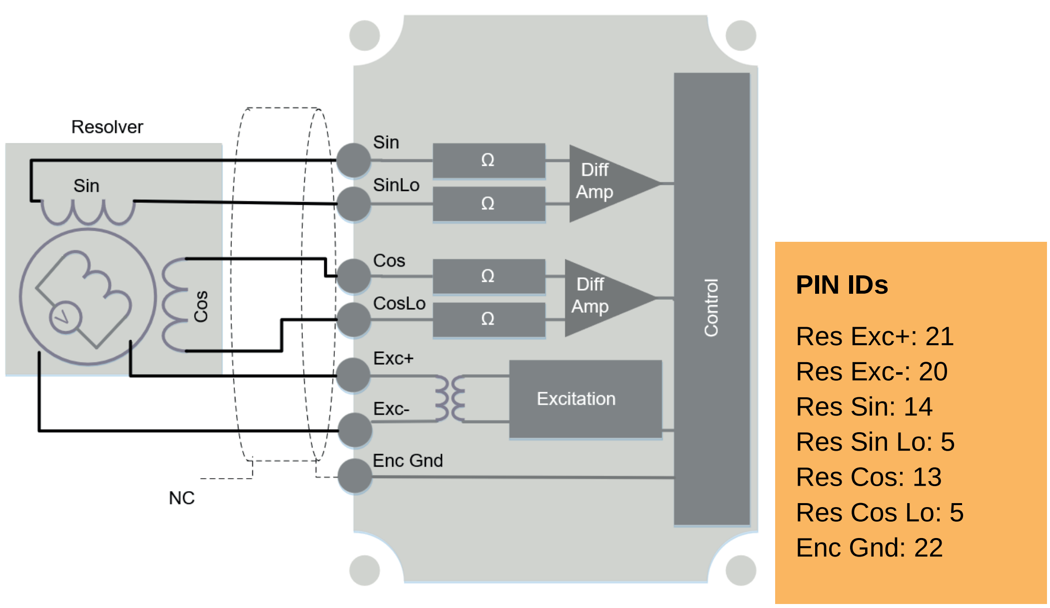


Figure 20 – Sample wiring for a resolver

NOTE: Resolver Sin Lo and Resolver Cos Lo are the same pins on Dragon 8

NOTE: Only connect a single type of encoder to the Dragon8 at any given time

6.2 Initial power up sequence

WARNING Incorrectly wired or configured vehicles may behave in unexpected ways

6.2.1 Checks prior to power up

Follow this checklist prior to applying power to your system:

- Confirm all connections are tightened to specified level.
- Ensure all plugs are fully inserted.
- Confirm power wiring connections are made to the correct terminals (B+, B-, +, M1, M2 and M3).
- Ensure the controller is securely mounted (from a mechanical and thermal perspective).
- Check the routing of cables is safe with no risk of short circuit, overheating or cable insulation wear due to rubbing.

6.2.2 Checks after power is applied

Apply power and do the following:

- Use DVT (see page 59) or any configuration tool to complete the configuration process which starts on page 68.
- Using the drive controls ensure the wheels rotate in the expected direction. If they do not, check the motor wiring, encoder wiring and encoder configuration (page 70).

6.3 Discharge sequence after power down

WARNING Hazardous voltages will remain on the controller internally and on exposed power terminals for a period of time after the main power connections have been removed. Allow sufficient time for the DC link capacitors to discharge

WARNING Hazardous voltages may remain on the controller internally and on exposed power terminals after the main battery power connections and keyswitch power supplies have been removed if the controller is connected to a rotating permanent magnet motor

6.3.1 Controller discharge profile

The following graph shows the standard controller discharge curve which should be observed. Do not open the unit or work near exposed power terminals until the voltage has reduced to a safe level.

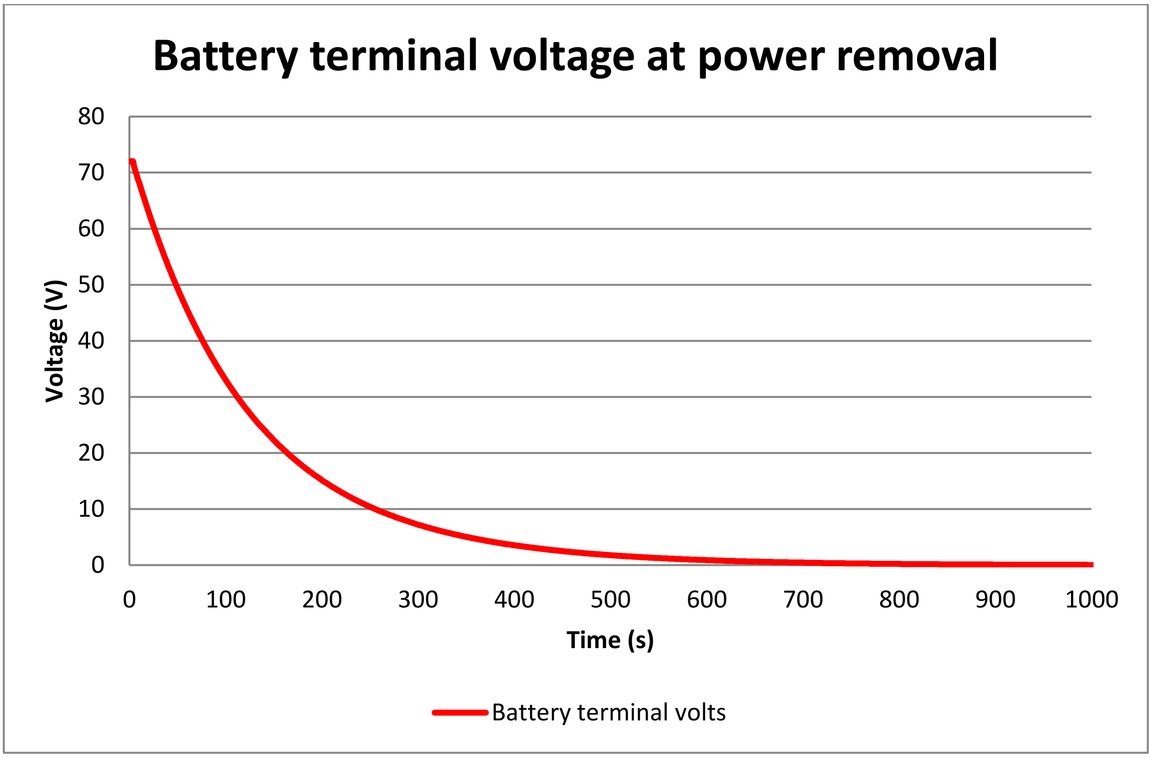


Figure 21 – Typical discharge curve for the Dragon8 controller

To determine the required time, note the time at which the "Voltage (maximum)" curve crosses the horizontal gridline corresponding to the supply voltage. Then note the time at which it crosses the horizontal gridline corresponding to the safe voltage level. The difference between the two times is the safe discharge time.

This information is for guidance only, and before any work is carried out on the high voltage connections, it is essential the voltage is checked using a DVM (digital voltmeter) and probes rated for at least 600V

NOTE: To achieve a shorter discharge time the vehicle system designer must ensure that a circuit is also incorporated to discharge the Dragon8 capacitor bank when it is disconnected from the battery

CAUTION If the controller is disabled and connected to a rotating permanent magnet motor, the discharge circuit will be exposed to the rectified back emf even if the controller keyswitch power supply is turned off. The line to line peak back-EMF must not exceed 145V. By maintaining a permanent connection to the battery when the motor is rotating, the battery can clamp this voltage to an acceptable level providing it can absorb the uncontrolled regenerative energy

Chapter 7: Configuration

Chapter 7 - Configuration

7.1 Introduction

This section covers how Dragon8 software is configured once hardware has been designed and installed into a vehicle. All the Dragon 8 parameters have default values and the amount of configuration needed is dependent on your particular system.

The main topics are:

- DVT configuration tool: installation and use
- CANopen: an introduction to the protocol and its use in BorgWarner products
- An overview of the configuration process outlining what needs to be done and the order in which it must be done
- The configuration steps

7.2 DVT configuration tool

DVT is BorgWarner's proprietary configuration tool. It allows the user to monitor, configure and duplicate the parameters of any BorgWarner CANopen node such as the Dragon8 controller. The information presented here is an overview only. Contact BorgWarner for more information about DVT and the functions it provides.

7.2.1 DVT functionality

DVT provides the following facilities:

- Configuration of controller IO, CANbus and motor parameters
- Loading DCF configuration file into the BorgWarner controller
- Saving of DCF configuration file from controller to file on computer
- Controller status and fault diagnosis
- Data logging of controller/motor performance on test bench or vehicle
- Update controller firmware

7.2.2 Saving, duplicating and restoring a node's configuration

You can use DVT to:

- Save a node's configuration. This can be used at some later date to clone the node's configuration.
- Duplicate a node's configuration, in real time, to another node on the CANbus.

- Restore a configuration to a node.

For example, if you want to save the Dragon8 controller configuration, you will need to create a DCF file. To do this, open the DVT Configuration helper by clicking the “**H**” icon at the top of the DVT main window.

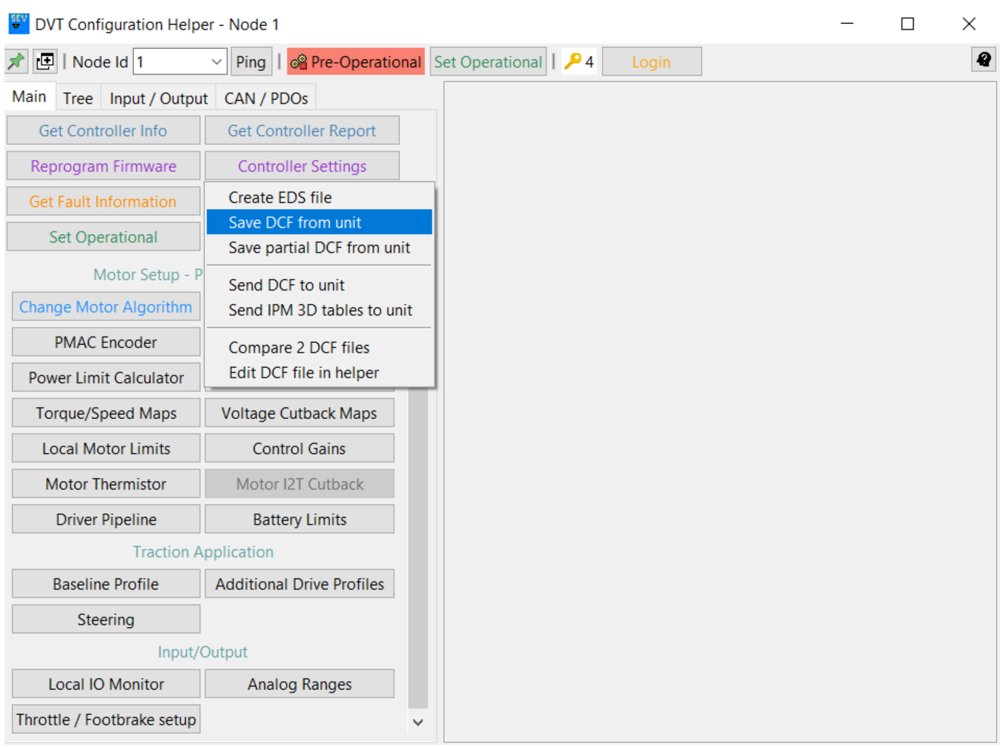


Figure 22 – DVT Configuration Helper

7.2.3 Data Logging

You can use DVT to monitor data or parameters of a BorgWarner node in real time and graph the data, using the vehicle interface window.

7.3 CANopen Configuration

This section assumes you have an understanding of CAN and are familiar with its use. If you are new to CAN or CANopen please refer to the CiA (CAN in Automation) website, www.can-cia.org for further information.

The following information provides an introduction to the important CANopen terminology used in this manual and how it relates to the configuration of your Dragon8 controller.

7.3.1 CANopen protocol

CANopen is a CAN higher layer protocol and is defined in the DS301 ‘Application Layer and Communication Profile’ specification. All CANopen devices must adhere to this standard. To provide greater standardization and interoperability with 3rd party devices, Dragon8 is designed to use the CANopen protocol for configuration on its CANbus and meets V4.02 of DS301.

7.3.2 Object Dictionary

The Dragon8 controller uses CANopen principally for configuration purposes. All settings and configuration can be accessed via the controller’s object dictionary, and parameters can be monitored and adjusted using CANopen’s SDO protocol. This protocol is also implemented in DVT, allowing it to be used as the primary device configuration tool.

Any device connected to the CANopen network is entirely described by its Object Dictionary. The object dictionary defines the interface to a device. Within the Object Dictionary, all parameters are assigned a unique index and sub-index. Thus, all parameters can be uniquely addressed by this pair of numbers.

There are two important text files associated with the Object Dictionary. These are:

7.3.2.1 EDS (Electronic Data Sheet)

An EDS is a text file representation of the Object Dictionary structure only. It contains no data values. The EDS is used by configuration software such as BorgWarner’s DVT to describe the structure of a node’s Object Dictionary. An EDS for each Dragon8 model and software version, is available from BorgWarner. The EDS file format is described in the DSP306 – Electronic Data Sheet Specification.

NOTE: Each Object Dictionary matches a particular Dragon8 software revision, and its structure is hard coded into the controller software

7.3.2.2 DCF (Device Configuration File)

This is a text file similar to an EDS except that it contains data values as well as the Object Dictionary structure.

DCFs are used to:

- Download a complete pre-defined configuration to a node's Object Dictionary.
- Save the current configuration of a node's Object Dictionary for future use.

7.3.3 Network Configuration

7.3.3.1 General

Use the following procedure to setup the Dragon8 controller on the network:

1. Set node ID and baud rate in 5900h to the required values. Node IDs must be unique, and the baud rate must be the same for each node.
2. Set SYNC COB-ID in 1005_h to 0x40000080 for the SYNC producer, or to 0x00000080 for the SYNC consumers. Bit 30 is set to indicate to a node if it is the SYNC producer. Only one node in the network should be configured as the SYNC producer. This should normally be the VCU. On the SYNC producer, set the SYNC rate in 1006_h.
3. Set the EMCY message COB-ID to either 0x00000000 or 0x80 + node ID in 1014_h. Setting to 0x00000000 will automatically calculate the EMCY COBID from the node ID.

WARNING EMCY COB-IDs must be configured correctly to ensure the master handles EMCYs from slaves correctly

4. Configure the heartbeat producer rate in 1017_h. This is the rate at which this node will transmit heartbeat messages.
5. Configure the heartbeat consumer rate in 1016_h. A consumer should be configured for each node to be monitored.

WARNING Heartbeats must be configured correctly for correct network error handling. The master node should monitor heartbeats from all slave nodes. Slave nodes should, at a minimum, monitor heartbeats from the master node

Loss of CANbus communication from any one node must cause a heartbeat fault to occur.

6. Where supported, hardware CANbus fault detection should be enabled at 5901_h to ensure CANbus fault detection is always enabled.
7. Configure additional SDO servers. An SDO server allows another CANopen device to SDO read/write from a node's object dictionary. Each node has one default SDO server (1200_h) which is reserved for communication with configuration tools like DVT or the calibrator. Another 3 SDO servers can be configured at 1201_h to 1203_h. These should be used as follows:
   a. On slave nodes, configure a server to allow the master node to communicate.
   b. If there is a display in the system, configure a server to allow the display access.
8. Configure RPDOs (1400_h to $17FF_h$) and TPDOs (1800_h to $1BFF_h$) appropriately for the system.
9. Configure the RPDO timeout function if required. See section PDO (page 63) for more

information.

10. Set up the VCU to comply with the required H-protocol and I-protocol messages for motor control and I/O control.

7.3.3.2 3rd Party CANopen Devices

At power up, the Dragon8 master will communicate with all slave nodes to identify which nodes are BorgWarner devices and which are not using the vendor ID in 1018_h. This instructs the Dragon8 how to handle EMCY messages from each node.

Dragon8 knows how to react to EMCYs (faults) from BorgWarner slaves and can take appropriate action. Dragon8 does not know how to react to EMCYs from 3rd party devices, so the required fault reaction to 3rd party device EMCYs must be set at 2830_h.

7.3.3.3 PDOs

The controller supports 5 RPDOs (receive PDOs) and 5 TPDOs (transmit PDOs). Up to 8 Object Dictionary entries can be mapped to each PDO. Every PDO must have a unique identifier (COB-ID).

Setup RPDOs and TPDOs to transmit and receive non-critical data between CANbus nodes.

NOTE: H-protocol and I-protocol should be used to communicate motor and I/O data

The easiest way to do this is using DVT. If you are using a 3rd party configuration tool, the relevant Object Dictionary indices are listed in Table 17.

Feature	Object indices	Notes
Input mapping	1400h-15FFh	RPDO communication parameters
	1600h-17FFh	RPDO mapping
Output mapping	1800h-19FFh	TPDO communication parameters
	1A00h-1BFFh	TPDO mapping

Table 17 – Objects associated with mapping

Dragon8 supports RPDO timeout fault detection. This can set a warning, drive inhibit or severe fault depending on the configuration in 5902_h.

NOTE: RPDO timeout can be used for non-CANopen systems which do not support heartbeat messages. By default, RPDO timeout is disabled, and normal CANopen heart beating protocol (see section Network Configuration (page 62)) is assumed to be used

.

7.4 H-Protocol

Although device configuration takes place using standard CANopen messages which are used to access the device's Object Dictionary, the proprietary H-Protocol is used to communicate motor control and status information over a CAN network.

H-Protocol is an enhanced motor control protocol. It is designed specifically for use with traction applications that require fast response times and a fine degree of control, but is equally suited to any electronic motor control application.

H-Protocol allows a VCU to control:

- Inverter bridge state
- Motor output torque
- Motor speed limits in both the forward and reverse directions
- DC current limits for both drive and regeneration
- Overall torque limits for both driving and braking torques

H-Protocol allows a VCU to monitor:

- Motor speed and actual output torque
- Motor, inverter, and internal component temperatures
- DC voltages and currents
- Inverter bridge state
- Fault codes

7.4.1 J1939 Compatibility

The network layer used by H-Protocol is intended to be compatible with J1939 type networks. Whilst non-standard PGNs are used to represent the data, the J1939 concepts for routing data and providing peer-to-peer communication between a VCU and motor controller are used heavily by H-Protocol.

The PGNs used by H-Protocol can be configured by adjusting the parameters in the object dictionary at index 3F00h. Any PDU1 format PGNs can be used by H-Protocol. However, the following default configuration is recommended wherever possible:

Name	Description	PGN (dec)	PGN (hex)
HC1	Torque demand message 1	69632	0x11000
HC2	Torque demand message 2	69888	0x11100
HC3	Battery demands	70144	0x11200
HS1	Torque feedback	71680	0x11800

HS2	Inverter status feedback	71936	0x11900
HS3	Temperature feedback	72192	0x11a00
HS4	Fault Information	72448	0x11b00
HS5	Encoder Information	72704	0x11c00
HD1	Debug Currents	75776	0x12800
HD2	Debug Voltages	76032	0x12900
HD3	Debug Temperatures A	76288	0x12a00
HD4	Debug Temperatures B	76544	0x12b00
HD5	Debug Control PMAC	76800	0x12c00
HD6	Debug Control FV	77056	0x12d00

Table 18 – Default H-protocol PGN configuration

Further details regarding the layout of signals within these messages is available from BorgWarner on request.

If a VCU is not available to generate motor control demands in H-Protocol format, TracApp can be used instead.

H-Protocol includes an integrated timeout feature. If the motor controller does not receive H-Protocol commands for a specified timeout period, the motor will automatically output zero torque, and will also attempt to report this condition to the controlling device.

7.5 I-Protocol

I-Protocol works alongside H-Protocol to allow monitoring and provide control of digital and analogue input and output devices.

I-Protocol allows a VCU to control:

- Digital outputs (contactor drives)

I-Protocol allows a VCU to monitor:

- State of digital inputs
- Analogue input voltages
- Fault codes

7.5.1 J1939 Compatibility

Like H-Protocol, I-Protocol is intended to be compatible with J1939 and communicates using PDU1 type PGNs. The PGNs used by the IO controller can be configured in the Object Dictionary at index 3F01h. However, the default PGNs listed below should be used if possible:

Name	Description	PGN (dec)	PGN (hex)
UO1	User Analog (digital) Output Control 1-4	81920	0x14000
UO2	User Analog (digital) Output Control 5-8	82176	0x14100
UF1	User I/O Fault Status and Digital Inputs	83968	0x14800
UI1	User Analogue Inputs 1-4	84224	0x14900
UI2	User Analogue Inputs 5-8	84480	0x14a00
UI3	User Analogue Inputs 9-12	84736	0x14b00
UI4	User Analogue Inputs 13-16	84992	0x14c00

Table 19 – Default I-Protocol PGN Configuration

Further details regarding the layout of signals within these messages is available from BorgWarner on request.

If a VCU is not available to generate motor control demands in I-Protocol format, TracApp can be used instead.

7.6 Configuration process overview

WARNING Electric vehicles can be dangerous. All testing, fault-finding and adjustment should be carried out by competent personnel

NOTE: It is recommended to save parameter values by creating a DCF, before making any alterations so you can refer to, or restore the default values if necessary. Do this using DVT

This part of the manual assumes you have a vehicle designed and correctly wired up with a CANopen network setup. Before you can safely drive your vehicle, it is necessary to go through the following process in the order presented:

7.6.1 Access authorization

To prevent unauthorized changes to the controller configuration there are 4 levels of accessibility: (1) User, (2) Service Engineer, (3) Dealer and (4) OEM Engineering. The lowest level is (1), allowing read only access, and the highest level is (4) allowing authorization to change any parameter.

To login write your 32-bit password to object 5000h sub-index 4. The access level can be read back from sub-index 1. The passwords for access levels 1 to 4 are fully configurable by the customer in 5000h sub-indices 5-8 so they can be made unique. Log in at access level 4 is required to change the passwords.

NOTE: Make a note of any changed passwords. Resetting forgotten passwords can only be performed by BorgWarner.

7.6.2 How NMT state affects access to parameters

Some important objects can only be written to when the controller is in the pre-operational state. DVT takes Dragon8 in and out of this state as required.

If you are not using DVT you may need to request the CANopen network to enter pre-operational before all objects can be written to.

The NMT state can be determined by monitoring the heartbeats or by reading 5110h. 0x05 = operational and 0x7F = pre-operational.

7.7 Motor characterization

Ensure you have completed the CANopen network setup process.

7.7.1 Supported motor algorithms

The firmware within the controller supports multiple motor control algorithms and which can be selected using object 4639_h:

- Permanent magnet AC
  - Surface permanent magnet
  - Interior permanent magnet (salient)
- Induction motor vector control

7.7.2 Determining Motor Parameters

Key motor parameters for permanent magnet ac and induction motor are adjustable in 4641_h.

NOTE: Contact BorgWarner or Authorized Distributors for more information on how to set up the Dragon8 controller for supported motor types

7.7.3 Speed Limit Tuning

The speed limit is controlled using PI loops, which can be configured in the Object Dictionary at index 4651_h. The following parameters can be configured:

- Standard proportional and integral gains (4651_h, 1+2). Used to configure the loops during normal operation.
- Low speed proportional and integral gains (4651_h, 3+5). Used to configure the loops at low speeds (<50 RPM) and during hill hold. These are normally set lower than the standard gains to dampen oscillation as the vehicle comes to a stop.
- Roll back integral gain (4651_h, 4). Used to boost the integral term to prevent vehicle roll-off down inclines, particularly when Hill Hold is enabled. Normally, this gain is higher than the standard integral gain.
- dw/dt gain (4651_h, 6). For speed mode this is used to boost the torque output in speed mode, when a large increase in speed demand occurs. For torque mode this is used to apply compensatory torque to damped oscillations induced from the vehicle drive train. Not used in torque mode.
- Integral initialization factor (4651h, 7). Used to initialize the integral term on entry to speed limit in torque mode. This factor is multiplied by the actual torque to set the integral term. Not used in speed mode.
- Speed filter pole (4651_h, 8). Used to filter speed used by speed limit loop.
- Speed pre-limit threshold (4651_h, 9). Speed limit algorithm will start cutting back torque

when speed is within this threshold of the maximum.

7.8 I/O configuration

Ensure you have completed the CANopen network setup and Motor Characterization processes described above.

The individual characteristics of the I/O in your application need to be setup. Setup each hardware I/O object, including wire-off protection.

I/O control is managed using the I-Protocol. Refer to the I-Protocol documentation for more information.

NOTE: Before starting the mapping process it is a good idea to draw out a map of what you want to do. The amount of mapping required depends on the electrical wiring of your vehicle. Check to see if the default settings satisfy your needs before making changes

7.8.1 Encoder

WARNING It is important that the encoder parameters are entered correctly. If this information is not correct, motor control may not be possible

7.8.1.1 General encoder settings

Encoder selection and settings applicable to all encoder types are contained in 4630h and 4631h.

Dragon8 supports four encoder types:

- Resolver absolute position sensor
- Sine-Cosine absolute position sensor
- UVW absolute position sensor
- AB incremental speed encoder

NOTE: AB is not suitable for synchronous motors (e.g. permanent magnet AC).

- For sensors requiring a DC power supply (Sine-Cosine, UVW, AB), connect to the appropriate 5V or 10V pin on the I/O header.
- If the encoder sequence is incorrect with respect to the motor, then this inversion can be performed within 4631_h, without rewiring the motor.
- Sensor latency compensation and advanced noise filtering is applied to all sensor types. Please contact BorgWarner for recommended settings for these items.

- If using a PMAC motor, the absolute offset of the encoder is configured in 4630_h, sub 4. A range of +/-180° may be input. Units are in electrical degrees.
- The software has provision for an approximate auto-detection of the encoder offset using a low-speed rotation test, provided the motor is unloaded. Please contact BorgWarner for information on this feature (or refer to the HVLP+Dragon8+Gen5 – Encoder AppNote).

7.8.1.2 Resolver configuration

Please refer to page 52 for electrical information on the resolver subsystem.

All resolver specific settings are located in 4632_h.

- The controller can support multi pole-pair resolvers - please see page 52 for information on pole pair values other than 1.
- The controller supports a range of resolver gains by manipulating the magnitude of the excitation waveform. The phase of the resolver must also be compensated for, in order to achieve optimum performance. Resolver gain and phase settings can be auto-detected by the Dragon8. Please contact BorgWarner (or refer to the HVLP+Dragon8+Gen5 – Encoder AppNote) for information on tuning resolver magnitude and gain settings.

7.8.1.3 Sin/Cos configuration

Please refer to page 51 for electrical information on the sin/cos subsystem

Sin/cos specific settings are located in 4633_h.

- The controller can support sin/cos encoders with multiple waves-per-revolution. Please see page 51 for information on waves-per-revolution values other than 1.
- The minimum and maximum voltage levels of the sin/cos encoder must be entered in 4633_h.
- To assist in configuration, the controller provides real-time feedback of the minimum and maximum sin/cos voltage levels. A rotating motor is required to determine these thresholds.
- To account for any sin/cos sensor latency, please ensure the correct latency is set in the general encoder settings (4631h). Please contact BorgWarner for recommended latency settings for specific sin/cos sensors (or refer to the HVLP+Dragon8+Gen5 – Encoder AppNote)

7.8.1.4 UVW configuration

Please refer to page 50 for electrical information on the UVW subsystem.

For a PMAC motor, a full 360º sequence of UVW pulses must be present for each electrical cycle of the motor.

UVW specific items are located in 4634_h.

- If the UVW inputs are inverted (active-low) then this inversion can be accounted for in the UVW settings.
- If significant latency is present, this can be accounted for in the general encoder settings (4631_h). Please contact BorgWarner for recommended latency settings (or refer to the HVLP+Dragon8+Gen5 – Encoder AppNote)

7.8.1.5 AB configuration

Please refer to page 49 for electrical information on the AB subsystem.

Please note, AB is not suitable for PMAC motors since absolute position is required.

AB specific items are located in 4635h.

- The pulses per revolution must be set to match the encoder.
- If the AB inputs are inverted (active-low) then this inversion can be accounted for in the AB settings.

7.8.2 Digital inputs

The state of the digital inputs can be monitored using I-Protocol.

NOTE: Digital inputs are interpreted as both active high and active low. The value returned via the I-Protocol is individually configurable

Digital input statuses are constantly monitored and interpreted and are output using the I-Protocol as "active", "inactive" or "error".

To configure digital inputs:

- Set active high/low logic at 4680h.
- Set digital input polarity at 6802h. This is used to configure normally closed/open switches.

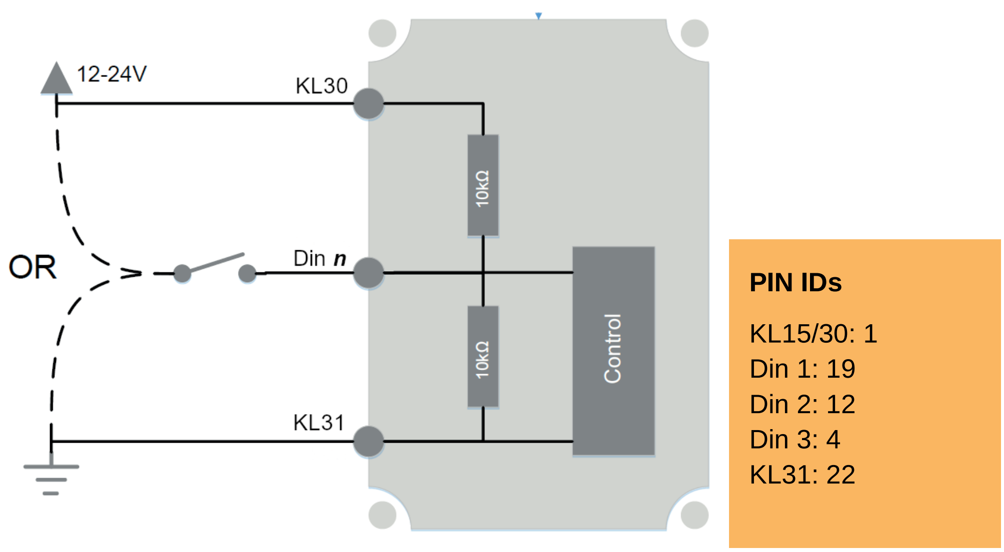


Figure 23 – Dragon8 Digital Inputs

7.8.3 Analog inputs

The analog input voltage are read from I-Protocol messages, values are 12bit fixed point values with a resolution of 1/256 V/bit (4:8 bit format), with 0xfff used to indicate that a channel is not used.

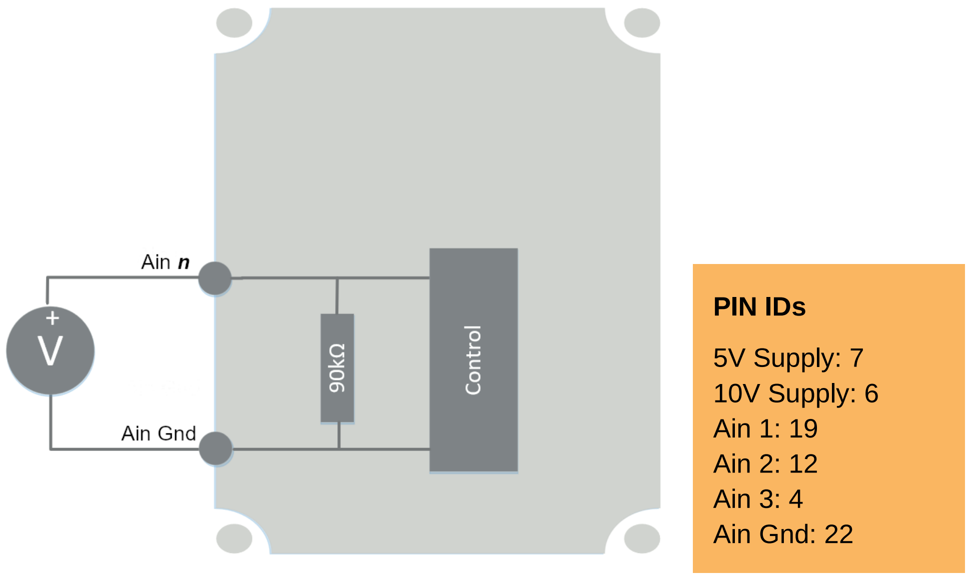


Figure **24 – Dragon8 Analog Inputs**

The following table summarizes the analog inputs and any special features:

Name	Pin	Usage
Analog Input 1	19	Input from external voltage source or the wiper from a 3-wire potentiometer. Use pin 6 (10V) or pin 7 (5V) as supply for 3-wire potentiometer.
Analog Input 2	12	
Analog Input 3 (Motor thermistor)	4	Use for motor thermistor input or 2-wire potentiometer input. Has internal supply.

Table 20 – Analog inputs

7.8.3.1 Wire-off detection

Enable wire-off detection at 46C0$_h$ to 46C2$_h$. For each input specify the allowable range of input voltages. To disable, set the ranges to maximum.

7.8.3.2 Motor thermistor input

You can connect a thermistor sensor to the Motor thermistor input.

Type	Specification
PTC Silistor	Philips KTY83, PT1000 etc.

Table 21 – Motor thermistor input

To setup go to object 4620h:

- Configure as 'none', 'thermistor' or 'CAN based thermistor'
- Program the resistance / temperature profile in 461Fh. This is an 8-point table which allows a programmable thermistor map to be configured.
- For CAN based thermistors, the temperature can be loaded into object 4600h sub 16 using an RPDO.

Read the measured motor temperature (PTC) or switch state at object 4600h.

7.8.4 Digital (contactor) outputs

There are 2 digital outputs which can be used to control loads such as contactors, horns, lights, etc.

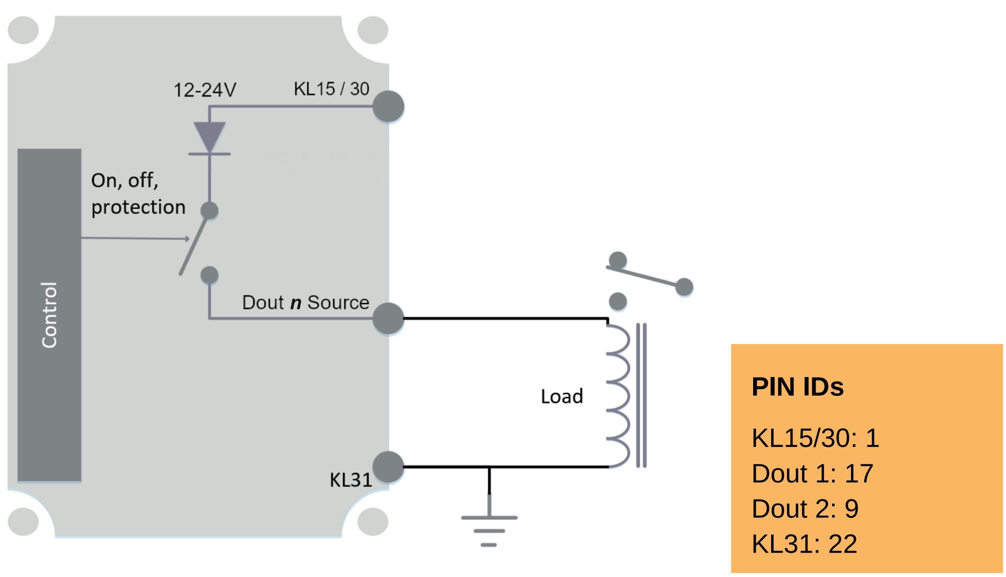


Figure 25 – Dragon8 Digital Outputs

7.8.4.1 Error control

WARNING It is important that contactor outputs, on nodes other than the master, must have appropriate error configuration to protect against CANbus faults. This section explains how to configure the outputs to go to a safe state in the event of a CANbus fault. It is the installer's responsibility to define what a safe state is for each output

In a CANopen network, the slave node on which the digital (contactor) outputs are different to the VCU node which calculates the output value. If the CANbus fails, the VCU is no longer able to control the slave outputs. In this situation, the outputs may need to change to a safe value. This is achieved with error control.

To configure error control:

- Set each output at object 6C43h to use its last set value or the value at 6C44h if the CANbus fails.
- Set values if needed at 6C44h for each output. These values are 32-bit integers, but the bottom 16-bits are ignored. The top 16-bits give the error value in 1/256 V/bit.

Some examples of typical configurations may be:

- Electro-mechanical brake on slave node. If CANbus communication is lost, it may be desirable to apply the electro-mechanical brake on the slave device. In this case, enable error control in 6C43h and set the error value in 6C44h to 0.
- Power steer contactor on slave node. If CANbus communication is lost, it may be desirable to leave the power steer output in its previous state. In this case, disable error control in 6C43h.
- CANbus communication error lamp on slave node. If CANbus communication is lost, it may be desirable to activate an output on the slave device. In this case, enable error control in 6C43h and set the error value in 6C44h to an appropriate voltage for the lamp.

NOTE: The above examples are for illustration purposes only. It is the responsibility of the installer to decide on the required state for each output in the event of a CANbus failure.

7.9 Vehicle performance configuration

If your vehicle system does not include a VCU capable of providing raw motor control commands via H-Protocol, then the vehicle application sub-systems within the controller can be utilized to provide these signals for you.

Vehicle sub-systems such as TracApp and PumpApp can take in external signals using I-Protocol, and generate the H-Protocol commands appropriate for driving the vehicle.

TracApp is capable of providing drive signals for a range of vehicle types, covering on-road and industrial applications.

7.9.1 Requirements

In order to use TracApp, the following signals must be provided as a minimum:

- An analogue throttle signal
- Two digital signals, forward and reverse, used to select the drive direction

Depending on the application, other signals will be required in order to maintain safe operation. For instance, an FS1 switch may be required by the application in order to validate the throttle position.

Vehicle application subsystems can be enabled by setting Object Dictionary index 5800h to enable master functionality. Note, on a multi node system, it is only necessary to enable this on one node, as this will be providing H-Protocol drive commands for all other nodes via CAN.

For information regarding how to map physical H-Protocol and I-Protocol inputs and outputs to vehicle functions, refer to BorgWarner Application Note “Mapping J1939 Signals to Vehicle Application Subsystems”.

7.9.2 Safety Interlocks

7.9.2.1 FS1

The FS1 switch is normally part of the throttle assembly. It closes when the throttle is pressed. The throttle voltage is ignored until FS1 is closed.

FS1 features are configured at 2914_h:

- SRO (static return to off): inhibits drive if FS1 is closed for the SRO delay without any direction (forward or reverse) being selected.
- FS1 recycle: forces the operator to lift their foot off the throttle before allowing drive after a direction change.

7.9.2.2 Deadman

The deadman switch operates similar to the FS1 switch, whereby, it inhibits drive until it is active. However, the deadman switch applies the electro-mechanical brake immediately on deactivation, whereas FS1 waits for the vehicle to stop before applying the brake.

7.9.2.3 Seat

The seat switch indicates operator presence on the vehicle. Drive is not allowed if this switch is open. If the seat switch opens during drive for a period longer than the seat switch delay, a fault is set, disabling drive. To clear a seat fault, close the seat switch, open FS1 and deselect the forward/reverse switch.

Set the seat switch delay at object 2902_h.

7.9.2.4 Handbrake

If mapped to a digital input, the handbrake switch inhibits drive if the vehicle handbrake is applied. Controlled roll-off detection is still active when the handbrake is applied in case the brake fails.

7.9.2.5 Sequence Fault Masking

If an application does not require it, sequence fault checking can be disabled on selected drive inputs. This is set at 2918_h.

Similarly, drive inputs can be masked when clearing drive inhibit faults. This is set at $291A_h$.

CAUTION These masks must only be applied if the application has other adequate means of protection. It is the responsibility of the installer to ensure this

7.9.3 Throttle

7.9.3.1 General

TracApp is compatible with analogue input signals that are provided via I-Protocol. To setup throttle inputs see ‘Analogue’ on page 73.

CAUTION Inputs with wire-off detection should be used for the throttle input to detect wiring faults. This is especially important if a wire-off sets maximum throttle. See section Analog inputs (page 73) for more information. Configure throttle wire-off detection threshold at 2910_h, 21

Setup the characteristics of the throttle at 2910_h, sub-indices 2 to 21.

Define the throttle voltage input: this is the relationship between the throttle voltage and the throttle value. Separate relationships can be specified for forward and reverse. Each relationship has two points, a start and an end. The points are configured differently for standard and directional throttles as shown in Figure 26 and Figure 27 respectively.

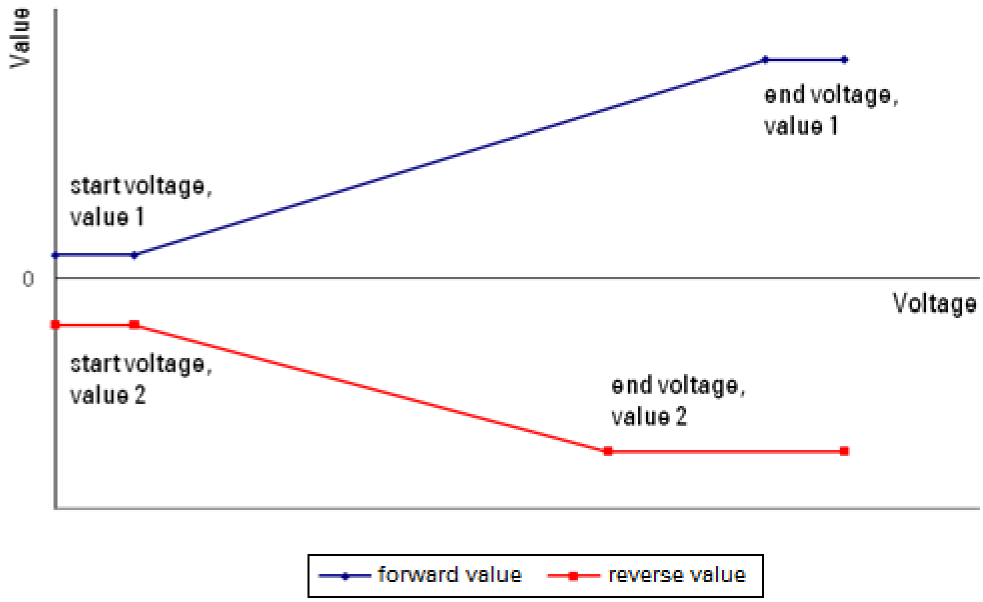


Figure 26 – Standard throttle configuration

NOTE: If the reverse characteristic is the same as the forward characteristic, just set all the reverse throttle parameters to 0 in 2910$_h$

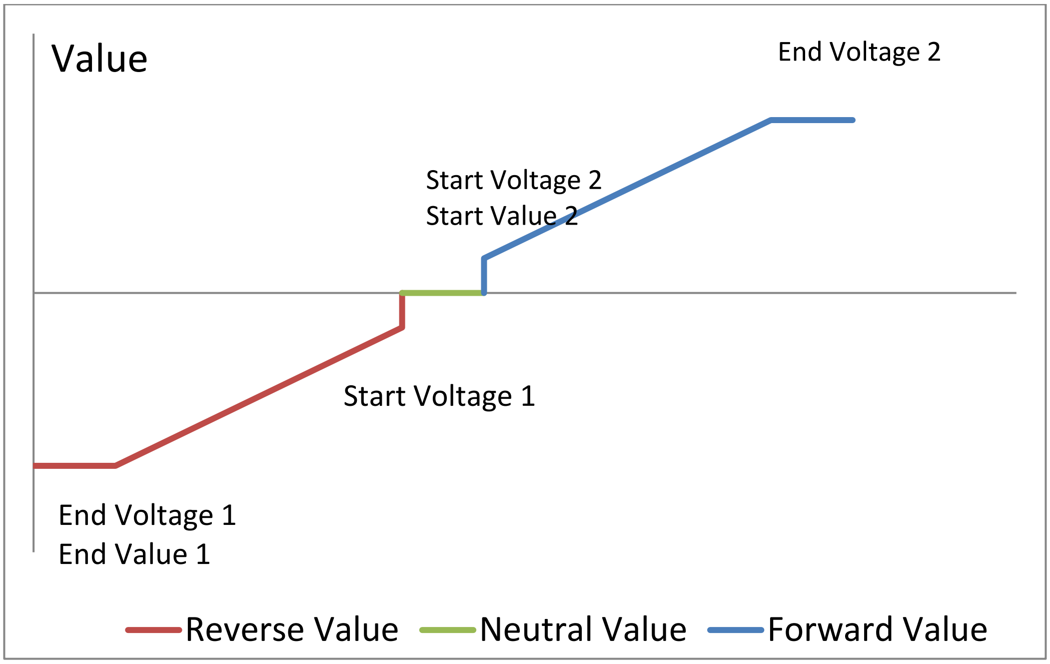


Figure 27 – Directional throttle configuration

Define the input characteristic: this is a profile to the throttle value and can be linear, curved, crawl or user-defined as shown in Figure 28. The curved and crawl characteristics give greater throttle control at low speeds.

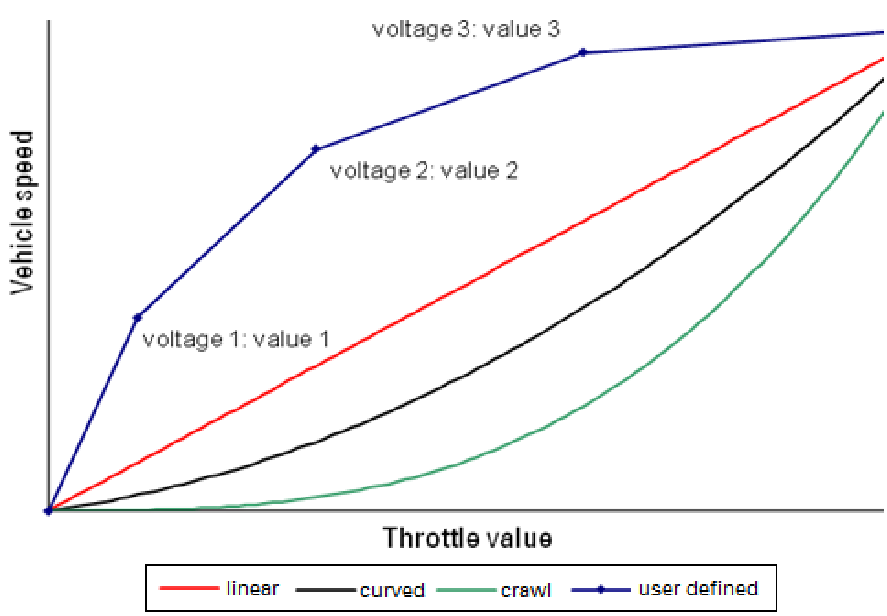


Figure 28 – Input characteristics

The throttle value calculated from the voltage can be read at 2620h.

7.9.3.2 Dual Throttle Inputs

Single and dual throttle inputs are supported.

Single throttle inputs are normally used with other interlock inputs (e.g. FS1, deadman, etc.) and use a single input voltage to determine driver demand.

Dual throttle inputs use two separate input voltages, each of which is converted to a throttle value using 2910h, sub-indices 3 to 6 (throttle input 1) and sub-indices 7 to 10 (throttle input 2). If the throttle values differ by more than 5%, a throttle fault is set and the system will not drive.

To enable dual throttle functionality, map a second analogue input to 2224h. The throttle value for the second throttle input can be read at 2626h.

Dual throttle systems allow a virtual FS1 feature, which can be used instead of an actual FS1 switch. This feature can be enabled on dual throttle systems using 2910h, 1.

CAUTION The voltage input characteristics of the two analogue throttle inputs must be different.

7.9.3.3 Creep Torque

Set creep torque at 291fh. Creep torque allows a small amount of torque to be applied as soon as the throttle is closed. This can be used on some vehicles to overcome the friction required to achieve initial vehicle movement.

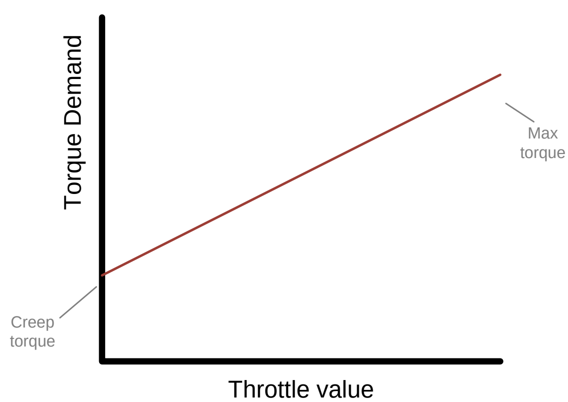


Figure 29 – Illustration showing behavior of creep torque

Increasing the creep torque level can improve how the vehicle feels when drive is first selected and the vehicle starts to move. However, too much creep torque can make the vehicle uncontrollable at low speeds.

CAUTION Creep torque will be applied as soon as drive is selected and the throttle is closed. Do not increase the creep torque value to a level that would cause unexpected high levels of torque output for comparatively low levels of throttle push. If in doubt, set the creep torque level to 0%.

7.9.4 Driveability Features

CAUTION These features are used to configure how the system uses throttle information and how it handles speed limits (in torque mode). The installer must ensure these features are configured appropriately

Set the following driveability features at 2910_h sub-index 1:

- Enable/disable proportional braking. If enabled, the braking torque during direction braking is proportional to the throttle.
- Enable/disable directional throttle. If configured as a directional throttle, the throttle voltage indicates the direction as well as the speed demand. This removes the need for forward and reverse direction switches.
- Proportional speed limit enable/disable. If enabled, speed limit is proportional to the throttle, otherwise speed limit is fixed at the forward or reverse maximum speed. Only used in torque mode.

WARNING: Proportional Speed Limit is not recommended for on-highway vehicles as it can cause the traction motor/wheel to remain locked or brake severely if the wheel is momentarily locked due to loss of traction on a slippery surface and/or mechanical braking

- Braking directional throttle enable/disable. If enabled, a directional throttle can be used to demand a drive or braking torque in conjunction with the direction switches. Only used in torque mode.
- Handbrake fault. If enabled, a handbrake fault is set when a direction is selected whilst the handbrake input is active.
- Proportional speed limit during braking enable/disable. If enabled, speed limit is proportional to throttle only in drive states. Maximum speed limit is allowed in braking states. Only used in torque mode and for open loop slip motors. Proportional speed limit above must be enabled for this option to have any effect.
- Driveability Consolidation. Normally, driveability profiles are only used to reduce vehicle performance, however, if this is enabled, an active driveability profiles over-writes the baseline. This allows vehicle performance to increase when a profile is active. Note, that this feature is not available in all software builds.
- Allow step change in steering angle. If enabled, steering angle can change instantly with steering voltage. If disabled, steering angle is rate limited to 90º/s, which prevents sudden steering angle changes in the event of a steering sensor wire-off.

- Virtual FS1 enable/disable. If enabled, this sets up a virtual FS1 feature on systems with dual throttle inputs configured.
- Positive (absolute) Steer Angle only enable/disable. If enabled steer angle is always positive in both directions. Used for single traction systems with steering cutback. Motor mapped must be left motor
- Separate Seat Regen Braking enable/disable. If enabled, separate regen setting is activated for regenerative braking with operator off the seat. Seat Regen settings are set at 2928_h.
- Slave Left Motor Speed Inversion enable/disable. Inverts left motor slave actual speed when slave inversion switch activates.
- Proportional speed limit during drive enable/disable. If enabled, speed limit is proportional to throttle only in braking states. Maximum speed limit is allowed in drive states. Only used in torque mode and for flux vector motors. Proportional speed limit above must be enabled for this option to have any effect.

Set the following driveability features at 2910_h, sub-index 22:

- Direction selected indication in controlword is latched enable/disable. If enabled the selected direction bit in the control word holds the previous selected direction and doesn't return to neutral. This will help prevent the vehicle from rolling back uncontrolled on an incline if the throttle is pressed very briefly when hill-hold or controlled roll-off is active.
- The latching on the seat regen braking enabled/disable. If enabled (default) the seat regen braking state can only be exited by closing the seat switch, then changing the direction selection, for example from Forward to Neutral. If disabled, the seat regen braking state will be exited when the seat switch is closed.
- Brake feathering during seat regen braking enable/disable. If enabled (default) brake feathering will be applied to the braking torque during seat regen braking state. If disabled it will use the level set in 2928_h to 0 RPM.

An s-curve profile can be applied to the speed target (in speed mode) or maximum speed (in torque mode). This can be set at $290A_h$.

7.9.5 Acceleration and braking

See ‘Driveability profiles’ for more information on page 86.

Some vehicles can exhibit shock due to the rapid reversal of torque after a direction change. 2909_h can be set to force the vehicle to remain stationary for a period before driving in the new direction.

To prevent early exit from neutral braking, a debounce timer can be set at $290D_h$. Neutral braking only finishes when the vehicle has been stopped for longer than this time. This can help prevent early exit of neutral braking due to motor oscillation caused by under damped suspension.

On vehicles with gearbox meshing issues, a slower rate of torque ramp up at low speeds can be configured at $291C_h$. This slow rate of change of torque lessens shock due to gear meshing. Used in torque mode only.

Brake feathering reduces neutral and foot braking torques as the vehicle speed approaches 0 to prevent any roll-back in the opposite direction. This is set at $290E_h$. Use $290E_h$,1+2 to set start and end speeds for feathering, $290E_h$, 3 to configure the final torque at the end of braking and $290E_h$, 4+5 to configure entry and exit ramp rates for feathering torque to prevent disturbance in torque when changing between drive and braking conditions. Used in torque mode only.

7.9.6 Footbrake

The controller can use a switch or analogue voltage as the footbrake input. If a footbrake switch is mapped, it applies maximum foot braking when the switch is closed. The footbrake switch object (2130_h) must be mapped to a digital input.

If the footbrake input is an analogue voltage, configure the voltage levels in the same way as the throttle. The footbrake voltage (2221_h) must be mapped to an analogue input.

Configure the characteristics of the footbrake at 2911_h:

- Drive/foot braking priority. If the throttle and footbrake are pressed at the same time, this setting determines whether the system attempts to drive or brake.
- Minimum speed for braking. Foot braking stops when the vehicle speed drops below this level.
- Footbrake voltage input and Input characteristic. These settings are similar to those for the throttle. Refer to the Throttle section above for more information.
- Footbrake priority timeout allows the configured priority to change after a timeout period. Setting zero will disable this feature.

The footbrake value calculated from the voltage can be read at 2621_h.

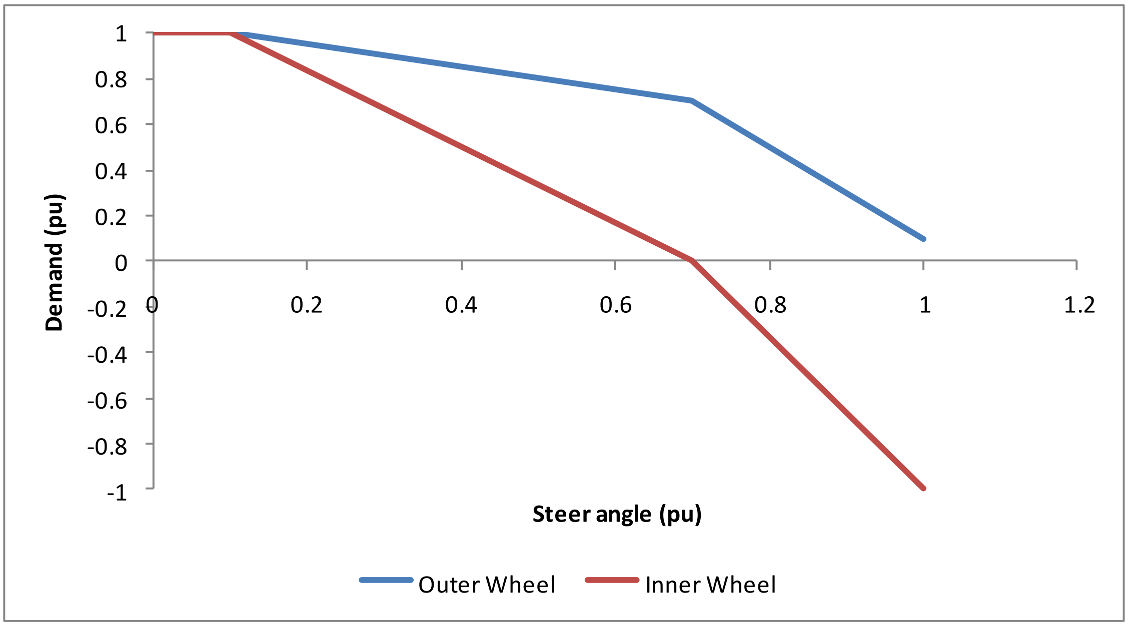
7.9.7 Steering inputs – twin driving motor systems

CAUTION Loss of steering information can make a vehicle operate erratically. The analogue input use for the steering sensor should have suitable wire-off protection configured

Twin motor systems, which use the drive motors for turning, require some means of determining the angle of the steering wheel.

To do this use one of these options:

- A steering potentiometer to give an analogue voltage which is a linear function of the steering angle. The steer potentiometer voltage (2223_h) must be mapped to an analogue input.
- Four digital inputs representing 'inner left', 'inner right', 'outer left' and 'outer right'. The inner switches indicate the steering angle where torque to the inner wheel motor is removed. The outer switches indicate the steering angle where inner wheel motor changes direction. The outer switches are optional. The steer switches ($212B_h$ to $212E_h$) must be mapped to digital inputs.
- Steering angle from 3rd party CAN device. This can be received via RPDO on object 2624_h in 0.01º/bit resolution.
- To configure steering inputs, go to index 2913_h in the Object Dictionary:
- Setup the voltages corresponding to fully left, fully right and straight ahead. Using this information, Dragon8 calculates the steering angle based on the voltage from a steering potentiometer.
- Setup the steering map. This map defines the relationship between the inner and outer wheel speeds and the steering angle. Each map has 4 user definable points as shown in Figure 30.



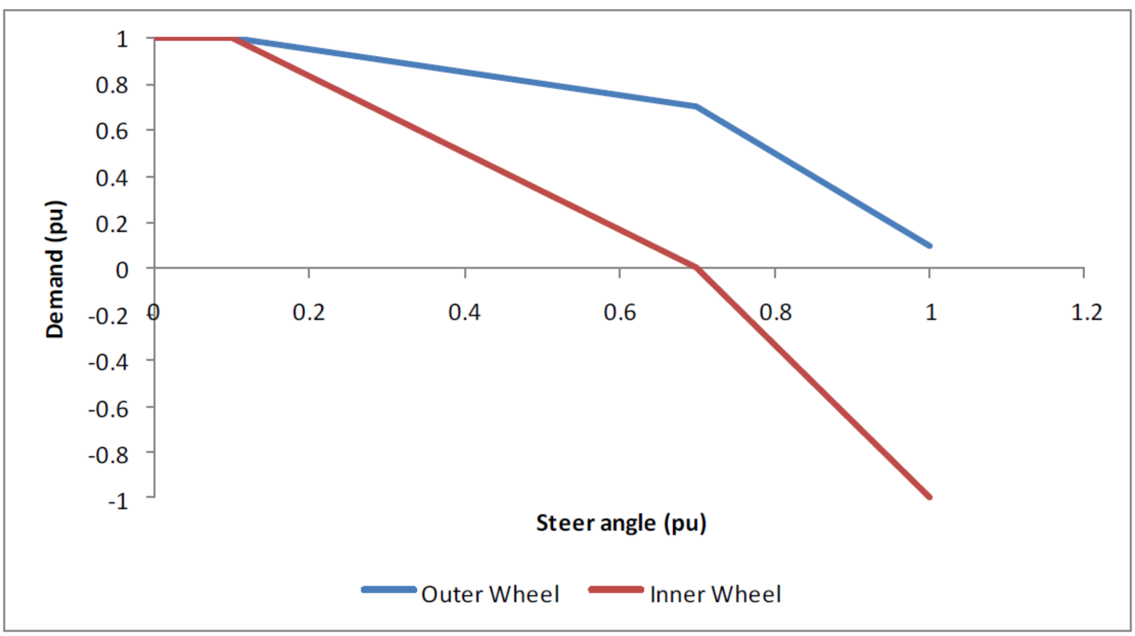


Figure 30 – Graph of speed vs. steering angle

The speed and steering angle are normalized. Speed is normalized to maximum vehicle speed and the steering angle to 90º.

In speed mode, outer wheel speed target and maximum torque is scaled according the outer wheel map. Inner wheel speed target and maximum torque is scaled to the outer wheel demands according to the inner wheel map.

In torque mode, both inner and outer wheel maximum speeds are scaled according the outer wheel map. The outer wheel target torque comes from the throttle. The inner wheel target torque is scaled to the outer wheel actual torque according the inner wheel map.

In object 2913_h, 0 to 1 is represented by values in the range 0 to 32767. The inner wheel is scaled according to the outer wheel. Where a demand (P.U.) of -1 is shown at 90º for the inner wheel, this means the inner wheel demand will be equal and opposite to the outer wheel.

The calculated steering angle can be read at 2623_h. An angle value of -32767 indicates full steering to the left, +32767 full steering to the right and 0 is straight ahead.

If steering switches are used instead of a steering potentiometer, only part of the steering map is used as shown in Table 22.

Value	Description
2913_h,9	Outer wheel speed during inner wheel cutback
2913_h,11	Outer wheel speed during inner wheel reversal
2913_h,17	Inner wheel cutback speed
2913_h,19	Inner wheel reverse speed

Table 22 – Objects to set when using steering switches

NOTE: During a turn the inner wheel speed is slowed by power reduction instead of braking to prevent the outer wheel motor working against the inner wheel motor

7.9.8 Driveability profiles

WARNING: Ensure driveability profiles are disabled when not required. Activation of a driveability profile can cause driving parameters to change

Driveability profiles allow you to set maximum values for speed, torque, acceleration and deceleration for use in a range of operational situations. In addition, in torque mode, there are ramp rates for speed limits as well. Figure 31 and Figure 32 show the change in speed and torque target under various driving conditions over a period of time.

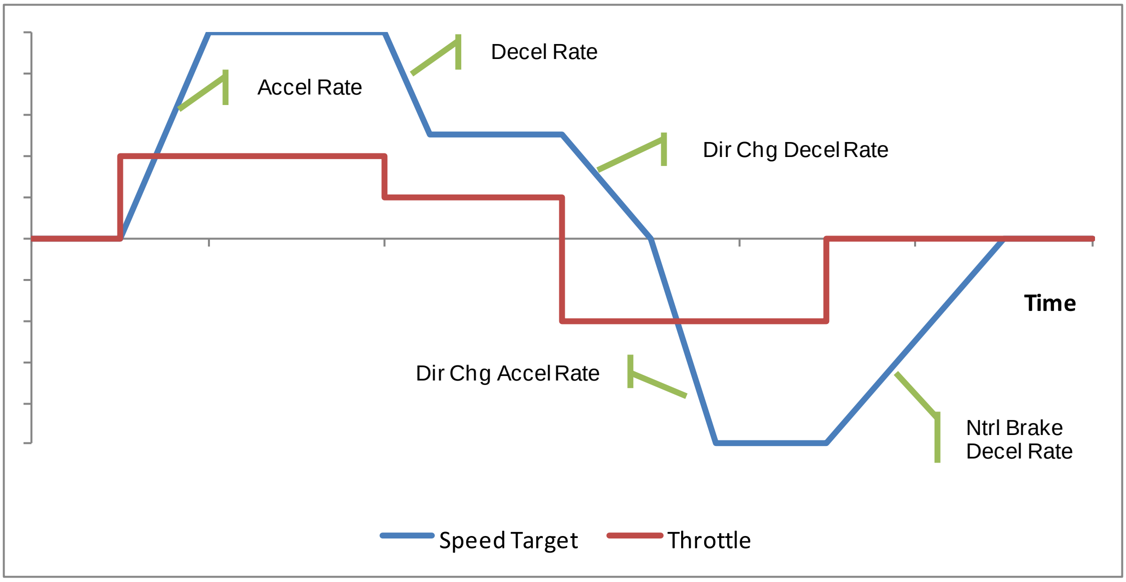


Figure 31 – Speed mode acceleration/deceleration

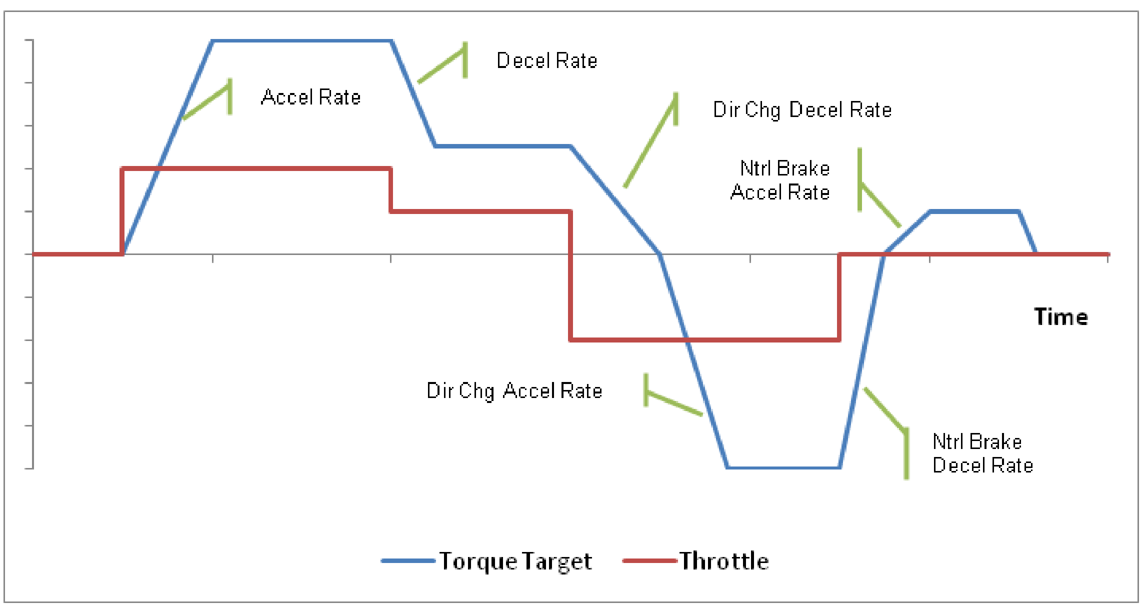


Figure 32 – Torque mode acceleration/deceleration

In Torque mode, the acceleration and deceleration rates control the rate of change of torque. In Speed mode, the acceleration and deceleration rates control the rate of change of speed.

You can select reverse while driving in the forward direction with your foot still on the throttle. In this situation the controller applies braking in the form of a direction change deceleration rate down to zero speed. It then applies a direction change acceleration rate to increase the vehicle's speed in the reverse direction up to the set maximum speed as shown above.

Configure the following driveability profiles to suit your application (each containing the same set of parameters):

- Traction baseline profile: the default and highest set of values (2920_h).
- Driveability select 1 profile: invoked when driveability select 1 switch is active (2921_h) or an alternative trigger is active (see below).
- Driveability select 2 profile: invoked when driveability select 2 switch is active (2922_h) or an alternative trigger is active (see below).

The traction baseline profile contains the default maximum values. All of the remaining profiles apply lower, modifying values to the baseline profile. BDI and service profiles, when configured, are automatically applied by the software under preset conditions. For example, you may want to limit the acceleration and maximum speed of a vehicle when the battery gets low to maximize the operating time before recharge. The remaining profiles are applied by the driver with a switch.

User profiles can also be invoked by internal software triggers, such as BDI low, service required or low speed. These can be selected to suit specific application requirements. Set the profile triggers in 2931_h.

Speeds in driveability profiles are scaled according to the vehicle gear ratio (2915_h). This is used to convert speed in RPM to any other preferred unit such as KPH or MPH. To remove this scaling and leave driveability profile speeds in RPM, set 2915_h,3 to 1.

Torques in driveability profiles are in 0.1%/bit resolution. These are converted to Nm using the motor rated torque value at object 6076_h.

Ramp rates in driveability profiles are in either RPM/s for speed mode, or %/s for torque mode. In speed mode, RPM/s becomes “User Defined Units” / s if the gear ratio is used to rescale the driveability profile speeds.

Speed limit ramp rates are only used in torque mode and are in RPM/s (or user defined units / s).

WARNING: In addition to the speed limit ramp rates in the profiles, $291E_h$ can be used to configure safety limits on speed limit ramping. The installer should set these ramp rates to suitable levels to ensure speed limits cannot ramp faster than could actually happen on a vehicle. This can protect against harsh braking if traction wheels are momentarily locked

7.9.9 Smoothing Output Torque

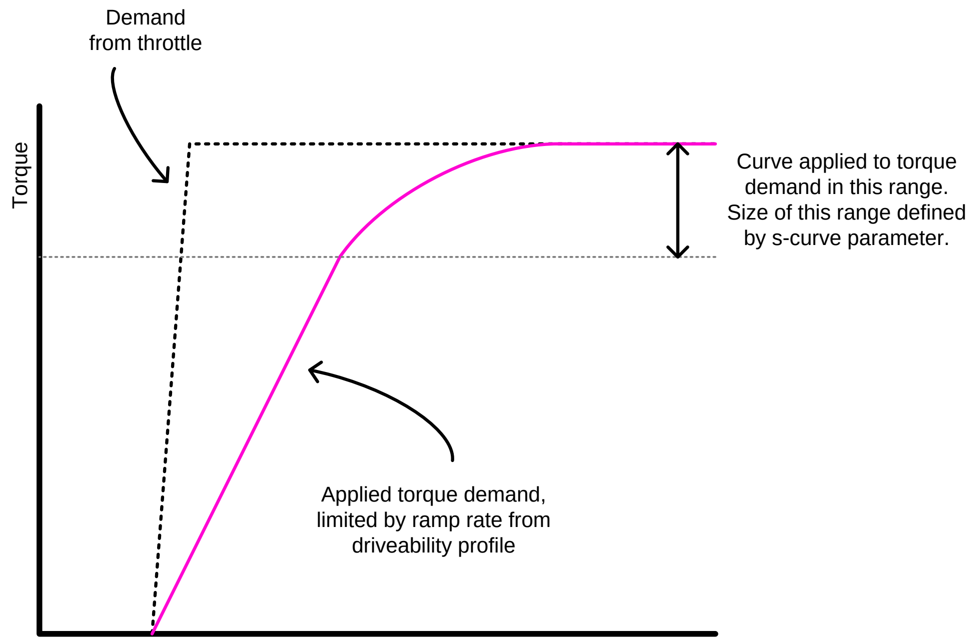


Figure 33 – Illustration of s-curve on torque demand

The controller provides an option to insert an s-curve to the torque demand as it approaches the value requested by the throttle. This curve feature can serve two purposes:

The amount of curve applied can be configured in the object dictionary at index 2933_h. Generally, applying a greater curve range will result in smoother drive, but too much can lower vehicle response. S-curve is applied according to this table:

Value in 2933_h	S-curve behavior
0	None applied
1	Curve applied within 0.2% of target
2	Curve applied within 0.4% of target
3	Curve applied within 0.8% of target
4	Curve applied within 1.6% of target
5	Curve applied within 3.2% of target

Table 23 – Torque S-curve configurations

This table continues, with each increment in 2933 h doubling the range over which the curve is applied.

7.9.10 Scenarios

For certain vehicle types, particularly on-highway vehicles or electric motorcycles, the possibility of wheel locking during drive must be considered.

During braking, the controller will maintain a speed limit to ensure the vehicle does not over speed if entering braking whilst travelling downhill. If proportional speed limit is set then the speed limit will follow actual speed toward zero whenever actual speed is dropping rapidly, usually due to some external influence such as application of mechanical brakes.

If the brakes are applied too harshly, then there is possibility to lock the drive wheels. In these circumstances, the normal reaction of the driver is to release the brake to allow the wheels to rotate again. The correct operation of the controller in this scenario is to allow the wheels to continue to rotate, and not impose a speed limit.

The maximum rate at which the speed limit can increase or decrease is specified in object 291E h. By limiting the rate at which the speed limit can decrease, we can ensure that if the brakes are released after they had locked the drive wheels, the controller's speed limit will allow them to rotate again. The operation of this is shown in Figure 34 below.

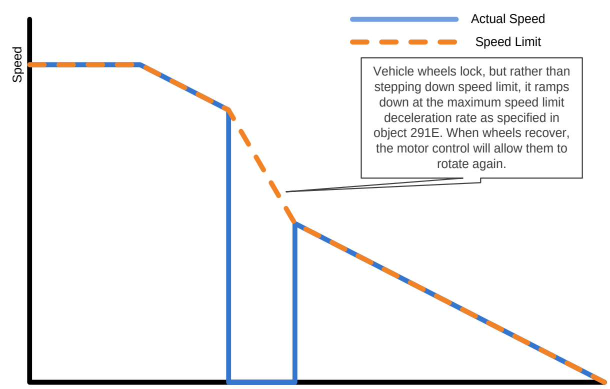


Figure 34 – Example of behavior of speed limit when drive wheels are locked

WARNING: It is important to consider the behavior of the vehicle under all drive conditions, including when traction is lost due to locking of the drive wheels. When testing a vehicle, check that the vehicle behaves in a safe manner when performing harsh braking on low-friction surfaces such as gravel

7.9.11 Controlled roll-off

WARNING: Controlled Roll-Off is not recommended for on-highway vehicles as it can cause the traction motor/wheel to remain locked or brake severely if the wheel is momentarily locked due to loss of traction on a slippery surface and/or mechanical braking

Controlled roll-off limits a vehicle to a slow, safe speed if it starts to move without any operator input. Primarily, it is meant to limit uncontrolled movement if a vehicle's brakes fail (or haven't been applied) on an incline. Controlled roll-off operates whether an operator is present or not (seat switch state).

Configure the following at object 2930_h:

- Enable/disable controlled roll-off
- Set a roll-off maximum speed
- Set a roll-off maximum torque

Alternatively, Dragon8 can apply an electromagnetic brake if one is mapped and roll-off is detected. Refer to 'Electro-mechanical brake' on page 96 for more information.

7.9.12 Hill hold

WARNING: Hill Hold is not recommended for on-highway vehicles as it can cause the traction motor/wheel to remain locked or brake severely if the wheel is momentarily locked due to loss of traction on a slippery surface and/or mechanical braking

A vehicle on a hill can be held at a standstill for a configurable time after the operator selects neutral. After the time has expired (or if the seat switch indicates the operator is not present), hill hold terminates and the vehicle can start to move due to gravity if on an incline. If enabled, the system will enter controlled roll-off after hill hold.

You can set the hill hold delay at object 2901_h. A value of 0 to disables the hill-hold feature.

In speed mode, drive torque is disabled whilst neutral braking to stop. However, drive torque must be re-enabled when entering hill hold to allow torque to be applied to hold on the incline. The speed threshold to re-enable drive torque is set at 2908_h.

7.9.13 Inching

WARNING: Ensure inch switches are only mapped to digital inputs when required. Activation of these inputs can cause a drive condition to occur

Inching allows an operator to maneuver a vehicle, at low speeds, towards a load. Inching can be initiated with one switch. A time-out is used to prevent the vehicle from continuing to drive indefinitely if the switch gets stuck or goes short circuit.

To configure inching:

- Ensure forward and reverse inching switches have been mapped to two digital inputs.
- Specify an inching speed (0% to 25% of the full speed of the vehicle) at 2905_h sub-index 1. This is either a speed target in speed mode, or maximum speed in torque mode.
- Specify an inching throttle (0 to 100%) at 2905_h sub-index 3. This gives a torque target in torque mode. This is not used in speed mode.
- Specify a time-out (0.1 s to 5.0 s) at 2905_h sub-index 2.

7.9.14 Belly Switch

WARNING: Ensure the belly switch is only mapped to a digital input when required. Activation of this input can cause a drive condition to occur

The belly switch is normally connected to the end of the tiller arm on class 3 vehicles. When activated it forces a drive condition in forward at a user specified throttle value and maximum speed for a specified time.

To configure belly:

- Ensure the belly switch is mapped to a digital input.
- Specify the maximum belly speed at $290C_h$ sub-index 2.
- Specify a belly throttle at $290C_h$ sub-index 1. This will determine the torque demand in torque mode or speed demand in speed mode.
- Specify a belly time out at $290C_h$ sub-index 3. The belly function will cease after this time has expired.

7.9.15 Driveability select switches

WARNING: Ensure the driveability switches are only mapped to digital inputs when required. Activation of these inputs can cause driving parameters to change

There are two driveability select switches (2126_h and 2127_h).

To enable either of these they must be mapped to digital inputs. When they are active, the corresponding driveability profiles (2921_h and 2922_h) are applied.

See Driveability profiles (page 86) for more information.

7.9.16 Economy

The economy input is an analogue input which can be used to increase vehicle efficiency and extend battery life. It is normally controlled using a potentiometer mounted on the vehicle's dashboard. The economy voltage (2222_h) must be mapped to an analogue input.

Efficiency is improved by reducing the acceleration rate or the maximum torque.

- Configure the economy input at object 2912_h as follows:
- Economy function: select acceleration or torque.
- Economy voltage input: These settings are similar to those for the throttle (see page 77).
- The economy value calculated from the voltage can be read at 2622_h.

7.9.17 Seat Regenerative Braking

The seat switch can be used to override the current driveability settings with a higher value as set in 2928h. This disables drive and allows stronger braking to quickly bring the vehicle to a halt when the driver is not present and in control. This overrides the following settings:

- Maximum torque, Acceleration and Deceleration rates in Neutral Braking
- Maximum torque, Acceleration and Deceleration rates in Foot Braking

Seat regen can be configured to only be activated when above a set speed to prevent braking torque when the vehicle is already stationary. A “Seat Warning” fault is set under this condition.

7.9.18 Pump configuration

The controller can use a mixture of switch and analogue voltages as the pump input. In addition, the power steer function can be used as an extra input to the pump if the pump motor is required to supply pump and power steering.

7.9.18.1 General Setup

Configure the pump features at $2A00_h$:

- Inhibit pump when BDI drops below cut-out level. If already operating when the cut-out occurs, the pump will continue to operate until all pump inputs are inactive.
- Drive Enable switch and/or Seat switch input disables pump.
- Ignore Line Contactor state. Allows the pump to operate if it is not connected to the battery through the line contactor. Should be set if the pump also supplies power steering and the power steer is required to operate when the line contactor is open.
- Use Power Steer target velocity as pump input, if pump also supplies power steering.
- Enable minimum pump speed. Enable this to force the pump to run at minimum speed ($2A01_h$, 2) even when there is no trigger. Can be used to maintain minimum pump pressure.
- Pump to stop on Low Battery. Enable to force pump to stop immediately on low battery condition.
- Use power steer demand to minimum pump speed. Enable this to force the pump to use power steer demand as a minimum speed. Can be used to maintain minimum pump pressure for power steering.
- Set the pump minimum and maximum speed, maximum torque, acceleration and deceleration at $2A01_h$. The pump speed is calculated as the value from the inputs multiplied by the maximum speed.

7.9.18.2 Priority/additive inputs

Each pump input can be configured as a priority input or an additive input. When calculating the pump demand, the controller selects the demand from the highest priority active input, and then adds the demand from all the active additive inputs.

Configure priority/additive levels in $2A10_h$ and $2A11_h$, and $2A20_h$ to $2A26_h$.

7.9.18.3 Pump throttles

There are 2 pump throttle inputs, which can be configured independently at $2A10_h$ and $2A11_h$. The pump throttles allow proportional control of the pump speed.

Configure inputs as priority or additive and set the voltage levels in the same way as the traction throttle. The pump throttles must be mapped to analogue inputs.

7.9.18.4 Pump switches

There are 7 pump switch inputs. Configure each input as priority or additive and assign it a value at $2A20_h$ to $2A26_h$. The pump switches must be mapped to digital inputs.

7.9.18.5 Pump Driveability Profiles

Pumps have configurable driveability profiles. Profiles are triggered by pump driveability select switches (2152_h and 2153_h). One or more of these switches must be mapped to enable pump profiles.

Each profile allows the installer to reduce acceleration and deceleration rates, throttle and switch values and maximum torque.

Set pump driveability profiles at $2A30_h$ and $2A31_h$

7.9.19 Power steer configuration

7.9.19.1 General

Power steering can be provided using:

- Contactor. Map the power steer contactor drive object to an analogue output.
- Pump motor controller. Configure pump to provide power steering. Power steer demand is added to pump demand.
- Dedicated motor controller. Map power steer application motor object to motor control slave.

NOTE: Power steer motors always run in speed mode. Ensure the motor slave is also configured for speed mode in 6060_h

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The power steer can be triggered by a number of events:

- Vehicle moving
- FS1 switch activating
- Direction selected.
- Seat switch activating
- Footbrake activating

CAUTION The power steering function will always attempt to execute, even if the line contactor is open due to a fault condition. This is to ensure power steering continues to operate at all times

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Set the power steer motor speed, acceleration and deceleration at $2B01_h$. This is not required if the power steer motor is operated by a contactor.

7.9.19.2 Variable Assist Power Steering

Dragon8 supports a variable assist power steering algorithm which can be used to reduce the power steering speed as vehicle traction speed increases to a user configurable level. Set the reduction factor and traction speed in $2B02_h$. This allows power steering effort to be reduced as vehicle speed increases to prevent steering becoming too light.

7.10 Vehicle features and functions

Ensure you have completed the CANopen network setup, Motor Characterization, I/O Configuration and Vehicle Performance Configuration processes described above.

7.10.1 Line contactor

A line contactor can be mapped to a digital output on the Dragon8. Its purpose is to isolate the controller and motor from the battery during power down or when a serious fault occurs. It is normally closed whenever the system is under power. However, it can be configured to open after the vehicle has been stationary for a period of time via object 2820h.

Like all motor controllers, the Dragon8 uses a large internal capacitor bank across the inverter stage. Some form of capacitor pre-charge must be employed before the line contactor closes. Otherwise, very high inrush current will weld the contactor tips. The controller may be damaged, as well.

NOTE: It is recommended that the capacitors are charged to at least 90% of battery voltage before closing the line contactor. This may be done by a pre-charge relay (driven by the Dragon8) and an external resistor

The Dragon8 can be configured to control a pre-charge relay. If configured, it will close at power up and charge the capacitor bank through a resistor. If no faults are detected and the minimum pre-charge voltage is reached, the main line contactor will close. The minimum capacitor voltage required for the line contactor to close is set in object 5821_h.

7.10.2 Electro-mechanical brake

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WARNING: Electro-mechanical brakes are not recommended for on-highway vehicles. They can cause the traction motor/wheel to remain locked or brake severely if the wheel is momentarily locked due to loss of traction on a slippery surface and/or mechanical braking. An electro-mechanical brake normally fails to the applied state. Therefore, a loss of power, or wiring fault can cause the brakes to be applied even at a very high speed

The electro-mechanical brake can be mapped to a digital output. The brake will be mechanically engaged (preventing vehicle motion) when the associated digital output or the keyswitch is OFF. Conditions under which the brake is applied can be configured in object 2903h.

The brake can be set to engage when the vehicle stops or when roll-off is detected. If the brake is configured to apply when the vehicle stops, it will not be applied until the vehicle has been stationary for more than the brake delay time.

The brake can also be configured so that it is applied at speeds above zero in 2903h, 6, during the brake apply timer period. This allows brake operation when the vehicle speed never quite reaches zero.

In the event of a severe fault the brake can be configured (via 2905_h, 5) to apply immediately or to wait until the vehicle to stops before applying the brake. However, in the event of an encoder fault, the brake remains released.

WARNING: In the event of an Encoder Fault on a *slave node* causing a perceived zero speed by the master traction controller, the brake will apply regardless of the setting in 2905_h, 5. This applies only to multi node systems

It is possible to detect an electro-brake wire off by configuring a minimum brake coil current in 2903_h, 4. Should the coil current drop below this value whilst energized, then the controller will set a Drive Inhibit Fault and neutral brakes to a stop. The fault clears when neutral is selected, if the brake is commanded to be applied, or neutral is selected and the current exceeds the minimum value.

WARNING: It is not possible to configure electro brake wire off on slave nodes, where the brake is released via a CANopen PDO

To prevent vehicle roll away on inclines, the electro-mechanical brake normally does not release until the traction motor(s) are producing torque. This feature can be disabled using 2903_h,3.

7.10.3 External LED

This mirrors the operation of the controller's on board diagnostic LED. The external LED can be mapped to a digital output to drive a lamp on the vehicle dashboard.

7.10.4 Alarm buzzer

The alarm buzzer can be mapped to a digital output.

Configure the alarm buzzer output, if required, to be activated by one or more of these conditions at 2840_h:

- forward motion or forward direction selected
- reverse motion or reverse direction selected
- faults other than information faults
- controlled roll-off
- BDI low

A different cadence for each of the above conditions can be configured.

7.10.5 Brake Lights

A brake light output object is available and can be mapped to a digital output. The brake lights will illuminate whenever the footbrake is pressed (providing either an analogue or digital footbrake input is available) or if the system is in direction change braking.

7.10.6 Horn

Ensure a digital input switch is mapped to the horn button switch, and a digital output is mapped to the horn output.

7.10.7 Vehicle Speed Calculation

The controller can be configured to calculate vehicle speed from motor speed by setting a configurable ratio between these values in object 2915_h. Calculated vehicle speed can then be transmitted to the CANbus for use with compatible displays, or used to keep a log of total distance travelled by the vehicle.

The convention is to calculate vehicle speed as a signed number in 12.4 format in kph. This is required for accurate odometer measurement stored in the controller. If the display used requires different units than kph, a user speed calculation is also provided whose units are independent from all other features. Both the controller and user ratio calculations are located in object 2915_h. While vehicle speed is a signed value, the option to have unsigned user speeds is also provided (an absolute value will be calculated).

The ratio between motor speed and vehicle speed are dependent on vehicle drive train parameters such as gearbox ratio and wheel size. However, the ratio should be calculated such than when it is multiplied by motor speed (which is in rpm), the result is vehicle speed in kph 12.4 format. Use the following method to do this:

- Set the divisor (object 2915_h sub index 2) to a known speed point of the motor
- Set the multiplier (object 2915_h sub index 1) to the corresponding scaled vehicle speed for the known motor speed.

For example, if it is known that 1000rpm on the motor results in a vehicle speed of 5kph, then the divisor should be set to 1000, and the multiplier should be set to 0x0050, which is 5kph in Q4 format (12.4).

The same process should be repeated for the user speed ratio, setting the multiplier for the user speed in the desired custom format. Both the vehicle and user speeds, objects 2921_h and 2922_h, can be mapped to TPDO for transmission to other devices via CAN if required.

7.10.8 Distance Calculation

Total vehicle distance and trip distance counters are available at objects $29A0_h$ and $29A1_h$. Counters will operate and will be accurate provided that the vehicle speed calculated at object 2721_h is in kph in 12.4 format. Counters are available in the following formats:

- Distance travelled in km in 24.8 format
- Distance travelled in km in 0.1km/bit increments
- Distance travelled in miles in 0.1mile/bit increments

Both distance counters objects can be mapped to TPDOs for monitoring over the CANbus, or for use by a dashboard display. The trip distance counter can be reset by holding the reset switch,

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object $217D_h$, closed for 1 second.

The total vehicle distance counter cannot be reset by the user.

7.10.9 Service Indication

The controller can reduce vehicle performance and indicate to the operator when a vehicle service is required. The interval between services is user-configurable.

Configure the following at object 2850_h:

- Service indication: via an analogue (contactor) output (e.g. to drive a dashboard lamp) and/or Dragon8's LED.
- Source hours counter: selects the hours counter and is used to determine when a service is required.
- Service interval: hours between vehicle services. Can be used by the reset function (see below) or for information only.
- Next service due: Servicing is required when the source-hours counter reaches this time. This can be set manually, or automatically using the reset function; see below.
- Reset function: write to the reset sub-index at 2850_h to automatically reset the service timer for the next service. The next service due time is calculated as the source hours counter time plus the service interval.

7.10.9.1 Service profile

This is a driveability profile where you can set maximum torques, speeds and acceleration rates to be applied when a vehicle needs servicing (2925_h). See 'Driveability profiles' on page 86.

7.10.10 Traction motor cooling fan

This object can be used to drive a motor cooling fan when the operator is present on the vehicle (as indicated by the seat switch). The cooling fan object (2421_h) must be mapped to an analogue output.

7.10.11 Controller heatsink / motor cooling fan

An external fan to cool the controller heatsink or a motor may be connected to one of the analogue outputs. The fan will be turned on by the controller when either the heatsink temperature or the motor temperature exceed a specified temperature. The fan turns off when the nominated temperature is cold. The temperatures at which the fans should turn on and off, the analogue output to use for the fan, the fan voltage and the temperature source (heatsink or motor) can be programmed using the heatsink fan object ($5A01_h$). Note that the contactor driver outputs may be damaged if connected to capacitive loads. It is quite common for fans to incorporate capacitive elements, in which case a relay should be used to isolate the fan from the contactor driver output.

NOTE: The temperature set-point to turn on the fans should be higher than the set-point to turn off the fans

The fans will not operate if another function is configured to run on the specified analogue output

7.10.12 Motor over-temperature protection

The controller protects motors from over-temperature. It maintains a motor temperature estimate and can also accept a direct temperature measurement via an analogue input (for a thermistor) or a digital input (for an over-temperature switch).

The temperature estimate is calculated by monitoring current to the motor over time. The estimate is configured at 4621_h.

The estimate is always applied, since it can detect increases in motor temperature more quickly than the direct measurement. Direct measurement is normally done on the motor casing, which lags behind the internal temperature.

Additional protection is provided for thermistor wire-off conditions. If the temperature sensor input measures a completely short circuit or open circuit signal, then the output torque will begin to reduce gradually over time. A recovery rate can also be specified should the signal become valid again. This means that wire-off situations, should they occur during drive, do not result in an instant loss of torque. Both the torque ramp down and recovery rates can be configured using object 4620_h.

7.10.13 Motor over-speed protection

A facility to protect the motor or vehicle power train due to damage by over-speeding is available on the controller. A maximum speed can be configured at object 4624_h. Under normal operation the controller should output braking torque to prevent the over-speeding initially, if the measured speed exceeds this limit then the controller will shut down and a fault will be set.

CAUTION The trip speed offers a final level of protection for the vehicle mechanics, and should be set to a minimum level that would not be expected to be reached under normal operation

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7.10.14 Battery protection

The nominal battery voltage must be set at 2C00h.

7.10.14.1 Over voltage

Battery over voltage usually occurs during regenerative braking.

To provide protection set values for these parameters at 2C01h:

- Over voltage start cutback: the value at which the braking effort is linearly reduced to limit voltage increase.
- Over voltage limit: the value at which the controller cut-outs out. A fault is set if the voltage exceeds the cut-out voltage.

7.10.14.2 Under voltage

To prevent excessive battery discharge, set values for these parameters at 2C02h:

- Under voltage start cutback: the value at which the current drawn from the battery is reduced to limit voltage decrease.
- Under voltage limit: the value at which the controller cut-outs out. A fault is set if the voltage drops below the cut-out voltage for longer than the protection delay
- Protection delay: the time it takes for the controller to cut-out after the under-voltage limit has been reached (2C03h).

7.10.14.3 Battery Discharge Indicator (BDI)

CAUTION When not in use ensure the BDI function is disabled by setting the Cell Count (in $2C30_h$, 6) to 0.

Monitor battery voltage using Dragon8's Battery Discharge Indicator (BDI). The BDI presents the driver with a percentage remaining charge figure and has become an industry standard in recent years.

NOTE: The BDI is not a measure of the absolute battery charge remaining and therefore we recommend you regularly check the absolute value in accordance with the battery manufacturer's instructions

To use the BDI, configure the following parameters at $2C30_h$ in the Object Dictionary:

- Cell count: this is the number of battery cells and is normally half the battery voltage, as cells are usually 2 volts each.
- Reset voltage (V): set this to the cell voltage when the batteries have just been charged. This resets the BDI back to 100%.
- Discharge voltage (V): set this to the cell voltage when the battery is discharged.
- Cut-out level (%): this is the level at which the vehicle adopts the low battery driveability profile.
- Discharge rate (s/%): this is the rate at which the BDI remaining charge value discharges. Set to 0 to use default value of 16.8s to reduce by 1%. This default should suit most lead-acid battery types; however, this can be increased/decreased for different battery technologies.

NOTE: Setting the warning and cut-out levels to 0% disables the warning and cut-out functionality

An additional table exists at index $2C31_h$ which allows an initial BDI value to be specified at start up based on the measured battery voltage. At start up, the measured battery voltage is taken, and the corresponding BDI percentage remaining value is then used as the starting point for the BDI. After this, the BDI remaining value operates in the standard way. Note, this function is only available if the corresponding bit is set in object $2C30_h$ sub 1.

Read the percentage remaining charge value from 2790_h sub-index 1 in the Object Dictionary.

7.10.15 Battery Current Limit

Battery current is estimated from the measured motor currents and applied voltages. It can be limited by the controller for the purposes of efficiency or to protect batteries that are sensitive to high levels of current flow. Charge and discharge currents can be limited independently.

If limiting the discharge current flow, this can extend the time taken for the vehicle to reach top speed. Note that limiting the charge current flow back to the battery can impede the performance of regenerative braking.

Object 2870_h controls how the battery current limit is calculated. Sub-index 1 of this object can be set to one of the following values to specify how the current limit behaves:

Value	Mode
0x00	Master control of battery current limit disabled. To completely disable battery current limit, object 4623_h sub index 3 must also be set to 0x0000.

0x01	Battery current limit set by object 4623h sub index 2 and 3.
0x02	Battery current limit controlled by compatible BMS
0x03	Battery current limit set by object 4623h sub index 2 and 3, but the drive current limit is multiplied down by factors set in sub index 4 and 5 when driveability profiles are activated
0x04	Battery current limit is calculated to maintain a power limit as set in sub index 6 and 7.

Table 24 – Battery Current Limit Object 2870h configurations

Object 2871h provides a means to have TracApp cut back the torque demand in situations where the battery current limit is reduced. This is useful for configurations where an external BMS can cut back the current limits to low levels. Effectively, it prevents TracApp requesting torque that cannot be achieved.

Object 4623h shows the current limits that are in effect. Sub index 3 of this object allows you to specify the cutback aggressiveness and a measurement correction factor. Setting this to zero. Battery current flow can be monitored at object 5100h.

Note that regen currents flowing back to the battery are specified as negative numbers.

7.10.16 Displays

Dragon8 is compatible with SmartView displays.

Clearview displays use the CANopen protocol. To use, set up TPDOs to transmit the required data for the display.

SmartView displays use BorgWarner's proprietary CAN protocol. To use set the CAN baud rate to 100kHz at 5900h, enable SmartView and select hours counter and/or real speed at 2E00h.

Chapter 8: Monitoring Dragon 8

Chapter 8 - Monitoring Dragon 8

8.1 Reading status variables

All status information is contained either in the Dragon8 Object Dictionary, or transmitted using either H-Protocol or I-Protocol messages. Most service information can be accessed using SDOs. Some can be mapped to PDOs for continuous transmission to remote nodes such as displays and logging devices.

8.1.1 Motor Data

The following motor data is available on H-protocol:

- Motor torque, speed, battery current
- Available drive and brake torque
- Motor temperature
- Motor control and status words

The following motor data is also available on H-protocol debug messages

- Motor currents and voltages
- Additional motor debug information

8.1.2 Customer Input Data

The following customer input data is available on I-protocol:

- Digital input states
- Analog input voltages

8.1.3 Device Data

The following device data is available on H-protocol:

- Device temperature
- Power frame (DC link) voltage
- Highest priority fault

8.1.4 Identification and version

Read identification and version information at:

- 1008h – Controller name.
- 1009h – Hardware version.
- 100Ah – Software version.

- 1018h – Identity object. Contains CANopen vendor ID, product code, CANopen protocol revision, and controller serial number.
- 5500h – NVM (EEPROM) format.
- 5501h – Internal ROM checksum.

8.1.5 Supply monitoring

The controller measures the following supply voltages:

- KL15/KL30; measured as KL15 and KL30 (other products have separate KL15 and KL30 pins) inputs and read at 5100h.
- Capacitor voltage; measured at the B+ terminal. Read at 5100h and also available on H-protocol.

8.1.6 Hours counters

The controller supports many different hours counters for various functions. Some counters run on all units and some only run on the Dragon8 configured as the vehicle master.

NOTE: Hours counters are preserved with a minimum resolution of 15 seconds when the system is powered down

The hours counters are:

- KL15/KL30 key hours: increments while the keyswitch is in the ON position (5200h).
- Controller pulsing hours: increments when the controller is powering its connected motor (4601h).

8.2 Logging

The controller can log events in the system (along with additional event-related information) and minimum and maximum levels of important parameters. You need different levels of access to clear the contents of the logs.

Logs are normally reset individually. However, to reset all logs at once write to 4000h.

8.2.1 FIFO event logs

Events are recorded by these two separate FIFOs (first in, first out logs), which operate identically:

- System: this FIFO is 20 elements deep and is used for events such as software upgrades, user logins and some hardware upgrades (4100h to 4102h).
- Faults: this FIFO is 40 elements deep and is used for fault logging (4110h to 4112h).

At object 41X0h:

- Reset the FIFO
- Read its length

You can access the FIFO using objects 41X1h and 41X2h. The FIFO index is entered at 41X1h and the data is read from 41X2h.

8.2.2 Event counters

The controller provides 10 event counters at 4200h to 420Ah. Each event counter can record information about occurrences of one event. The allocation of event counters to events is user-configurable however Dragon8 will automatically count important events in unused counters. The information recorded in each event counter is:

- The time of the first occurrence
- The time of the most recent occurrence
- The number of occurrences

8.2.3 Operational monitoring

At objects 4300h and 4301h, Dragon8 monitors and records the minimum and maximum values of these quantities:

- Battery voltage
- Capacitor voltage
- Motor current
- Motor speed
- Controller temperature

Two instances of the operational monitoring log are maintained. Service engineers can access and clear the first log; the second is accessible and clearable only by BorgWarner engineers. The Customer copy is normally recorded and reset each time the vehicle is serviced. The BorgWarner copy records data over the controller's entire working life.

8.3 CANopen abort code

The controller will sometimes respond with a CANopen General Abort Error (08000000h) when the object dictionary is accessed. This can occur for many reasons. Object 5310h gives the exact abort reason as shown in Table 25.

0	None	**12**	Invalid value	**24**	Cannot read from DSP
1	General	**13**	EEPROM write failed	**25**	Peek time out
2	Nothing to transmit	**14**	Unable to reset service time	**26**	Reserved for future use
3	Invalid service	**15**	Cannot reset log	**27**	Reserved for future use
4	Not in pre-operational	**16**	Cannot read log	**28**	Reserved for future use
5	Not in operational	**17**	Invalid store command	**29**	Reserved for future use
6	Cannot go to pre-operational	**18**	Bootloader failure	**30**	Reserved for future use
7	Cannot go to operational	**19**	DSP update failed	**31**	Reserved for future use
8	Access level too low	**20**	GIO module error failed	**32**	Checksum calculation failed
9	Login failed	**21**	Backdoor write failed	**33**	PDO not copied
10	Range underflow	**22**	Reserved for future use		
11	Range overflow	**23**	Cannot write to DSP		

Table 25 – Abort Reason Codes

8.4 Faults and warnings

8.4.1 Introduction

In the event of a fault Dragon8 takes the following action:

1. Takes action appropriate to the fault severity. This can be either derating of motor power or speed or shutdown of the power frame.
2. Sends out an EMCY message on the CANbus and updates the highest priority fault ID in the H-protocol.
3. Flashes the LED in a pattern determined by the fault type and severity.
4. Logs the fault for later retrieval.

8.4.2 Fault identification

You can identify a fault as follows:

- Check the number of LED flashes and use the table below to determine what action can be taken
- Pick up the EMCY on the CANbus and read the fault condition using configuration software
- Interrogate the fault on the node directly using DVT or other configuration software.

8.4.2.1 LED flashes

Use below to determine the type of fault from the number of LED flashes. The LED flashes a preset number of times in repetitive sequence (e.g. 3 flashes – off – 3 flashes – off – and so on). Only the faulty node in a multi-node system flashes its LED. Possible operator action is listed in the right-hand column of the table.

LED flashes	Fault category
0 (off)	Internal hardware failure
1	Configuration fault
2	Input sequence fault
3	MOSFET/IGBT failure
4	Contactor failure
5	Miscellaneous
6	Analogue input failure
7	Battery faults
8	Temperature faults
9	Contactor coil short circuit
10	Unit is Preoperational
11	General
12	CAN or communication faults

LED flashes	Fault category
13	Internal faults
14	Peripheral faults
15	Service required

Table 26 – LED flashes

8.4.3 Fault list

Use DVT to access the active fault list. If you don't have DVT you can use any configuration tool as follows:

- Object 5300h gives information about all active faults. Read sub-index 1 to get the number of active faults. Write to sub-index 2 to select one of the active faults (0 = highest priority) and read back sub-index 3 to read the fault ID at that index.
- Object 5610h can be used to read a text description of the fault. Write the fault ID to sub-index 1 and read back the fault description from sub-index 2.

8.5 Upgrading the controller software

It is possible to field update the firmware of the Dragon8 controller, typically using BorgWarner's DVT configuration tool. However, in most cases this is not necessary as the controller will already have the latest firmware installed.

Please contact BorgWarner for assistance with this process.

WARNING Incorrect firmware can cause unexpected vehicle operation. You should ensure the firmware you are loading is a released version

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Chapter 9 - List of Figures and Tables

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