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RCU10 quadrature compensation unit

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Care of Equipment

The Renishaw RCU10 compensation system and associated products are precision instrumentation products and components and must therefore be treated with care.

Changes to Renishaw Products

Renishaw plc reserves the right to improve, change or modify its products and documentation without incurring any obligation to make changes to Renishaw equipment previously sold or distributed.

Safety

This manual gives recommendations for the safe installation and configuration of the RCU10 compensator system, and associated ancillary products.

It is the sole responsibility of the OEM/retrofit company to ensure that, in safety critical applications, any failure or deviation from expected operation of this product, howsoever caused, shall not cause the machine to become unsafe.

It is the machine supplier's responsibility to ensure that the user is made aware of any hazards that may be involved in the operation of their machine, including those covered in Renishaw product documentation, and to ensure that adequate guards and safety interlocks are provided.

This manual suggests a number of safety measures that can be included in machine design. However, it is the sole responsibilty of the OEM/system integrator to specify and integrate measures suitable for the application.

Symbol Definition

The following symbol is used in this manual and in the software to indicate areas requiring special attention:

WARNING: Information that is vital for the safe installation and operation of the RCU10 system.

Warranty

Renishaw plc warrants its equipment provided that it is installed and operated exactly as defined in associated Renishaw documentation.

Claims under warranty must be made from authorised service centres only, which may be advised by the supplier or distributor.

EU and UKCA Declaration of Conformity

Renishaw plc hereby declares that RCU10 Environmental Compensator is in compliance withthe essential requirements and other relevant provisions of:

- the applicable EU directives
- the relevant statutory instruments under UK law

The full text of the declaration of conformity is available at:
www.renishaw.com/RLECE

REACH

Information required by Article 33(1) of Regulation (EC) No. 1907/2006 ("REACH") relating to products containing substances of very high concern (SVHCs) is available at:

www.renishaw.com/REACH

China RoHS

For more information on China RoHS, visit:
www.renishaw.com/calcompliance

Disposal of waste electrical and electronic equipment

The use of this symbol on Renishaw products and/or accompanying documentation indicates that the product should not be mixed with general household waste upon disposal. It is the responsibility of the end user to dispose of this product at a designated collection point for waste electrical and electronic equipment (WEEE) to enable reuse or recycling. Correct disposal of this product will help to save valuable resources and prevent potential negative effects on the environment. For more information, please contact your local waste disposal service or Renishaw distributor.

Disposal of batteries

The use of this symbol on the batteries, packaging or accompanying documents indicates that used batteries should not be mixed with general household waste. Please dispose of the used batteries at a designated collection point. This will prevent potential negative effects on the environment and human health which could otherwise arise from inappropriate waste handling. Contact your local authority or waste disposal service concerning the separate collection and disposal of batteries. All lithium and rechargeable batteries must be fully discharged or protected from short circuiting prior to disposal.

Packaging

Packaging components	**Material**	**94/62/EC code**	**94/62/EC number**
Outer box	Cardboard - 70% recycled material	PAP	20
Insert	Cardboard - 70% recycled material	PAP	20
Bags	Low density polyethylene	LDPE	4

USA and Canada Regulations

FCC Compliance Statement

47 CFR Section 15.19

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions:

1. This device may not cause harmful interference, and
2. This device must accept any interference received, including interference that may cause undesired operation.

47 CFR Section 15.21

The user is cautioned that any changes or modifications not expressly approved by Renishaw plc or authorized representative could void the user's authority to operate the equipment.

47 CFR Section 15.27

This unit was tested with shielded cables on the peripheral devices. Shielded cables must be used with the unit to ensure compliance.

47 CFR Section 15.105

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in acordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

Canada - ICES

This ISM device complies with CAN ICES-003(A) / NMB-003(A).

Cet appareil ISM est conforme à la norme ICES-003(A) / NMB-003(A) du CAN.

General safety notice

The Renishaw laser encoder and compensator systems are designed for integration into the primary position feedback loop of a motion system. It is essential that the system is installed in accordance with the instructions in the installation guide and it is the responsibility of the system integrator to ensure that, in the event of a failure of any part of the Renishaw system, the motion system remains safe.

In the case of motion systems with powers or speeds capable of causing injury, it is essential that appropriate safety protection measures are included in the machine design. Further guidance on this can be found in the European Standard EN292 “Safety of machinery – Basic concepts, general principles for design”. It is the sole responsibility of the OEM/system integrator to select the safety measures appropriate for their application. The following is a list of measures that should be considered as part of that process.

1. The Renishaw system includes an Error signal output. The control system must be designed to stop the axis motion if this error output is asserted. In addition to the Error signal, the position feedback signals can also be configured to go tristate (open circuit) under fault conditions. Some controllers can be programmed to detect this, thereby providing a further level of protection in case of failure of the error signal output (see item 3 below). If the controller is not capable of detecting open circuit position feedback signals, this option must **not** be enabled.

2. The axis must include physical limit switches which, when tripped, will stop axis motion before damage occurs (soft limits alone are insufficient). Note that in the case of thermally compensated systems, positional corrections of several hundred ppm are possible. This should be taken into account when defining the relative positions of soft and hard axis limits.

3. Cable breakage detection (encoder disconnect). The position feedback and Error signal lines are all provided as differential line driven pairs. Failure in the cable or failure of the line drivers can be detected by checking that these differential pairs are always being driven in opposing states. If the lines are not in opposing states, the motion must be stopped.

4. Motor torque monitoring. If the motor torque exceeds an expected limit, the axis of motion must be stopped.

5. The machine must include an emergency stop button.

6. Following error detection, if the difference between the controller demand position and the axis feedback position exceeds an expected limit, then the axis motion must be stopped.

7. Guards, viewing windows, covers and interlocks may be used to prevent user access to hazardous areas, and to contain ejected parts or materials.

8. If the machine includes an independent tacho (velocity) feedback system, this should be cross-checked with the position feedback. For example, if the tacho indicates the axis is moving, but the position feedback doesn’t, then the axis motion must be stopped.

9. In the case of synchronised parallel motion systems (for example twin rail gantry drive systems), the relative positions of master and slave axes should be monitored. If the difference in their positions exceeds an expected limit, then axis motion must be stopped.

Note: In the case of measures 6 – 9, the limits need to be selected carefully depending on the application and the type of position compensation selected to avoid false alarms.

For further advice consult the appropriate machinery safety standards.

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Section 1

System overview

Contained in this section

1.1 Introduction

This manual covers the installation, configuration and operation of the Renishaw RCU10 real-time quadrature compensator system.

1.2 System overview

The RCU10 real-time quadrature compensation system overcomes environmental error sources in linear motion systems to improve process accuracy and repeatability. The RCU10 monitors a machine’s ambient environment, via a network of sensors, and uses advanced digital signal processing to perform real-time compensation on the position feedback signals.

The RCU10 can provide:

- Refractive index compensation, for laser encoders, using air pressure and temperature sensors.
- Scale thermal expansion compensation, for incremental linear encoders, using material temperature sensors.
- Thermal expansion compensation of machine structure and workpieces, using material temperature sensors.
- Format conversion – digital (A quad B) to analogue (Sin/Cos)
- Scale factor conversion – laser wavelength to engineering units

Figure 1.1 – RCU10-P with sensors

A functional block diagram of the RCU10 is show below:

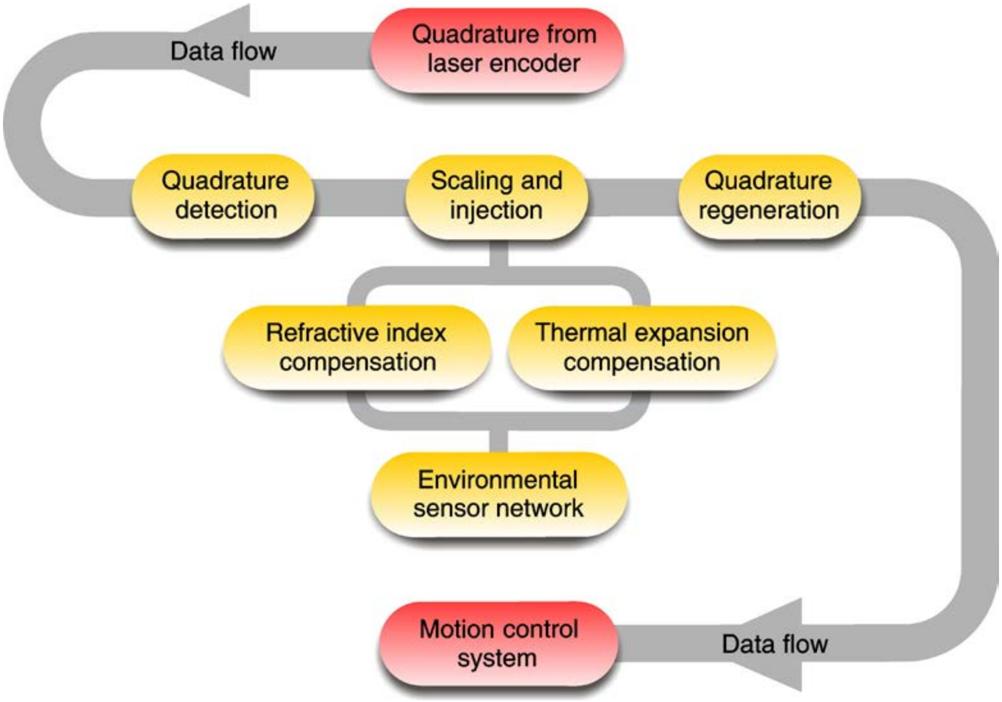

Figure 1.2 – Internal block diagram of operation when used in conjunction with a laser encoder

The RCU10 processor accepts digital quadrature, along with the environmental data collected by factory-calibrated sensors, and calculates the total amount of compensation necessary to correct the axis position. The required compensation is then applied through quadrature scaling and injection (addition or removal of quadrature pulses) into the encoder feedback signal, the total process being completely transparent to the motion controller. The corrected feedback signals are provided to the motion controller in either RS422 digital A quad B or analogue Sin/Cos 1 Vpp formats, with a nominal accuracy of ±1 ppm (refractive index only) or ±2 ppm (with 10 ppm/°C material compensation).

The RCU10 compensator is available in two models:

- RCU10-P, which contains an internal air pressure sensor
- RCU10, which does not contain an air pressure sensor

One compensator is required for each machine axis that is to be compensated.

When laser encoders are being used, one compensator in the system must be an RCU10-P so that the ambient air pressure can be determined and refractive index compensation applied. The basic RCU10 may be used for conventional (non-laser) encoders or for ‘slave’ axes in a laser encoder system.

When used as a multi-axis system, the RCU10s are linked via a high-speed serial link; this allows the RCU10s to share sensor information and operating data.

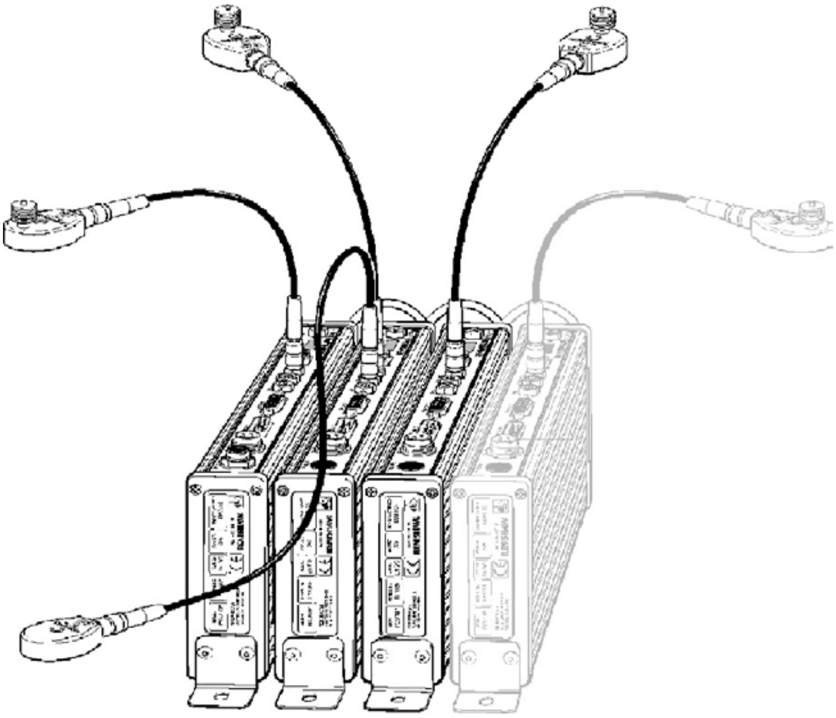

Figure 1.3 – Multi-axis system

1.3 Compensation functions

The RCU10 is capable of performing a number of processing functions on position feedback signals. These compensation modes can be enabled or disabled, depending on the application requirements and type of encoder used. The following section provides an overview of these modes. Full details can be found in Appendix G.

1.3.1 Scale factor

The RCU10 is capable of performing a fixed scale factor correction to convert the intrinsic encoder resolution into a more useable value (e.g. 633 nm -> 1 µm). The scale factors available depend on the input resolution and the type of output required.

This is the basic mode of operation when no compensation functions are enabled.

1.3.2 Air refractive index compensation

Air refractive index (wavelength) compensation is applied according to the environmental values received from the air temperature and pressure sensors. This mode of compensation is used with laser encoders to provide a consistent and accurate feedback signal regardless of current environmental conditions.

Since the wavelength of light is a function of the ambient conditions local to the beam path, without compensation errors can incur. This error is of the order of 1 ppm for each of the following changes in environmental conditions:

1 ppm for every	**1 °C** (≈1.8 °F)	Change in air temperature
	3.3 mbar (≈0.1 in/Hg)	Change in air pressure
	30% RH @ 40 °C	Change in relative humidity

Air temperature sensors are provided to monitor any local temperature variation within the boundaries of the machine. An air pressure sensor is built into the compensator unit (RCU10-P model only). Humidity is assumed to be relatively constant, and a fixed value may be entered via the configuration software.

To enable the RCU10 system to perform in real time, each of these sensors is read, and the related computation (Edlen's equation*).

* See Appendix G

1.3.3 Encoder thermal expansion compensation

When using conventional scale encoders, the positional accuracy of the system will depend on the thermal expansion of the scale substrate material. The RCU10 is capable of compensating for this effect by measuring the temperature of the scale and applying the relevant positional correction. This will significantly improve system accuracy when subjected to temperature variation.

To utilise this compensation mode, a material temperature sensor must be placed on the scale substrate material and the RCU10 configured with the scale's coefficient of thermal expansion (CTE) and the distance between the machine home and expansion origin position.

1.3.4 Workpiece thermal expansion compensation

The system can also perform material thermal expansion compensation. The function of this feature is to track workpiece temperature and perform compensation based on its CTE, such that the axis position is modified in real time to produce a part with the correct dimensions for current environmental conditions.

To utilise this compensation mode, a material temperature sensor must be fitted to either the part being machined, or a part of equivalent thermal characteristics. A reference location, from which the workpiece is expected to expand, should be identified (by consideration of part fixturing method etc). Once workpiece compensation is enabled, the machine position will be modified to account for workpiece expansion relative to this reference location.

Workpiece expansion concept

The size of a workpiece is proportional to its CTE and the ambient temperature. One of the major sources of error in large parts can be ‘feature misplacement’, which can result from thermal expansion or contraction of the part.

Consider two matching workpieces – one made at 30 °C (86 °F) and one made at 20 °C (68 °F). If these parts are machined without workpiece expansion compensation applied, they will not be the same size when brought together at the same temperature (the part made at the higher temperature will be smaller than the one made at the lower temperature).

By constantly monitoring the workpiece temperature, the RCU10 can use its CTE to calculate the expansion that has occurred relative to a nominal reference temperature of 20 °C (68 °F). This process ensures that parts machined in a poorly controlled environment will be as accurate and consistent as parts machined in an environment maintained at 20 °C (68 °F). That is to say, no matter what temperature the part is machined at, it will be the correct size when measured at 20 °C (68 °F).

Expansion is a greater problem in large workpieces because the amount of expansion is proportional to the distance from the reference point. For example, at a point 40 m (≈130 ft) from the reference point on an aluminium workpiece at 30 °C (86 °F), the error will be 8 mm (5/16 in).

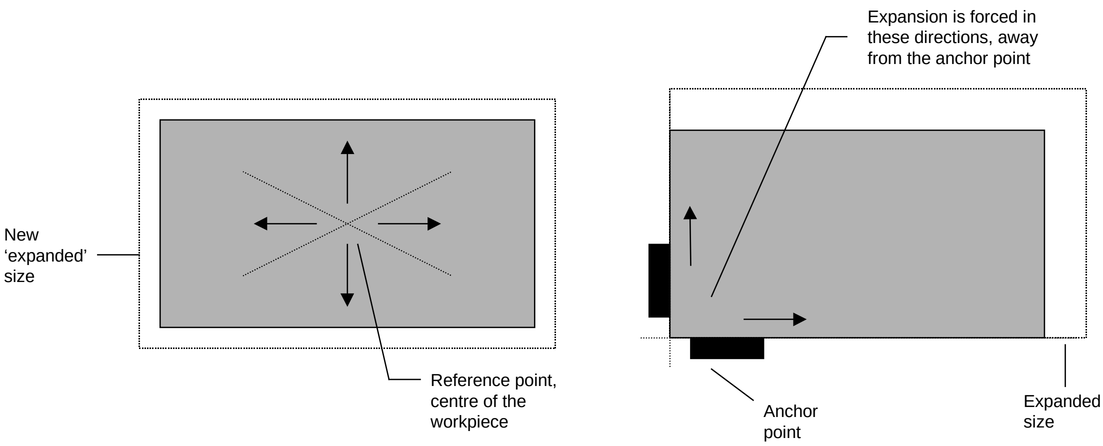

Figure 1.4 – Workpiece expansion

Workpiece compensation reference point

It is up to each user to establish a reference point suitable for their specific workpiece and application. Some experimentation may need to be carried out in order to determine how each fixture or workpiece behaves and thus the best way to apply compensation.

The process of defining a reference point can be complex and depends on many factors. It is up to the user to decide on the best jigging and anchoring options for the workpiece.

Expansion coefficients

The RCU10 recognises expansion coefficients as parts per million per degree Celsius or degree Fahrenheit (the unit of temperature used depends on how the user configures the system). The reference temperature for material expansion is 20 °C (68 °F).

Table 1.1 below shows example expansion coefficients for aluminium and steel:

Table 1.1 – Expansion coefficients

Material	ppm/°C	ppm/°F
Aluminium	20	11.11
Steel	10	5.56

Use the following formula to convert from ppm/°C to ppm/°F:

[ppm/°C] multiplied by 5/9 = [ppm/°F]

e.g. 20 ppm/°C x 5/9 = 11.11 ppm/°F

1.3.5 Structure thermal compensation

An additional source of positioning error may be the thermal distortion of the machine structure. This could manifest in a number of ways including:

- expansion of the spindle
- expansion of the machine structure

As long as the thermal effect is linear and not related to axis position, the RCU10 can be used to reduce the error.

To utilise this compensation mode, a material temperature sensor must be placed on the applicable part of the machine structure and the RCU10 configured with the number of micrometres of correction required per degree C.

1.4 Operational functions

A number of useful operational functions (some optional) are available on the RCU10 to provide flexibility and ease of use.

1.4.1 Selectable parameter tables

A number of 'parameter tables' are available for use during operation, which are selectable through external I/O. These allow easy 'switching' of a number of common options/operations, including:

- Dead path or reference offset from scale expansion origin
- Workpiece temperature sensor
- Workpiece expansion coefficient
- Workpiece origin offset
- Workpiece origin type

The use of these switchable parameters allows numerous functions such as:

- Multiple machine home positions
- Changing to an alternative machining zone
- Use of multiple workpiece material sensors (for multiple machine zones or other reasons)
- Changing of the material type (e.g. aluminium/steel)

1.4.2 Compensation buffering

When the RCU10 is in this mode, it will continue to monitor the encoder input and perform the relevant quadrature scaling. However, any injection required to maintain compensated position will be stored in a buffer within the RCU10. When the mode is disabled, any stored (buffered) count is slowly injected into the motion feedback loop and the fully compensated position re-established. The rate at which this compensation is injected is user-configurable.

This function is useful where an axis needs to be temporarily disabled, but the original position recovered at a later time. For example, some machines have an Emergency Stop button that can be used to temporarily stop machine operation, but continue after it is released without having to re-home the machine. In this case the injection compensation is buffered, preventing any movement during the 'E-stop' period which would cause a following error on the machine controller.

1.5 System components

The following provides a brief overview of the main system components:

Compensation unit with internal air pressure sensor (part number: RCU10-PX-XX)

Powered from 24 V dc, the RCU10-PX-XX contains the digital signal processor based compensation electronics and an internal air pressure sensor. For applications that use a laser encoder and require refractive index compensation, the RCU10-PX-XX unit is a requirement. In multi-axis applications, only one RCU10-PX-XX is necessary because compensation for additional axes is provided by RCU10-XX-XX units (detailed below). In these applications, the pressure sensor reading is distributed to other RCU10s in the network via a high-speed serial link.

Compensation unit (part number: RCU10-XX-XX)

Similar to the RCU10-PX-XX, however this assembly does not contain a pressure sensor.

Note that one RCU10 compensation unit is required for each axis to be compensated. For example, a three-axis laser encoder based system would need:

1 off RCU10-PX-XX
2 off RCU10-XX-XX

and a three-axis tape or glass scale encoder system would need:

3 off RCU10-XX-XX

Air temperature sensor (part number: RCU10-AT-XX)

The air temperature sensor is used in applications that require refractive index compensation. The sensor contains a calibrated thermistor to monitor ambient air temperature in the range of 0 °C to 40 °C. The temperature reading is converted into a digital signal inside the sensor, which reduces susceptibility to noise when the reading is transmitted to the RCU10.

Material temperature sensor (part number: RCU10-MT-XX)

The material temperature sensor is used in applications that require scale, workpiece or machine structure compensation. The sensor contains a calibrated thermistor to monitor material surface temperature in the range of 0 °C to 55 °C. The temperature reading is converted into a digital signal inside the sensor, which reduces susceptibility to noise when the reading is transmitted to the RCU10.

Sensor cable (part number: RCU10-TC-X5)

A five-metre cable that connects sensors directly to the sensor ports on the RCU10 units, or to the remote sensor distribution units (part number RCU10-DB-XX). In applications where more than five meters of cable is required, sensor cables can be daisy-chained enabling cable lengths in 5-metre increments to be configured.

RCU CS configuration software (part number: RCU10-CS-XX)

Supplied on a CD-ROM, this software enables the user to configure the compensation system to meet the requirements of the application. Communication with the RCU10 units is established through an RS232 or RS485 serial link; in some instances this may necessitate the use of a USB to RS232 converter (A-8014-0670) between the computer system and the RCU10 units.

High-speed serial link cable (part number: A-9904-1451)

The high-speed serial link cable allows a number of RCU10 units to be linked as a network. During configuration a multi-axis system can be set up by connecting the computer system to only one of the RCU10 units. Any information required by remote RCU10 compensators in the network is automatically distributed across the link to the appropriate RCU10 compensator when the configuration file is transmitted to the RCU10s.

Once in operation, the high-speed serial link enables parameters such as the environmental sensor readings to be shared amongst all compensators in the network.

PC RS232 cable (part number: A-9904-1456)

This is used to connect a computer serial port to the RCU10 compensation unit.

Laser encoder technical documentation (part number: A-9904-2407)

CD containing pdfs of data sheets and installation guides for laser encoder products.

1.6 Installation procedure overview

Since the RCU10 system may be used in a diverse range of applications, from simple open-loop calibration systems to complex multi-axis closed loop motion systems, it is difficult to specify an optimum installation procedure for all cases. However, if sections 2 to 6 of this manual are followed sequentially, as outlined in the procedure below, the user will be taken through a typical installation process.

Note: The user should be aware that to streamline the installation process, detailed information has been placed within the appendices. Reference to these appendices is made where appropriate.

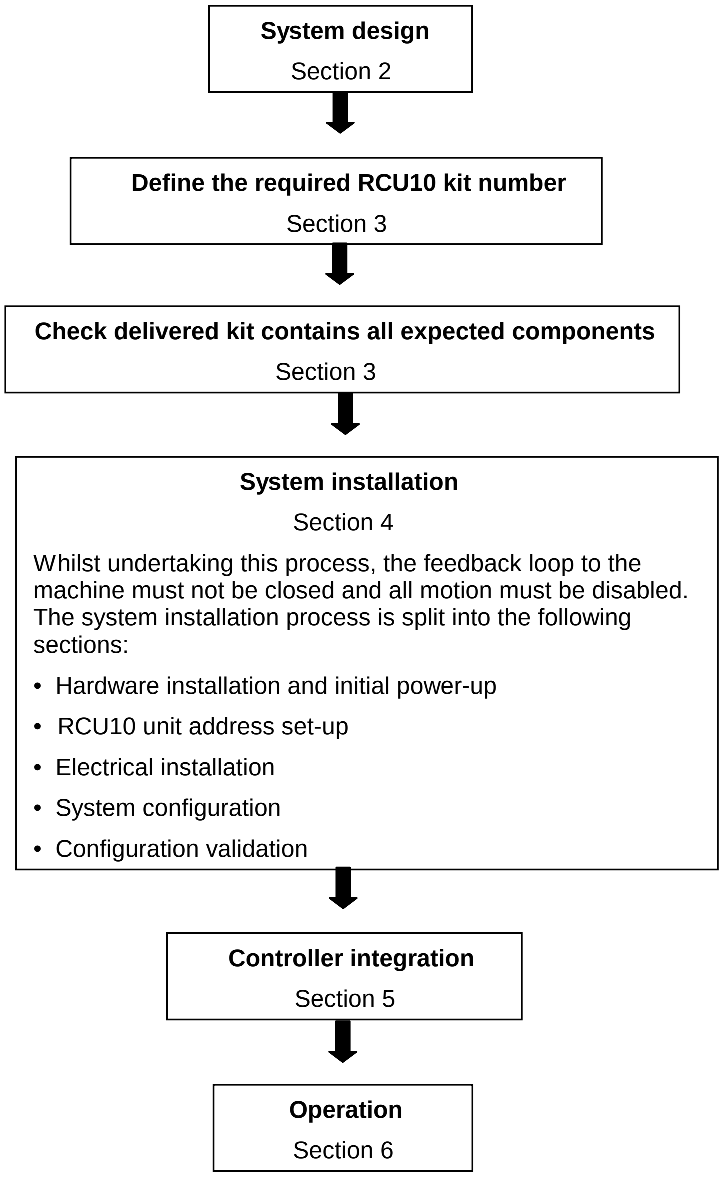

Figure 1.5 – Installation flow diagram

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Section 2

System design

Contained in this section

2.1 Requirements

The RCU10 has been designed for maximum flexibility so that it can suit a wide range of applications whilst maintaining simple configuration and installation. In order to use the RCU10 system certain requirements should be met:

- 24 V dc power source ±2 V with each compensator requiring up to 250 mA. The power source should have short circuit protection.
- An encoder that provides digital quadrature in differential RS422 format at one of the resolutions defined in Section 2.4.2.

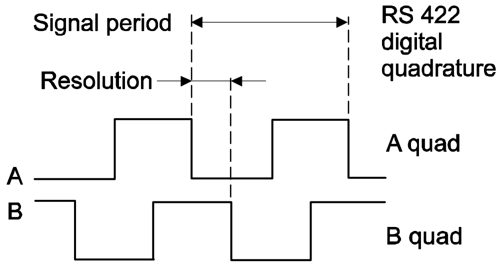

Figure 2.1 – RS422 differential line driver outputs

- An axis controller which:
  - accepts either:
    - digital quadrature in differential RS422 format, or
    - analogue (Sine/Cosine) quadrature in 1 Vpp format.
  - is capable of recognising an error condition by one of the following methods:
    - RS422 differential error line.
    - quadrature disconnection (loss of differential drive of digital inputs, amplitude drop in analogue input applications).
- In the simplest configuration it is possible to use the RCU10 without any input control lines. However, for basic or extended operation the controller should have input/output lines working at either 24 V or 5 V logic thresholds.

  Basic operation:

  - one controller output line (reset)
  - one controller input line (error)

  Extended operation:

  - controller output lines – maximum of six per axis (all RCU10 functions used)
  - controller input lines – maximum of three per axis (error, suspend and warning)

2.2 Sensors and sensor networks

2.2.1 Environment sensors

Two types of remote RCU10 sensor are available – one for sensing air temperature and one for sensing material temperature. Both sensors have built-in electronics to convert the temperature reading into RS485 data. Consequently, many sensors can be linked together to form a network. Furthermore, the signal is digital, making it less susceptible to electrical noise and allowing it to be transmitted without error over a longer distance.

Each sensor in a system needs a unique address for the network to work correctly. The RCU10 sensors are factory-programmed with an address that is the same as the serial number of the sensor (engraved on the sensor body).

Each sensor port can supply power to a maximum of four sensors, which means a total of eight connected to any single RCU10 axis.

The sensors for a particular axis do not have to physically plug into the related axis's RCU10; sensors may plug into any RCU10. The configuration software allows the user to assign any sensor data to any RCU10 within the system.

The sensors may be connected using the standard pre-made cables available in 5 m lengths from Renishaw. Alternatively, custom cables may be made by the user (connector kits are available). Please see Appendix B for standard and custom cable specifications.

Figure 2.2 – Air temperature and material temperature sensors

2.2.2 Sensor network connection

Two sensor network ports (J5 and J6 – see Figure 2.4) are provided per RCU10, to which all the air temperature and material temperature sensors are connected. Up to four sensors may be connected to each RCU10 sensor port using the sensor distribution box (as shown in Figure 2.3), making a maximum of eight sensors per RCU10. There is a limit of 32 sensors per multi axis system.

Additionally, of these 32 sensors, only 24 may be distributed. Distributed sensors are those configured to be used by RCU10s other than the RCU (or RLU) to which they are directly connected. This may be necessary when a sensor is to be used by more than one axis, or where connection to a different RCU10 is more convenient than connection to the one that will use it.

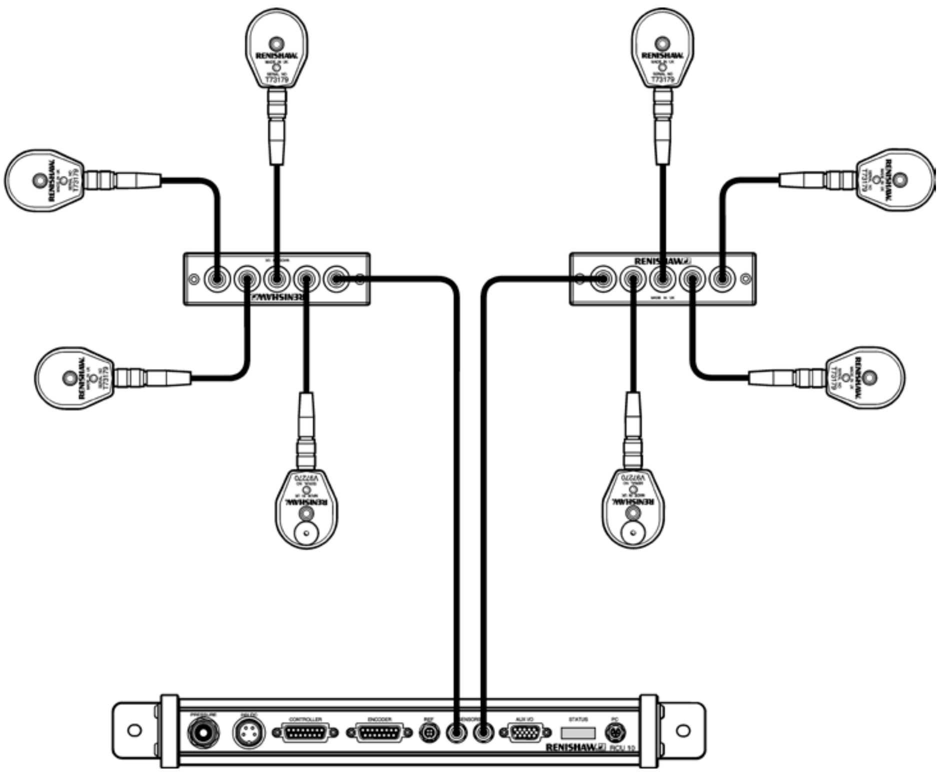

Figure 2.3 – Sensor distribution

2.3 Electrical connections

The following pages provide details of the RCU10 input and output ports and the signal functions and types. For information on the connectors and hardware installation details refer to Appendix B.

CAUTION: Do not connect anything other than Renishaw environmental sensors to the sensor ports.

2.3.1 Connector positions

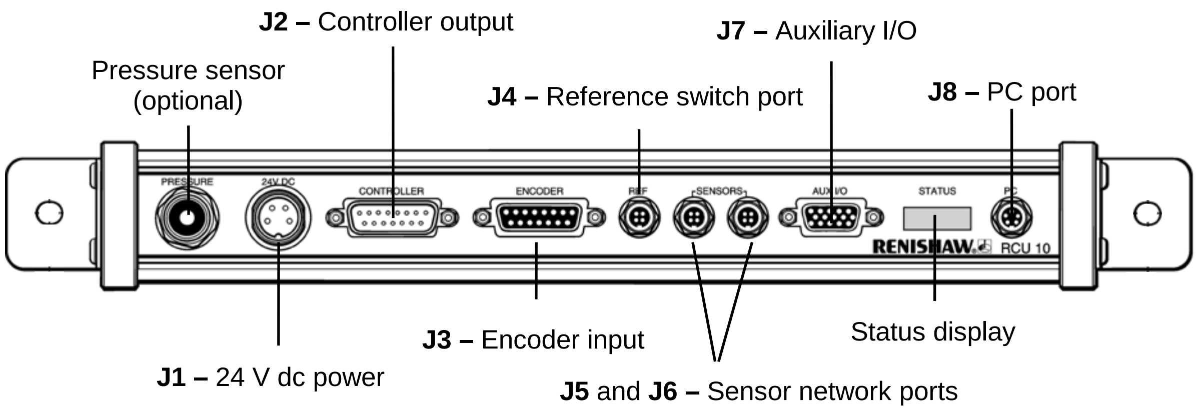

Figure 2.4 – Front panel layout

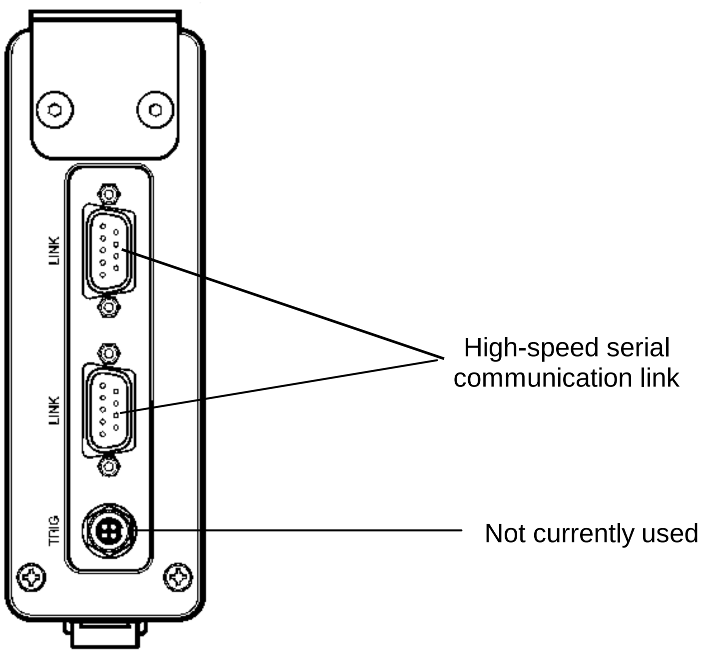

Figure 2.5 – Top panel layout

2.3.2 Connector functions

J1 – 24 V dc power

The RCU10 uses 24 V dc as its power supply. Power supply requirements can be found in Appendix A. If required, a power supply with a remote sense function can be used. For connector pinout and hardware installation details please refer to Appendix B.

Note: When using a network of RCU10s the 24 V supply should be applied simultaneously for all units.

CAUTION: The correct power supply voltage is 24 V ± 2 V. Power supplies outside this range may give unreliable operation.

J2 – Controller output

The controller output connector provides the position feedback signals that pass to the machine control or counter. These comprise digital A quad B (or analogue sinusoidal) encoder signals, reference Z pulse and error signals.

The RCU10 can be configured to provide output position data to the machine controller in either digital incremental A quad B (RS422 differential line driver output) or analogue incremental sine/cosine format (1 Vpp differential sine and cosine line driver outputs) using the configuration software. The output resolution of the RCU10 system may be selected from a number of available options, depending on the encoder input resolution and output format required.

Renishaw supplies connector kits to assist users in the construction of suitable cables – please refer to Appendix B for connector pinout and hardware installation details.

J3 – Encoder input

The RCU10 has been designed to accept digital quadrature from three main types of encoder:

- Renishaw RLE10 laser encoder
- Renishaw HS10 laser encoder
- Generic tape/glass scale

The encoder type is selected through the configuration software, and the encoder input port must be wired to suit the selected type. Renishaw supplies connector kits to assist users in the construction of suitable cables – please refer to Appendix B for connector pinout and hardware installation details.

The tables in section 2.4.2 show the available RCU10 output resolutions for a given encoder type and input resolution – along with the maximum velocities, as discussed in section 2.4.

WARNING: To ensure that the motion control system receives quadrature of the expected resolution and frequency, it is important to set both the input and output resolutions of the Renishaw system correctly. If the quadrature resolution is set incorrectly, the axis may move for distances and at speeds that are not expected. For example, if the output resolution of the RCU10 system is set to double that of the controller input, the axis may move twice as far and twice as fast as expected.

J4 – Reference switch port

The reference mark input may be used to receive a reference position marker pulse. Two options are available when configuring the RCU10: either a reference mark derived from the encoder (through the encoder where Z and /Z are the reference mark input lines), or connected to the REF input. The REF input can accept a range of actuator types that have solid state (high side or low side), 5 V logic signal or mechanical switch output formats.

The reference process is triggered by the current's rising edge on switch closure. The reference signal must last for at least one input encoder pulse transition and, once the process has been started, another cannot be activated for a period of 1 second. Providing this is adhered to, no restriction is placed on axis velocity during referencing, except for the repeatability caused by the time delay introduced by the interface circuit. Please refer to Appendix B for connector pinout and hardware installation details and section 2.5 for signal and phasing information.

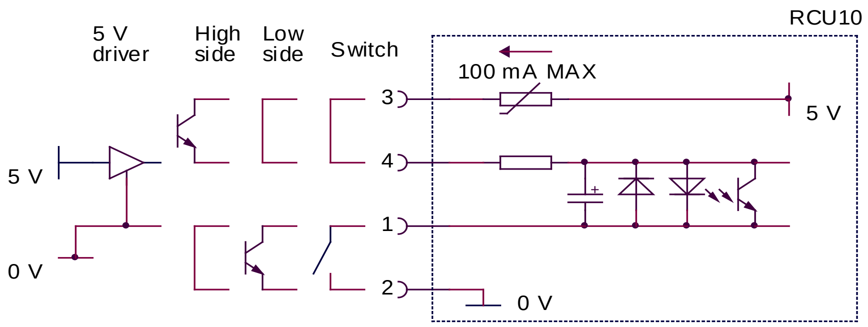

Figure 2.6 – Reference mark actuator connection

Notes: TTL driver signals are not suitable for use here. The thresholds are 3 V high and 1 V low.

The reference mark signal will only function in conjunction with quadrature, ie not stationary.

J7 – Auxiliary I/O

The auxiliary input/output connector provides various functions that can be used to control and monitor the operation of the RCU10. These functions are described below.

Table 2.1 – J7 pinouts (Auxiliary I/O)

Pin	Auxiliary I/O function	I/O		Active
1, 11	5 V and 24 V outputs	O	5 V and 24 V outputs @ 100 mA max. Link to PULL for voltage selection.	-
12, 13	Parameter table select 1 and 2	I	Used to select active parameter table. (Refer to parameter table operation in Appendix F).	-
3	/Workpiece compensation enable	I	Enables workpiece compensation.	LOW
4	/Workpiece compensation temperature freeze	I	Freezes the value of the workpiece temperature at the current value when activated.	LOW
7	PULL	-	All I/O is weakly pulled to the voltage set of this terminal i.e. 5 V or 24 V. Connect to 5 V (1) or 24 V (11) as required. **Note:** This must also be selected to match the RCU10 configuration.	-
5	/Seek reference	I	Enables search for reference mark input.	LOW
15	/Reset	I	Resets the RCU10 output error latch and HS10 laser (if used). Reset signal must be held active for a minimum of 100 ms to ensure correct operation.	LOW
14	/Compensation buffering enable	I	Enables the compensation buffering function.	LOW
6	/Error (24 V)	O	Outputs that may be used as an advanced option to determine the state of the RCU10 (see below).	LOW
9	/Suspend	O		LOW
10	/Warning	O		LOW

The port can be configured to work with either 5 V or 24 V logic I/O by connecting the PULL input, within the auxiliary I/O connector, to either 5 V (pin 1) or 24 V (pin 11) respectively. Also ensure that the relevant threshold is selected in the **Controller Logic** parameter in the system configuration (see section 4.2.3 for details). Please refer to Appendix B for connector pinout and hardware installation details.

J8 – PC port

The PC port is used to connect the RCU10 to the RS232 port of a computer. Once connected, the PC may be used with the Renishaw RCU CS software to both configure the RCU10 and monitor the RCU10 during operation.

The PC port may be used with either a standard RS232 interface or an RS485 interface. The RS485 format is used when long distances are required between the RCU10 and the PC or, in situations where a high level of electrical noise is expected. Connection should be made to either the RS232 or RS485 as required, but not to both simultaneously.

The PC may be connected using the standard pre-made RS232 cable available in a 1 m length from Renishaw. Alternatively, custom cables may be made by the user (connector kits are available). Please see Appendix B for connector pinouts and standard cable specifications.

Notes: New PCs are increasingly being supplied with no RS232 ports (ie USB ports only). Because of the interface problems this presents, Renishaw supplies a serial-USB adaptor (see section 3.3 for ordering details).

On multi-axis systems only one PC must be connected.

2.4 Velocity/resolution/bandwidth considerations

One of the key considerations in configuring an encoder feedback system is to ensure that certain frequency dependent parameters are configured correctly.

These parameters are:

- Encoder resolution
- Maximum required axis velocity
- RCU10 input sample rate
- RCU10 output resolution
- RCU10 output update rate
- Controller sample rate

The logical sequence for determining these parameters is as follows:

2.4.1 Encoder input frequency

- Determine the encoder resolution.
- Determine the maximum required axis velocity (see Tables 2.2 to 2.5 to determine the maximum velocity for different resolutions and encoders).
- Calculate the maximum encoder (edge-to-edge) frequency as follows:

$$\textbf{Encoder frequency (MHz)} = \frac{\textbf{Velocity (m/s)}}{\textbf{Encoder resolution (}\mu\textbf{m)}}$$

- Ensure that the encoder frequency is less than 20 MHz and less than the RCU10 sample rate setting.

Note: The input sample rate of the RCU should be at least 25% greater than the encoder output quadrature rate.

2.4.2 Output frequency

- Determine the RCU10 output (controller input) resolution.
- Calculate the maximum output frequency as follows:

$$\textbf{Output frequency (MHz)} = \frac{\textbf{Velocity (m/s)}}{\textbf{Output resolution (}\mu\textbf{m)}}$$

- Ensure that the RCU10 output update rate is at least 5% greater than the output frequency.
- Ensure that the controller sample rate is greater than the RCU10 update rate setting.

In the case where analogue (Sine/Cos) output signals are being used from the RCU10, the frequency of the sinusoids can also be calculated as shown above.

Note: The customer’s controller must have an input bandwidth which is at least 25% greater than the output quadrature rate of the RCU.

Table 2.2 – Maximum velocity for digital output resolutions - RLE10 or HS10 laser encoder

Encoder input resolution (nm)	RCU10 output resolution (digital (µm))						
	0.01	0.02	0.05	0.1	0.5	1	5
633							5.000 m/s
316						5.000 m/s	5.000 m/s
158					3.164 m/s	3.164 m/s	
79.1				1.582 m/s	1.582 m/s		
39.6 *			0.791 m/s	0.791 m/s			
19.8 *		0.396 m/s	0.396 m/s				
9.9 *	0.197 m/s	0.197 m/s	0.197 m/s				

* only available from RLE10

Table 2.3 – Maximum velocity for analogue output resolutions - RLE10 or HS10 laser encoder

Encoder input resolution (nm)	RCU10 output resolution (sinusoid period (µm))				
	20	25	40	50	100
316					5.00 m/s
158			3.164 m/s	3.164 m/s	3.164 m/s
79.1	1.582 m/s	1.582 m/s	1.582 m/s	1.582 m/s	
39.6 *	0.791 m/s	0.791 m/s			

* only available from RLE10

Table 2.4 – Maximum velocity for digital output resolutions - tape/glass scale encoder

Encoder input resolution (µm)	RCU10 output resolution (digital (µm))			
	0.1	0.5	1	5
0.1	2.000 m/s	2.000 m/s	2.000 m/s	
0.5		5.000 m/s	5.000 m/s	5.000 m/s
1			5.000 m/s	5.000 m/s
5				5.000 m/s

Table 2.5 – Maximum velocity for analogue output resolutions - tape/glass scale encoder

Encoder input resolution (µm)	RCU10 output resolution (sinusoid period (µm))		
	40	50	100
0.1	2.000 m/s	2.000 m/s	2.000 m/s

2.5 Referencing

2.5.1 Signal format and re-synchronisation

When using a laser encoder, the exact phasing of the reference signal relative to the sine and cosine signals cannot normally be guaranteed, because the position of the interfering light waves is not mechanically registered relative to the position of the reference switch. To overcome this, the RCU10 includes a circuit that re-phases the position signals so that the reference mark output occurs synchronised and in a repeatable position.

Digital interface re-synchronisation

The output is produced when A is high and B is high. The re-synchronisation process ensures a reference output will occur at 5 ±1 output quadrature counts later than the reference input.

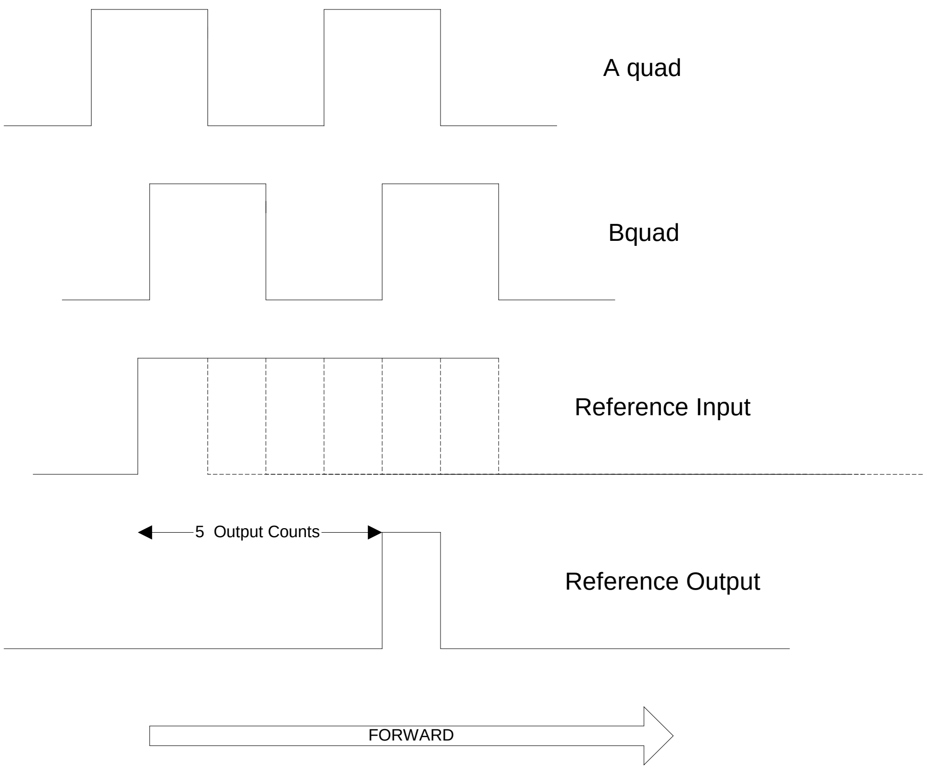

Figure 2.7 – Digital interface re-synchronisation

Analogue interface re-synchronisation

The output is produced between –45° and +135° and is valid when the amplitude of sine and cosine are equal. The re-synchronisation process ensures a reference output starts nominally 256 output counts later than the reference input and is valid at 320 ±1.

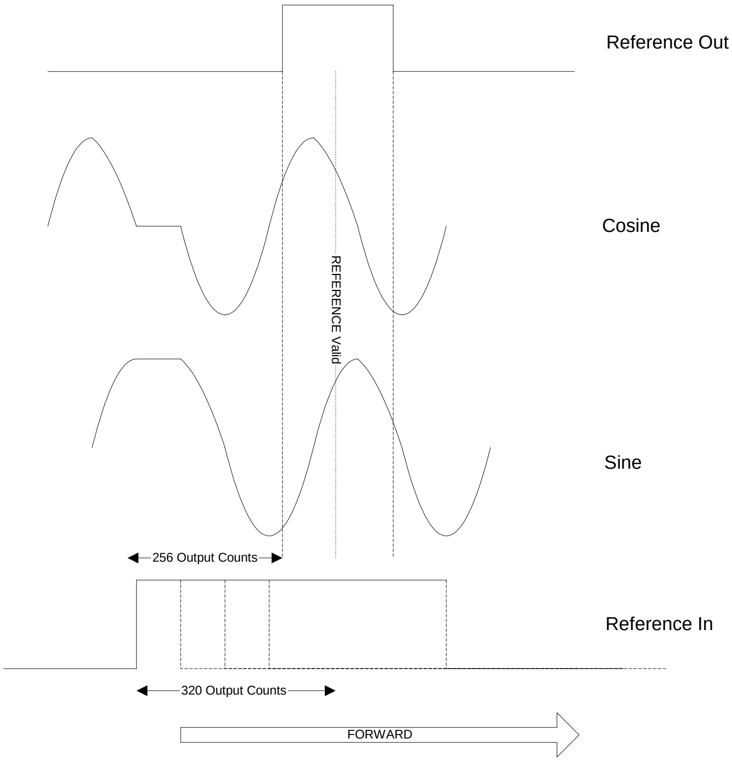

Figure 2-8 – Analogue interface re-synchronisation

2.5.2 Referencing options

Axis referencing with minimum control inputs

In the simplest configuration it is possible to use the RCU10 without any input control lines by linking 'Seek Reference' and 'Reset' to 0 V.

When 'Seek Reference' is linked permanently to 0 V, the reference mark input will be permanently active, and every time the machine passes over the reference actuator an output reference mark will be issued. In this case it is advisable that the reference position is located outside the normal working zone of the axis.

Linking 'Reset' permanently to 0 V will cause the RCU10 to automatically reset the error output state when the cause of the error has ceased. For momentary error conditions, the output will be active for at least 100 ms.

Figures 2.9 and 2.10 show the sequence for referencing the axis with laser and non-laser encoders respectively with both 'Seek Reference' and 'Reset' linked to 0 V.

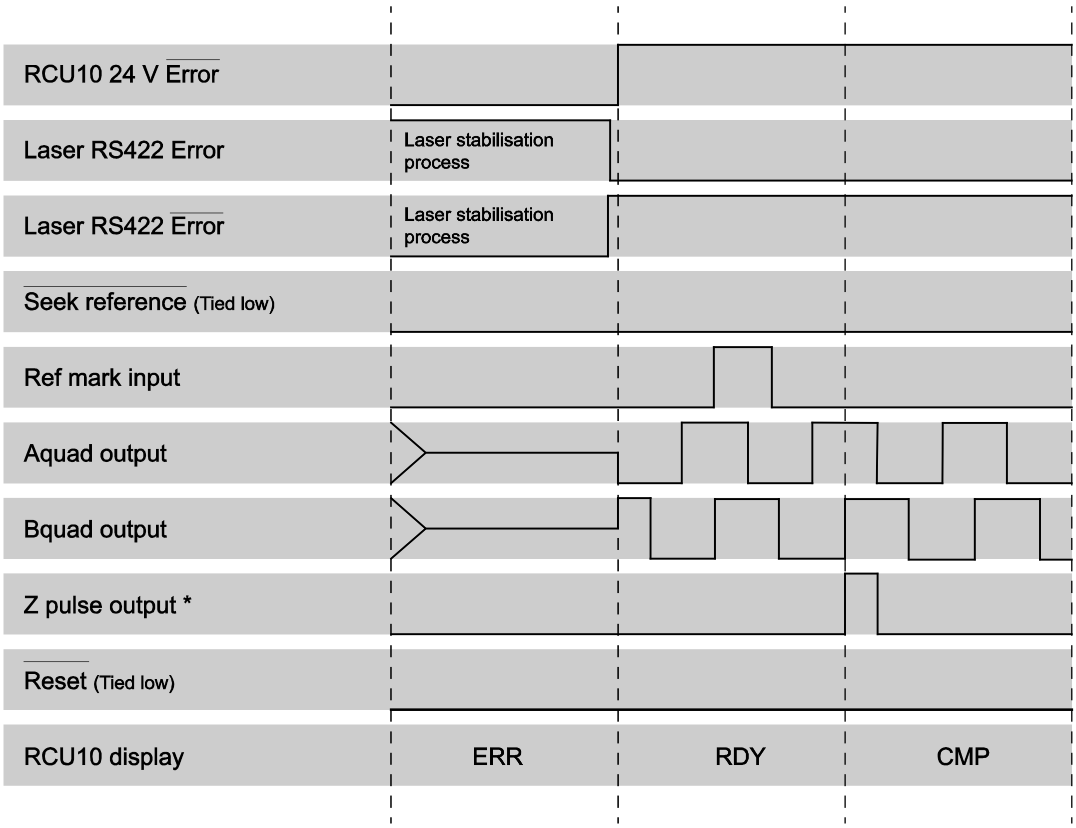

Figure 2.9 – Simple mode axis referencing sequence with laser encoder input and Seek reference and Reset inputs to RCU10 tied to 0 V

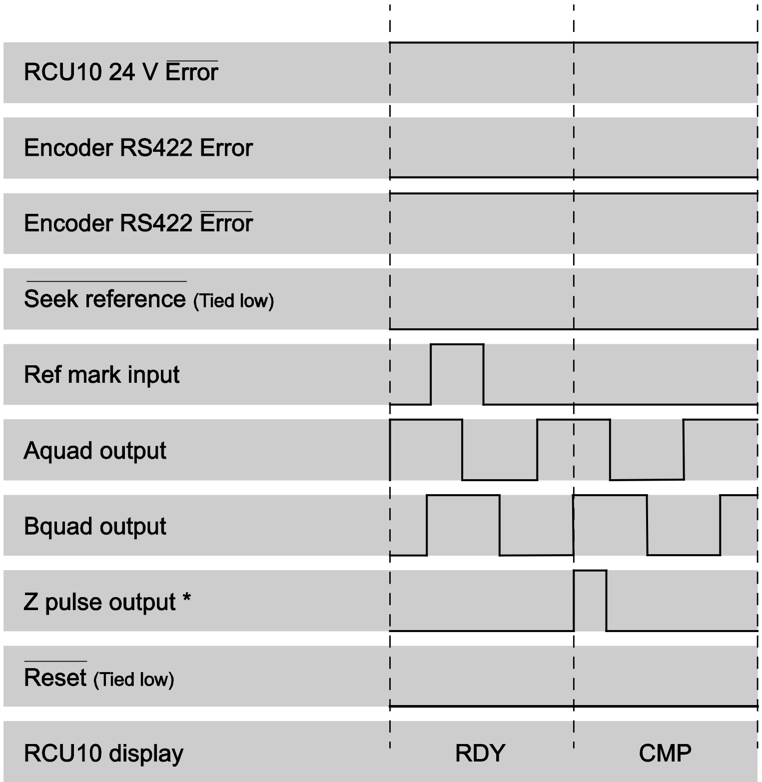

Figure 2.10 – **Simple mode axis referencing sequence with non-laser encoder input and Seek reference and Reset inputs to RCU10 tied to 0 V**

Axis referencing with 'Seek reference' and 'Reset' provided by the motion controller

In applications where it is not possible to locate the reference position outside the working zone, the 'Seek Reference' line can be used to enable a reference cycle. In this mode of operation, taking the 'Seek Reference' line low enables the reference mark input line into the RCU10. At all other times (i.e with 'Seek Reference' high) the reference mark request is ignored.

Figures 2.11 and 2.12 show the axis referencing sequence for laser and non-laser encoders respectively with when both 'Seek Reference' and 'Reset' signals are provided by the machine controller.

Note that following a power-up of the compensation system, it is recommended that a 'Reset' be applied as shown in Figures 2.11 and 2.12.

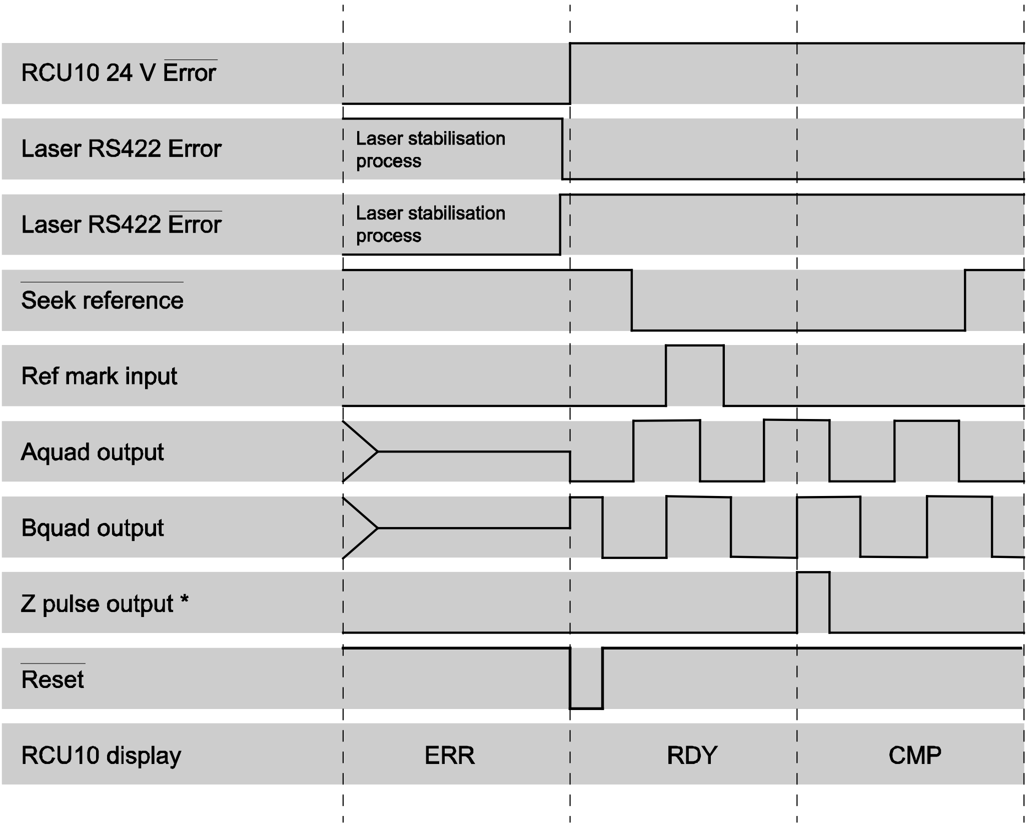

Figure 2.11 - Simple mode axis referencing sequence with laser encoder input

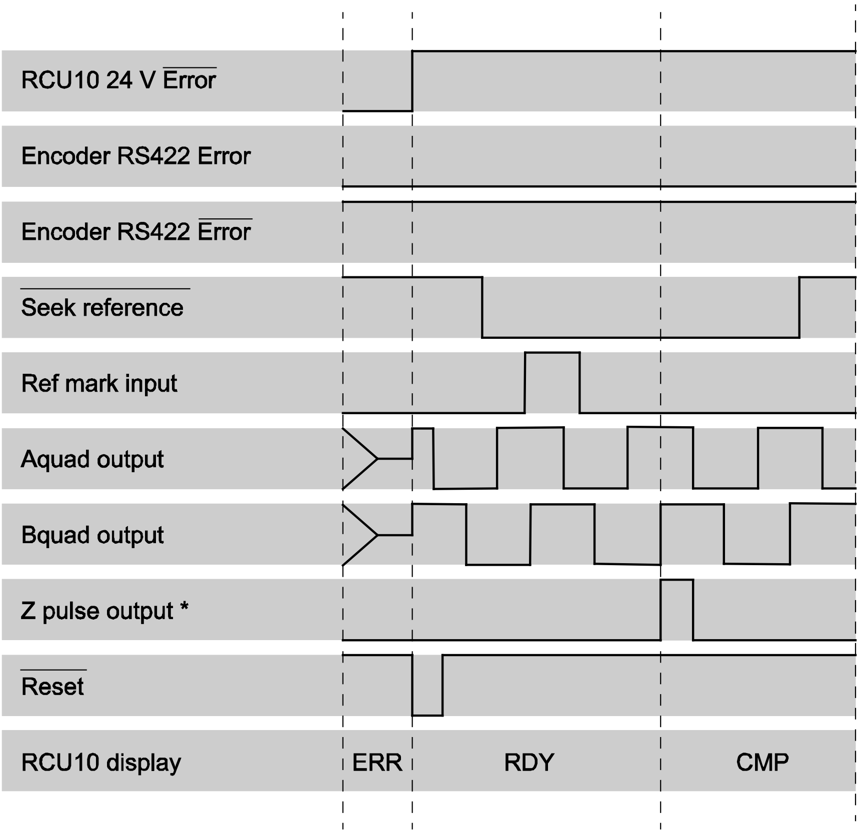

Figure 2.12 – Simple mode axis referencing sequence with non-laser encoder input

2.6 RCU10 component mounting

2.6.1 RCU10-XX-XX or RCU10-PX-XX

The RCU10 is intended to be mounted in an electrical control cabinet or similar environment. It is constructed with IP40 protection and therefore needs to be protected from harsh environmental conditions.

The RCU10 may be mounted in any orientation, although the status display window is intended to be read with the unit vertical (display window to the top).

If the RCU10-P is to be contained in a sealed enclosure, it will be necessary to port the pressure sensor aperture to the outside environment such that the correct air pressure is measured. This can be done by using 4 mm O.D. plastic tubing which will simply push fit into the aperture. To remove the plastic tube, push the collet towards the connector whilst pulling the tube.

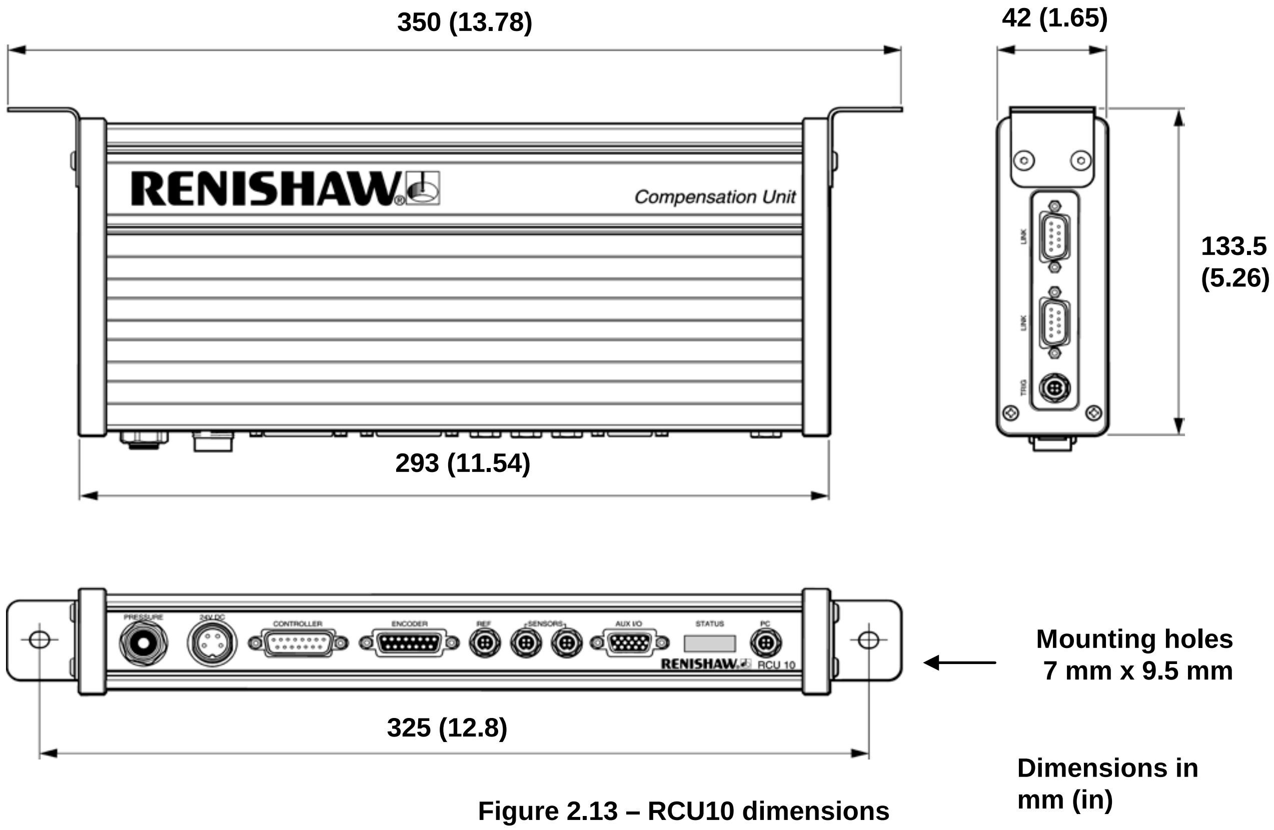

Figure 2.13 – RCU10 dimensions

For connector/cable clearance purposes, allow 100 mm (4 in) from the front face of the RCU10. Additionally, if a multi-axis system is being installed, allow 100 mm (4 in) from the top face of the unit for the high-speed serial link cables.

Note: Using the fixings supplied with the unit (M4 x 5 cap head screws + 4 mm plain washers) ensures that earthing is achieved directly through the brackets.

2.6.2 Air temperature sensor

RCU10-AT-XX

The air temperature sensor may be mounted either by the built-in magnetic base or using the central mounting hole. It is recommended for permanent installations that the mounting hole be used for security.

The sensor should be positioned in a dry location in air next to the laser beam. An armoured cable option is available for applications where there is a danger of the cable being stressed or cut.

The sensor is show below with both the standard and armoured cable options, with minimum clearance dimensions indicated.

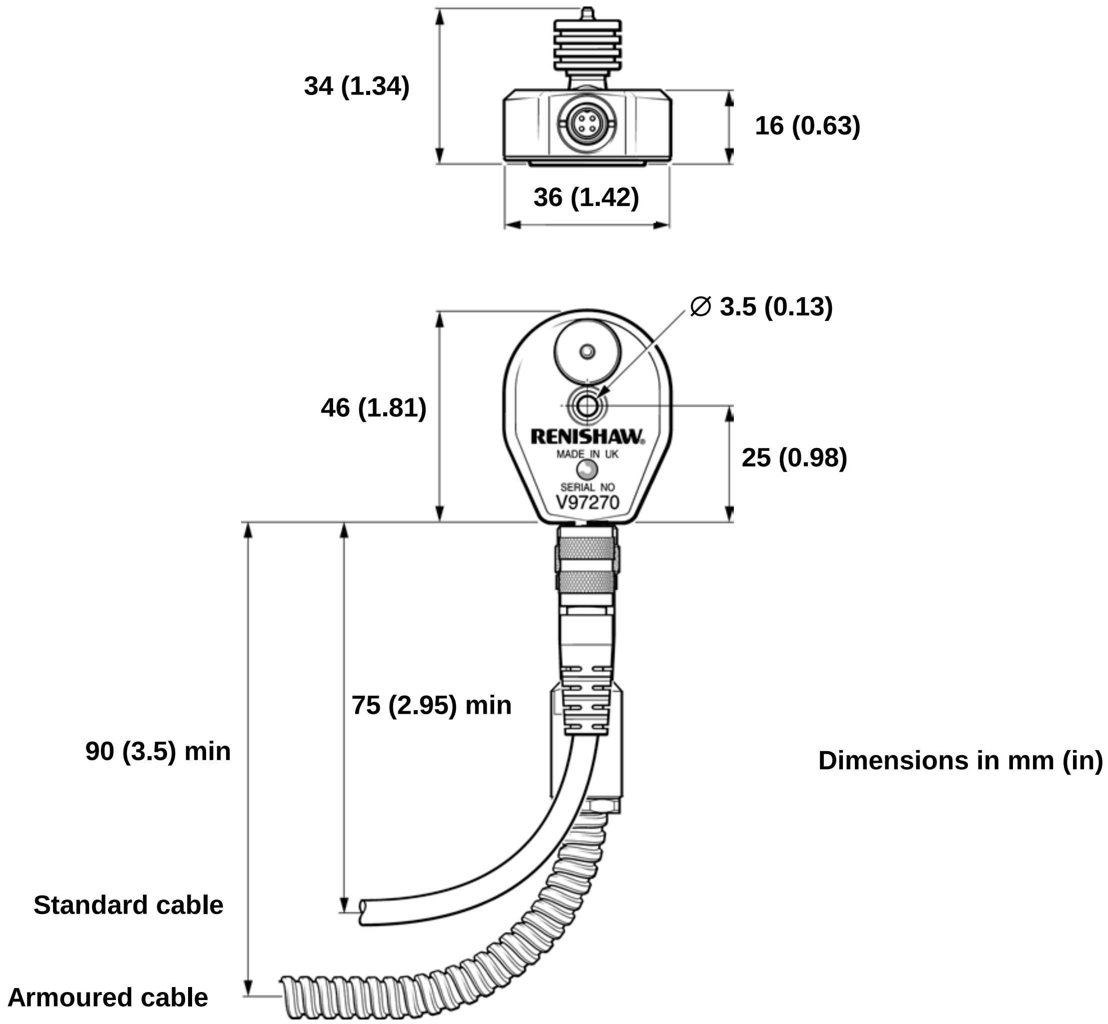

Figure 2.14 – Air temperature sensor dimensions

2.6.3 Material temperature sensor

RCU10-MT-XX

The material temperature sensor may be mounted in a similar way to the air temperature sensor, by using either the built-in magnetic base or the central mounting hole. It is recommended for permanent installations that the mounting hole be used for security.

The material sensors have IP67 protection and therefore can be placed in positions that may have liquid or particle contamination. It is common for material temperature sensors to be mounted in variable locations on a machine area, being removed and replaced as required. An armoured cable option is available for applications where there is a danger of the cable being stressed or cut.

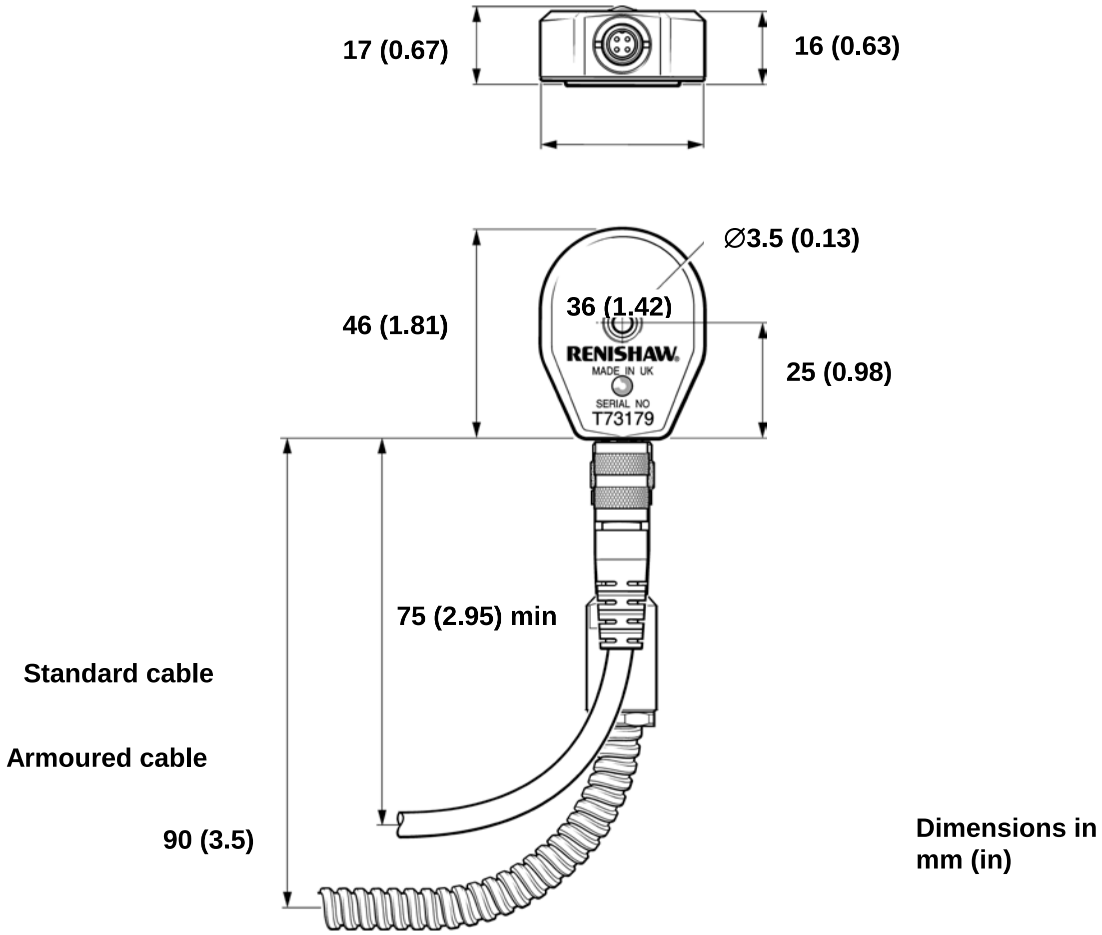

Figure 2.15 – Material temperature sensor dimensions

Note: For maximum accuracy it is important to maintain good thermal contact between the base of the sensor and the material being measured. Thermally conductive grease/oil or paste may be beneficial.

2.6.4 Sensor distribution box

RCU10-DB-XX

The sensor distribution box allows up to four sensors to be connected to a single RCU10 sensor port. One cable is attached to the RCU10 and the sensors are plugged into the distribution box at a remote location.

The box may be mounted vertically or horizontally, using either set of holes.

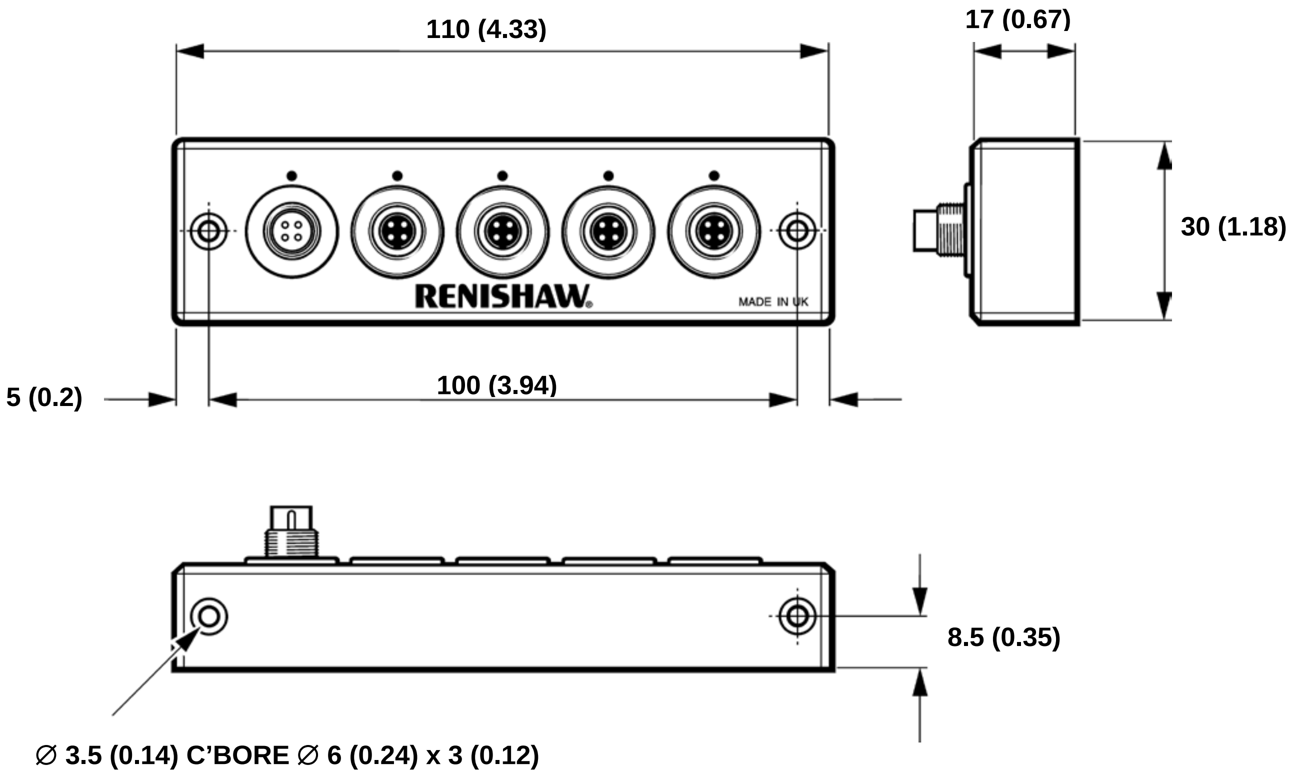

Figure 2.16 – Sensor distribution box dimensions

Section 3

Kit configuration and part identification

Contained in this section

3.1 Defining kit numbers

To simplify the ordering process, complete systems can be identified through one kit part number. The format of this kit part number is shown below, along with tables that identify the contents.

Kits for laser compensation applications include one RCU10-P, whilst kits for non-laser applications include only the RCU10 version.

Any of the parts may be ordered separately if required.

N - Total number of axes in system
Range: 1 – 6

N - Number of air sensors required
Range: 0 – 6

It is assumed that, if an air sensor is required, at least one axis will be using refractive index compensation. Therefore one of the RCU10s provided will be an RCU10-PX-XX which contains a pressure sensor.

A - Number of material sensors
Range: Z=0, A=1, B=2 etc (maximum = 25)

A - Number of standard 5 m sensor cables
Range: Z=0, A=1, B=2 etc (maximum = 25)

A - Number of sensor connector kits
Range: Z=0, A=1, B=2 etc (maximum = 25)

These are required if the user wants to make their own sensor cables.

RCU10-NNAAA

Figure 3.1 – RCU10 kit part numbers

3.2 Kit numbers and part identification

The following tables depict standard kits both for systems which use laser encoders and also those that are non-laser encoder based.

3.2.1 RCU10 kit numbers (laser encoder based systems)

Part number	Component description		RCU10-11ABZ	RCU10-22ACZ	RCU10-33ADZ	RCU10-44AEZ	RCU10-55AFZ	RCU10-66AGZ
RCU10-PX-XX	RCU10 compensation unit with pressure sensor		1	1	1	1	1	1
RCU10-XX-XX	RCU10 compensation unit		0	1	2	3	4	5
RCU10-AT-XX	Air temperature sensor		1	2	3	4	5	6
RCU10-MT-XX	Material temperature sensor		1	1	1	1	1	1
RCU10-TC-X5	Sensor cable		2	3	4	5	6	7
RCU10-CS-XX	RCU10 CS software		1	1	1	1	1	1
A-9904-1455	RCU10 connector kit		1	2	3	4	5	6
A-9904-1636	Sensor connector kit		0	0	0	0	0	0
A-9904-1451	High speed serial link		0	1	2	3	4	5
A-9904-1456	PC RS232 cable		1	1	1	1	1	1
A-9904-2407	Laser encoder technical documentation		1	1	1	1	1	1

3.2.2 RCU10 kit numbers (non-laser encoder based systems)

Part number	Component description		RCU10-10AAZ	RCU10-20AAZ	RCU10-30AAZ	RCU10-40AAZ	RCU10-50AAZ	RCU10-60AAZ
RCU10-XX-XX	RCU10 compensation unit		1	2	3	4	5	6
RCU10-MT-XX	Material temperature sensor		1	1	1	1	1	1
RCU10-TC-X5	Sensor cable		1	1	1	1	1	1
RCU10-CS-XX	RCU10 CS software		1	1	1	1	1	1
A-9904-1455	RCU10 connector kit		1	2	3	4	5	6
A-9904-1636	Sensor connector kit		0	0	0	0	0	0
A-9904-1451	High speed serial link		0	1	2	3	4	5
A-9904-1456	PC RS232 cable		1	1	1	1	1	1
A-9904-2407	Laser encoder technical documentation		1	1	1	1	1	1

3.3 Additional components and part identification

Part number	**Component description**	
A-8014-0670	Serial-USB adaptor	
RCU10-DB-XX	Sensor distribution box	
RCU10-AC-X5	Armoured sensor cable (5 m)	

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Section 4

System installation

4.1 System installation

Configuring an RCU10 system is a sequential process that requires careful preparation. Following sections 4.1, 4.2 and 4.3 should take you through the installation and configuration process. Configuration is carried out using the RCU10 configuration software (RCU CS).

The process of configuring an RCU10 system involves entering a certain amount of data – in the case of multi-axis systems, or those using multiple parameter tables, the amount of data can be quite large. To simplify this process, and to ensure errors are avoided, a set of sheets to record both the information required to configure an RCU10 system and the progress through the installation process is included in Appendix H.

4.1.1 Hardware installation and initial power-up

- Install the RCU10 units and environmental sensors into your machine, taking into consideration the mounting requirements detailed in section 2.
- At this stage the high-speed serial link cables and controller output cables should be disconnected.
- The remaining cables (J3 – Encoder input, J4 – Reference switch port, J5 and J6 – Sensor network ports and J7 – Auxiliary I/O) are not critical at this stage, and may be connected now or when configuration is complete.
- Apply 24 V power to all RCU10s.

4.1.2 RCU10 address set-up

In order for the RCU10s to operate as part of a network, each unit must have a unique address. All RCU10s are shipped from the factory with a default address of 1.

NOTE: This operation must be carried out on **every RCU10 to be used in a network** before connecting the high-speed serial link cables.

- Install the RCU CS software onto a suitable PC — for an overview of this software, including PC requirements and installation instructions, please refer to Appendix C. The screen layout for the RCU CS is shown in Figure 4.1. Note the menus, buttons and status bar because they will be referred to throughout the rest of this section. For a more detailed description of the menus, buttons and status bar please refer to Appendix C.

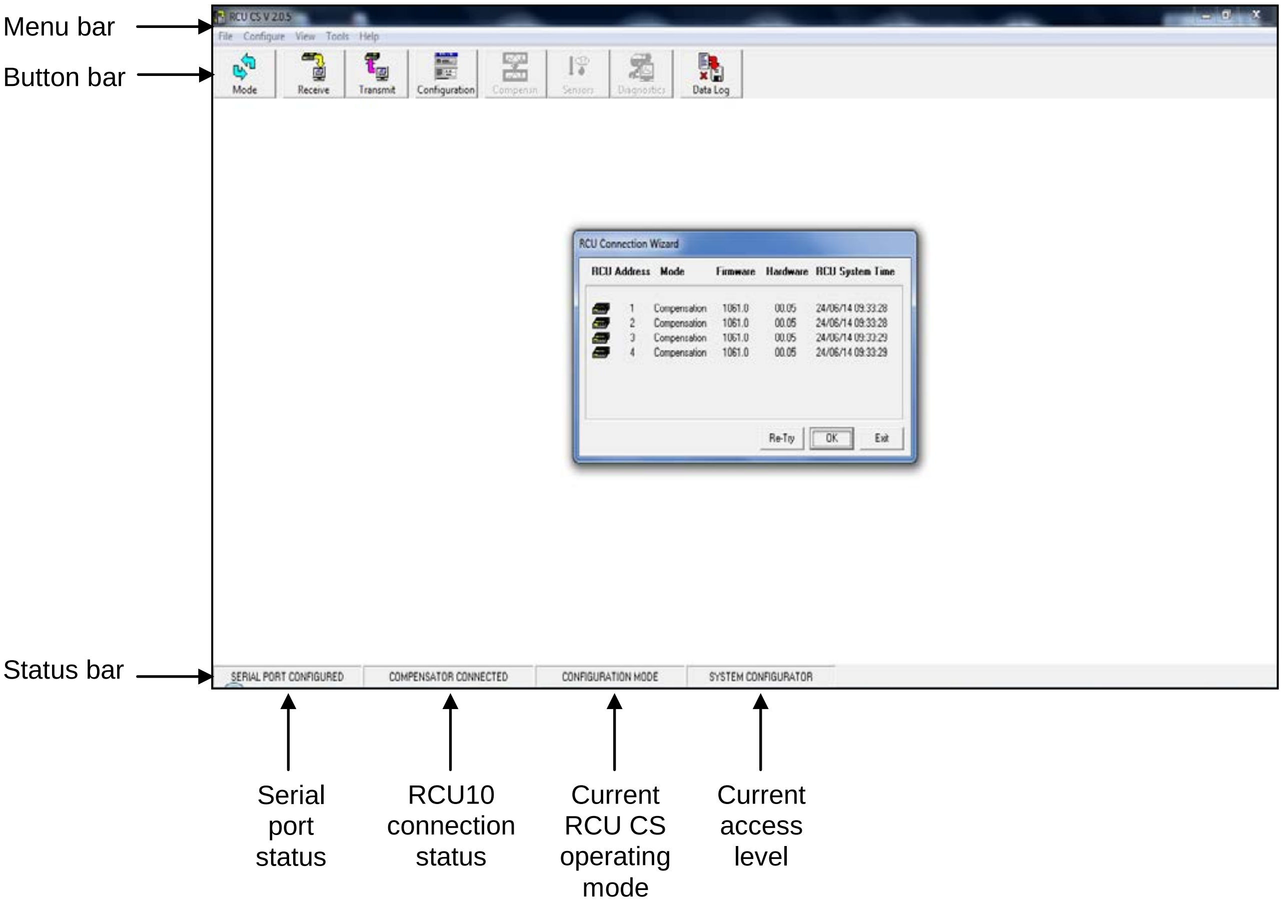

Figure 4.1 – RCU10 status display

- Connect the PC to the RCU10 that is to be configured, using the PC cable provided. Click the **Receive** button on the RCU CS screen. The connected RCU10 unit should be detected with a default address of 1.

- Select the **Compensator Address** function from the **Configure** menu. A confirmation dialogue will appear, displaying the current RCU10 address setting. Select **Yes** to change the address.

- Enter the new system address in the window displayed. The addresses can be in the range 1 to 6.

NOTE: Each unit **must** have a unique address before connection as part of a network, for example a six-axis system must have RCU10s addressed as 1, 2, 3, 4, 5 and 6. It is important to ensure that compensators are numbered sequentially. They may be connected in any order, however the physical end units must be identified in the software for correct termination.

- Once you have acknowledged the new address, the RCU CS will reset the RCU10 and re-establish communications. The connected RCU10 will now register with its new address.

- Repeat this process of setting network addresses for **all** RCU10 units in the system.

4.1.3 Electrical installation

Once all the RCU10 units have been set to unique addresses, a network may be established:

- Remove power from **all** RCU10s.
- Connect the high-speed serial link cables across the link connectors on the end of the RCU10s (either link connector may be used because they are part of a common serial bus).
- If your system was supplied with external high-speed link terminators, connect these into the spare sockets on the RCU10s at either end of the system.
- Connect the sensor cables, noting the sensor and the RCU10 that it is connected to (see Appendix H for information sheets).
- Re-apply power to all RCU10s simultaneously (RCU10s in a network must be powered simultaneously in order to allow them to connect to each other correctly).
- Ensure the configuration PC is connected to an RCU10 unit; it may be connected to any RCU10 in a multi-axis system.
- Press the **Receive** button on the RCU CS screen to establish communications.
- The RCU connection wizard screen will appear. Check that all the expected RCU10s are detected and that all units are in configuration mode before selecting **OK** to proceed.

4.1.4 RCU CS settings

A number of options may be set using the RCU CS before proceeding with configuration:

System time

The real-time clocks on the RCU10s may be set to the current PC time.

Note: Ensure that the PC time is correct before using this option.

- Select **Set System Time** from the **Tools** menu.
- A message box will display the time that has been set in the real-time clocks for all the connected RCU10s. This time will be set the next time the system is reset by a mode change, transmission of configuration data or by selecting **Re-boot RCU** from the **Tools** menu (see Appendix F.2.1.6 for more details).

RCU CS display units

The user may select the display units used by RCU CS. These settings are purely for display purposes on the RCU CS software and do not affect operation.

- Select **Configure Units** from the **Tools** menu.
- Air pressure units may be either **Millibars** or **Inches of Mercury.**
- Temperature units may be either **Celsius** or **Fahrenheit**.
- Distance units may be either **Metric** or **Imperial** (when using imperial distance measurements, values are entered and displayed in decimal format). Three options are available: **Inches**, **Millimetres** or **Metres**.

4.2 System configuration

Press the **Configuration** button in the button bar. The following window will appear:

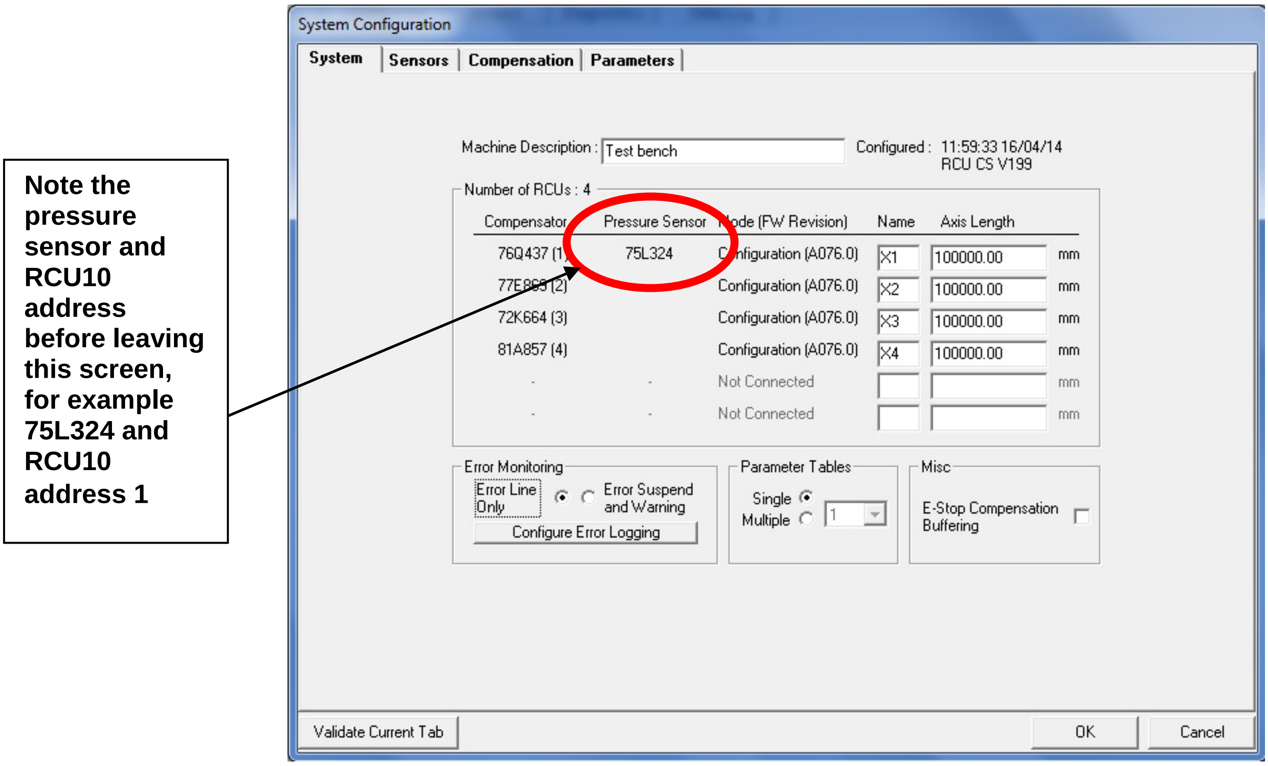

Figure 4.2 – Configuration window (System tab)

Each of the four tabs: System, Sensors, Compensation and Parameters, must be configured in turn. The following sections take you through this process.

4.2.1 System configuration

- Select the **System** tab of the system configuration window.
- Configure each setting on the **System** tab according to the descriptions shown below.
- Make a note of the pressure sensor serial number and the RCU10 address that it is connected to before completing the configuration on this page.
- When complete, press **Validate Current Tab** to ensure that there are no errors.

NOTE: Pressing **Cancel** at any time will cause all changes made by the user to be lost. Pressing **OK** will check the entire configuration for validity before storing it into the computer's memory.

Machine Description: May be used to identify the machine to which the RCU10 system is installed (text field).

Axis Name: A unique identifier of up to two characters for each axis (e.g. X1).

Axis Length: The length of the axis (in scale encoder applications the RCU10 checks that the axis position has not exceeded the total length specified – compensation is not applied to any extra length).

Error Monitoring: **Error Line Only** – standard error mode in which the RCU10 produces an 'Error' output for any system error.

Error, Suspend and Warning Lines – extended error mode in which the RCU10 produces a three level error output (Error/Suspend/ Warning) depending on priority (see Appendix F.1.2 for further details).

Configure Error Logging: Enables storage of system events/errors for diagnostic purposes. It is recommended that this is left at the default setting.

Parameter Tables: **Single** – a single (fixed) set of configuration parameters is available for each RCU10.

Multiple – up to four (user I/O – switchable) parameter tables are available for each RCU10. This is selectable from the drop-down list. Refer to section F.1.5 for details.

E-Stop: Enables the compensation buffering enable line on the J7 – Auxiliary I/O connector. This puts the RCU10 into a state where position is monitored and the relevant quadrature pitch conversion is performed, but any required injection (due to environmental changes) is stored in a buffer. On disabling this line, any stored compensation is introduced into the feedback path to re-establish position.

4.2.2 Sensor network configuration

All sensors that are to be used in a multi-axis RCU10 system must be identified before they can be assigned to any functions. The serial number of the sensor is used as a unique identifier on the sensor network.

- Select the **Sensors** tab of the system configuration window:
  - Pressure sensor
  - Air temperature sensor
  - Material temperature sensor
  - Laser head (HS20 only)
- Add all system sensors ensuring that the **Serial Numbers**, **Sensor Types** and the **Connected RCU Addresses** (RCU10 to which the sensor is physically connected) are entered correctly. The connected RCU address is taken from a drop-down list that displays all possible RCU10s in the network. In this menu **Other** refers to any unconnected RCU10 units.
- On this screen the Error/Warning boundaries for the environmental sensors can also be configured **–** these are a set of global limits that may be used as alarms to indicate that an abnormal environmental condition has occurred. The system configurator has the option to apply limits to the air and material temperature sensor readings: minimum, maximum and also the rate of change. If the limits are exceeded, an error/warning is asserted which can halt operations until either the temperature settles within the defined range or the rate of change slows to a level within the set limit.

NOTES:
1. RCU10 Error/warning boundary settings are independent from the sensor's internal range and rate of change settings. Consequently, two different types of errors may be asserted. These are described in Appendix D.
2. Pressure sensor settings are not user-configurable and are set by the RCU CS on transmission of the configuration.

- When complete, press **Validate Current Tab** to ensure that there are no errors before proceeding.
- The laser head functionality is provided as a signal strength feedback from the HS20 laser head when it is connected to the sensor network. This provides the user with a visual signal strength indication on the RCU-CS sensors window.

NOTE: Pressing **Cancel** at any time will cause all changes made by the user to be lost. Pressing **OK** will check the entire configuration for validity before storing it into the computer's memory.

A completed sensor configuration should look similar to that shown in the screen below:

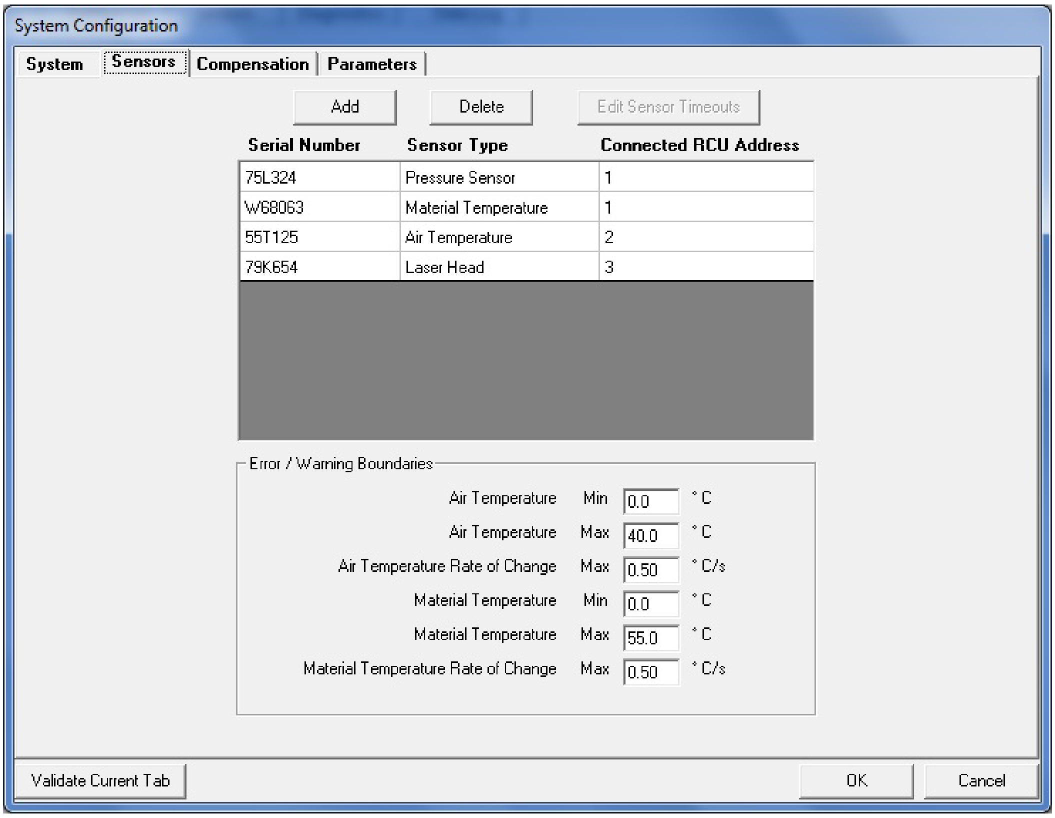

Figure 4.3 – Completed configuration window (Sensors tab)

4.2.3 Compensation settings configuration

At this stage each axis must be configured to specify encoder input settings, compensation settings, encoder output settings, safety limits and other axis-specific functions.

- Select the Compensation tab from the system configuration window.

Configuration is split into five main sections: **Encoder Input**, **Compensation**, **Output To Controller**, **Limits** and **Misc**. It is recommended that you follow this order during configuration.

- Configure each setting according to the descriptions shown on the following pages.
- When all axes are configured, ensure that **Inhibit Compensation Mode** is **deselected** to allow the system to enter compensation mode. Do not deselect this until the axis configuration has been checked through.
- When **each axis** is complete, press **Validate Current Tab** to ensure that there are no errors before proceeding to the next axis.

NOTES: For this screen there are sub-tabs for **each axis** in the system. Each of these sub-tabs must be configured individually before moving on to the **Parameters** tab. Pressing **Cancel** at any time will cause all changes made by the user to be lost. Pressing OK will check the entire configuration for validity before storing it into the computer's memory.

If a cell turns RED, this is because the setting is invalid or unavailable. Hover the mouse pointer over the cell to determine the cause of the error.

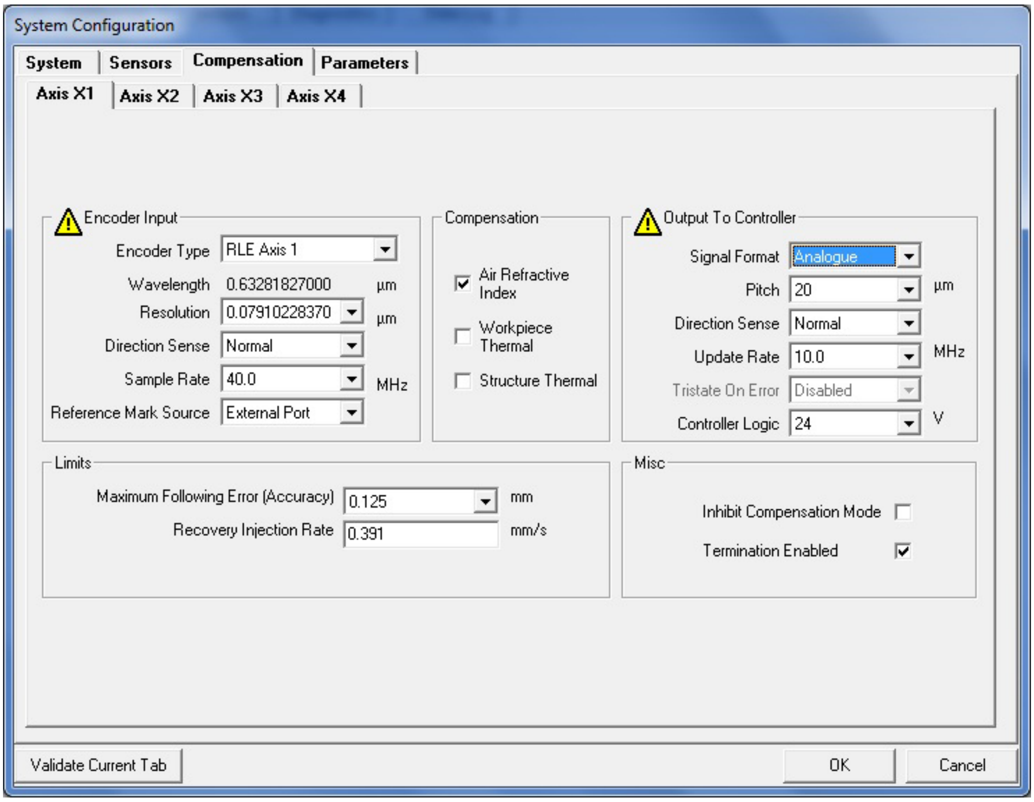

Figure 4.4 – Configuration window (Compensation tab)

Encoder Input

Encoder Type: Selects the type of encoder used from a pre-defined list: RLE Axis 1, RLE Axis 2, HS10 or Linear Tape and Glass.

Wavelength/Pitch Each encoder type has a different wavelength. This option displays the wavelength characteristics of a specific type in micrometres.

Resolution: Selects the resolution (electrical edge-to-edge separation) of the encoder. Only valid resolutions for the type of encoder selected will be displayed. **See configuration warning 1 on page 4-12.**

Direction sense (input): Sets the input quadrature direction. This must be selected such that the RCU10 input counts in the same direction as the machine control. **See configuration warning 2 on page 4-12.**

Sample Rate: Selects the rate at which the RCU10 samples the quadrature signal from the encoder. The default value is 2.5 MHz. **See configuration warning 3 on page 4-12.**

Reference Mark source: Selects the source for the reference mark signal between:

Encoder – uses the reference signal (Z, /Z) from the encoder connector, in RS422 format.

External Port – uses the RCU10's J4 – reference switch port.

Compensation

These settings are used to select which modes of compensation are enabled on the RCU10 hardware.

Air Refractive Index: Selects the air refractive index compensation algorithm required for laser axes (if applicable).

Encoder Compensation: Selects the linear encoder expansion compensation algorithm required for tape/glass scale axes (if applicable).

Workpiece Thermal: Selects the workpiece thermal expansion compensation algorithm.

Structure Thermal: Selects the machine structure thermal expansion compensation algorithm.

Output to Controller

Signal Format: Selects the format of the feedback signals that are output by the RCU10; either:

Digital RS422 format A quad B signals, or
Analogue 1 Vpp sinusoidal (Sine/Cos) signals.

Resolution: Selects the RCU10 feedback signals' output resolution value. Refer to section 2.4.2 for a table of valid input/output resolution combinations. **See configuration warning 1 on page 4-12.**

Direction sense (output): Sets the output quadrature direction. This may be used to obtain the correct direction sense for the machine control. **See configuration warning 2 on page 4-12.**

Update Rate: Selects the rate at which the output quadrature is 'clocked'. This setting represents the maximum frequency that can be seen at the RCU10 output. Care should be taken that the controller can accept the frequency selected. The default setting is 2.5MHz. **See configuration warning 3 on page 4-12.**

Tristate On Error: The output quadrature signal may be configured to transfer into a high impedance (undriven differential) when an error occurs on the RCU10. Ensure that the controller is capable of recognising this if it is enabled. This selection is not available if analogue output format is selected. **See configuration warning 4 on page 4-12.**

Controller Logic: Selects the voltage level used on the Auxiliary I/O port, between 5 V and 24 V. This must be selected to match the link settings on the PULL pin of the Auxiliary I/O connector (refer to section 2.3.2 for details).

Limits

Maximum Following Error (Accuracy): Sets the error limit for the maximum error that can occur between the input and output counts of the RCU10. User-selectable from 11 fixed settings ranging from 1 mm to 1 µm.

Recovery Injection Rate: Sets an injection rate that is used to re-inject movement when certain functions are operated (e.g. deactivating workpiece compensation at distance, compensation buffering).

Misc

Inhibit Compensation Mode: When selected, the RCU10 will only power up into configuration mode. When deselected, the RCU10 will automatically power up into compensation mode.
The factory default setting is on, and should be changed only after final checking of each axis configuration. This setting should be the same for all units.

Termination Enabled: On a multi-axis system, the physical end units in the system must have this option enabled to prevent "ringing" on the high-speed serial link transmission lines. The software will allow either 0 or 2 to be selected in a system. This function should be configured as shown in the table below (the table assumes that the RCU10 units have been configured and installed sequentially).

NOTE: Do not enable internal termination if your system was supplied with external high speed link terminators.

	RCU10 unit number					
	1	2	3	4	5	6
1 axis system	✘					
2 axis system	✓	✓				
3 axis system	✓	✘	✓			
4 axis system	✓	✘	✘	✓		
5 axis system	✓	✘	✘	✘	✓	
6 axis system	✓	✘	✘	✘	✘	✓

CONFIGURATION WARNINGS

1. To ensure that the motion control system receives quadrature of the expected resolution and frequency, it is important to set both the input and output resolutions of the encoder system correctly. If the quadrature resolution is set incorrectly, the axis may move for distances and at speeds that are not expected. For example, if the output resolution of the RCU10 system is set to half that of the controller input, the axis may move twice as far and twice as fast as expected.

2. It is important to set both the RCU10 input and output direction senses correctly. An incorrect direction sense may cause the machine to move in the opposite direction to that expected, potentially accelerating until it reaches the axis limits. In the case of parallel twin rail drives, it is important that the direction sense is carefully considered. Failure to do this may cause opposite ends of the cross member to move in opposite directions, possibly causing damage to the machine.

3. To maintain the integrity of the position feedback system it is important that:

   a) The RCU10 input sample rate (RCU10 input bandwidth) is set above the maximum predicted output rate of the encoder quadrature (encoder output bandwidth). The input sample rate of the RCU should be at least 25% greater than the encoder output bandwidth.

   b) The output update rate of the RCU10 (RCU10 output bandwidth) is set below the maximum sample rate of the motion control system (motion controller input bandwidth). The customer’s controller must have an input bandwidth which is at least 25% greater than the output bandwidth of the RCU.

4. This Tristate On Function should only be enabled if the input stage of the motion control system can detect a tri-state condition on the quadrature lines. If the tri-state condition is detected, all motion must be disabled immediately.

4.2.4 Parameter settings configuration

The **Parameters** tab includes several operational parameters that control the performance of the compensation functions. For a full description of parameter tables and their implementation, refer to Appendix F.

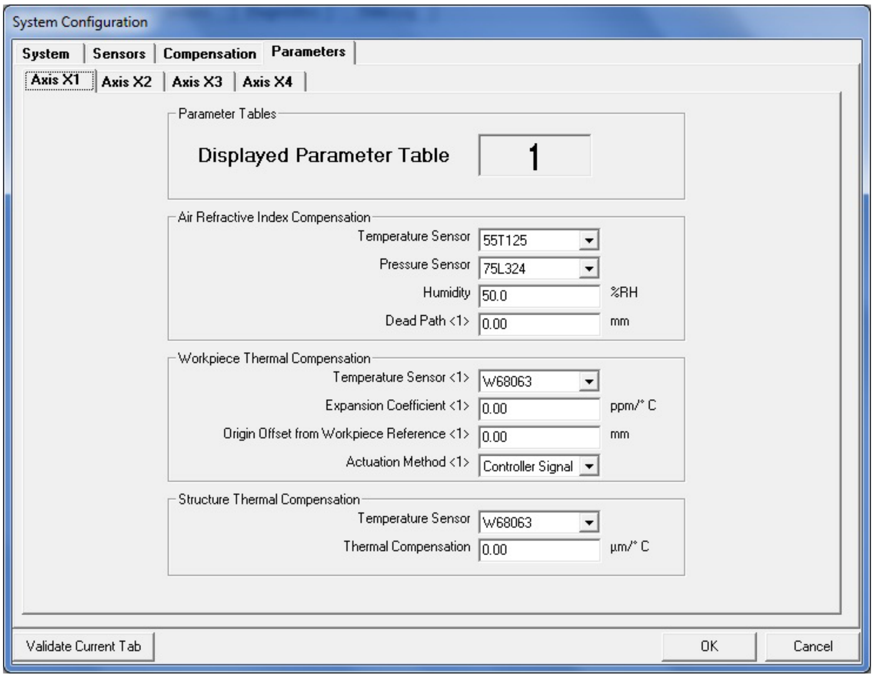

Figure 4.5 – Configuration window (Parameters tab) laser axis

- Select the **Parameters** tab from the system configuration window.
- Configure each setting according to the descriptions shown on the following pages.

Note: Only the compensation functions enabled in the **Compensation** tab will be available on this tab screen.

- When **each table** is complete, press **Validate Current Tab** to ensure that there are no errors before continuing on to the next table (validate current tab will validate all parameter tables – not just the one visible). To move to the next table for the axis, press the right arrow key by the **Displayed Parameter Table** number.
- Data that is definable across different parameter tables is indicated by **<n>** to the right of the text (where n is the parameter table number). All other data is common across all parameter tables for that particular RCU10 axis.
- When all tables have been validated, continue to the next axis and repeat the procedure until all tables on all axes have been completed. If a cell turns red it indicates the selected value is invalid or unavailable. Hover the mouse over the cell to determine the cause of the error.
- When configuration is complete, press **OK** to store the configuration into the computer's memory, ready for transmission to the RCU10 network.

Air Refractive Index Compensation

Temperature Sensor: Select the air temperature sensor to be used in the compensation algorithm. Common for all parameter tables in one RCU10 axis.

Pressure Sensor: Select the air pressure sensor to be used in the compensation algorithm. Common for all parameter tables in one RCU10 axis.

Humidity: Define the relative humidity value to be used in the compensation algorithm. Common for all parameter tables in one RCU10 axis.

Dead Path <>: Define the laser dead path value to be used in the compensation algorithm. Unique to each parameter table in one RCU10 axis. Dead path is the separation between the optics when the axis is at the reference position. See Appendix G for an example.

Encoder Thermal Compensation

Temperature Sensor: Select the material temperature sensor to be used in the compensation algorithm. Common for all parameter tables in one RCU10 axis.

Expansion Coefficient: Define the coefficient of expansion for the scale substrate to be used in the compensation algorithm. Common for all parameter tables in one RCU10 axis.

Reference Offset from Scale Expansion Origin <>: Define the position of expansion origin relative to the home reference position of the RCU10. Data is stored locally in each RCU10 compensator.

Workpiece Thermal Compensation

Temperature Sensor <>: Select the material temperature sensor to be used in the compensation algorithm. Data is stored locally in each RCU10 compensator.

Expansion Coefficient <>: Define the coefficient of expansion for the material being machined for use in the compensation algorithm. Data is stored locally in each RCU10 compensator.

Origin Offset from Workpiece Reference <>: Define the position of expansion origin relative to the workpiece reference position of the RCU10.Data is stored locally in each RCU10 compensator.

Actuation Method <>: Select the method of activating workpiece expansion. Data is stored locally in each RCU10 compensator.

Controller Signal: Workpiece thermal compensation is activated by a signal through the J7 – Auxiliary I/O connector from the machine control. Usually activated in the control using M-codes (see Appendix F.1.4.1 for details).

Axis Reference: Workpiece thermal compensation is activated automatically at machine reference when the RCU10 references, so workpiece thermal compensation is effectively on permanently.

Structure Thermal Compensation

Temperature Sensor: Select the material temperature sensor to be used in the compensation algorithm. Common for all parameter tables in one RCU10 axis.

Thermal Compensation: Define the coefficient of thermal compensation required in order to achieve the desired thermal structure compensation. Common for all parameter tables in one RCU10 axis.

4.2.5 Transmitting the configuration

Once the configuration has been completed, it is necessary to transmit it from the PC into the RCU10 units. The RCU10 units will then store the configuration in non volatile memory so it is retained even if the RCU10s are switched off.

- To transmit the configuration to the RCU10 system, click on the **Transmit** button in the button bar or select **Transmit Configuration** from the **Configure** menu. A dialogue will appear for confirmation **–** this may take a few minutes on a large network.
- You will then be given the option of saving the configuration to a file on your PC as a back-up. Click **Yes** or **No** as appropriate to continue. It is recommended that a back up copy of the configuration file is made at this stage.
- RCU CS will respond with a message to advise of the system reset. Click **OK** and the system will reset (a series of clicks may be heard from relays inside the RCU10s).
- The **RCU Connection Wizard** will be displayed to re-establish communications with the network. This will show all axes in configuration mode. Click **OK** to continue operating with the system.

Changing operating modes

Once the configuration has been completed and transmitted to the RCU10(s), the system may be switched into compensation mode (normal operational state).

This may be done by one of two methods:

- Change the mode manually using the **Mode** button in the button bar. This is a toggle button and will always try to change mode, i.e. if in compensation mode it will change into configuration mode and vice versa.
- Remove and then restore power to the system. At power on, the RCU10 will always try to enter compensation mode.

NOTES: The RCU10 will not change into compensation mode if the **Inhibit compensation mode** setting is not cleared in the configuration (this applies to all RCU10 units in a network) or any critical errors are detected at power up.

Any data that has been entered into the PC but not transmitted to the RCU10 will be lost if proceeding with a mode change.

The mode shown on the status bar is not updated until the connection wizard is closed.

Compensation algorithms and parameter table selections will not be implemented until after the system has been referenced.

WARNING: The RCU10 system may be returned to configuration mode at any time if it is required to make changes to the parameters or configuration. The RCU10 does not provide valid feedback signals when in configuration mode. For safety reasons it is important that the machine or axis is safely disabled before proceeding with a mode change. The RCU10(s) asserts the RS422 error line to ensure that this occurs.

4.3 Configuration validation

Before proceeding to controller integration, the validity of the RCU10 system configuration needs to be verified. Now that the system is in compensation mode, this is simply a case of observing that the display on the front of each RCU10 unit shows RDY. If this is the case, then the next stage of installation is controller integration as described in section 5 of this manual.

If ERR is displayed on any of the RCU10 units, then select the Diagnostics button on the RCU CS button bar. The system status screen will be displayed (as shown in Figure 4.6), with the axis or axes which are displaying error having either the Comms or Status indicator RED.

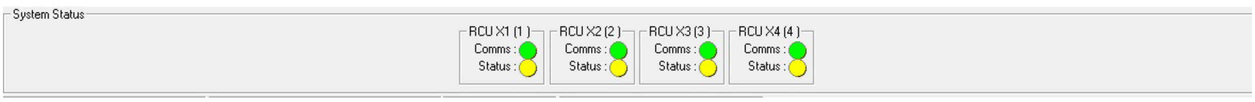

Figure 4.6 – Three-axis system status display

To obtain expanded diagnostic information on any axis that shows an error, position the cursor over the axis name of the axis concerned and double-click. The diagnostic screen shown below will be displayed.

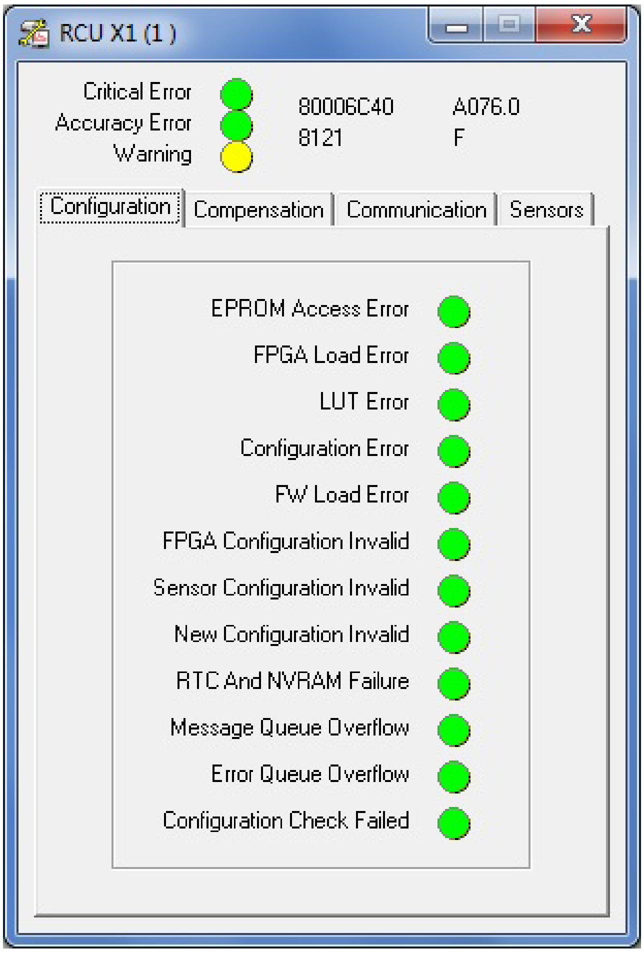

Figure 4.7 – Axis diagnostic information

Step through the **Configuration**, **Compensation**, **Communication** and **Sensors** tabs to find the source of the problem, which will be depicted by a RED indicator.

Having identified the source of the problem, refer to Appendix D for corrective action guidance.

Once all errors have been corrected, as shown by both Comms and Status indicators for all axes being green and the RCU10 status window displaying RDY, progress to controller integration.

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Section 5

Controller integration

Contained in this section

5.1 Introduction

RCU10 installations are likely to differ considerably – it is therefore impractical to provide a detailed description of the preparation required in integrating the RCU10 into a control system. However, this section aims to provide a general overview of the important steps that must be taken to ensure the effective integration into the control loop, whilst maintaining the safety and integrity of the machine.

5.2 Safety function testing

It is **imperative** that the safety features of the RCU10 and the encoder connected to the RCU10 are checked before proceeding with integration of the RCU10 into the axis feedback loop.

This must be done to ensure that the axis or machine is stopped and disabled upon the occurrence of error conditions.

WARNINGS:

1. The Renishaw system continuously checks for a variety of internal errors that may cause invalid position feedback signals. If a fault is detected, the Error signal output is asserted. The status of this line should be monitored by the controller and if it is asserted on any axis the machine control MUST stop all axes of motion.

2. It is the responsibility of the system integrator to ensure, in the event of a failure of any part of the Renishaw system, that the motion system remains safe. In the case of motion systems with powers or speeds capable of causing injury, it is essential that appropriate safety protection measures are included in the machine design. It is recommended that these safety measures are tested during system integration by deliberately introducing single faults into the system (obviously such tests need to be carried out carefully to ensure injury cannot occur during such tests).

It is advisable to conduct these tests without activating the axis drives. Wherever possible, they should be carried out by simply monitoring the states of the error lines and not in a closed-loop environment.

5.2.1 RCU10 error testing

Having checked that the RCU10 will recognise errors and assert the correct output signals, the next stage is to ensure that the control can recognise and respond to those signals.

Single error line

- Ensure that the drives are inactive, and that they will not become active during the test procedure.

- With reference to the wiring diagrams in Appendix B, connect the RCU10 controller output cables to the encoder inputs of the machine controller.
- Power up the RCU10 system to place it into compensation mode.
- Clear the initial error asserted at start-up by sending a **Reset** signal to the RCU10.
- Simulate an error condition to place the RCU10 into error. The simplest method for this test is to disconnect any connections from J3 – Encoder input port on the RCU10.
- Check the RCU CS compensation screen to ensure that the error has been recognised and handled by the relevant RCU10. The relevant axis's output position should turn red and the error signal should also be red to indicate the error.
- Check that the machine control detects the error from the RCU10.
- Repeat for all RCU10s in the system and ensure that the machine control recognises the different error lines.

5.2.2 Encoder error testing

- Ensure that the drives are inactive, and that they will not become active during the test procedure.
- With reference to the wiring diagrams in Appendix B, connect the encoder output cables to the encoder input connection on the relevant RCU10 unit.
- Clear the initial error asserted at start-up by sending a **Reset** signal to the RCU10.
- Simulate a fatal error on the encoder. This may be a beam block on a laser encoder, or a similar "beam block" type of error on a tape scale with a piece of paper placed between the head and the scale.
- Check the RCU CS compensation screen (see Appendix D, section D.3.1) to ensure that the error has been recognised and handled by the relevant RCU10. The relevant axis's output position should turn red, the error signal should also be red to indicate the error and the error output should go active.

NOTE: In the case of systems where the reset signal in the J7 – Auxiliary I/O connector has been hard-wired active to "auto reset" the RCU10, ensure that the fatal error condition remains in place for the duration of this test.

- Remove the source of the error and send a Reset signal to the RCU10 through the J7 – Auxiliary I/O connector to clear the error. Check that the RCU10 error clears and the axis count position returns to green.
- Repeat for all encoders connected to RCU10s in the system.

NOTE: The machine control or drive may be using one or more of the methods available to detect an error from the RCU10. Ensure that **all** these methods detect the error signal.

Multiple error lines on Aux I/O

When using multiple error lines (Error, Suspend and Warning), it is important to check the functionality of each line to ensure that the machine control responds correctly to each type of error asserted.

Error line

- Ensure that the drives are inactive, and that they will not become active during the test procedure.
- Power up the RCU10 system to place it into compensation mode.
- Clear the initial error asserted at start-up by sending a **Reset** signal to the RCU10.
- Assert an error on the encoder to place the RCU10 in error. This may be a beam block on a laser encoder, or a similar “beam block” type of error on a tape scale with a piece of paper placed between the head and the scale.
- Check on the machine control that the **Error** line is active.
- Remove the source of the error condition and send a **Reset** signal to the RCU10 to clear the error.
- Check on the machine control that the **Error** line is inactive.

NOTE: This error line is for information only and is not safety critical.

Suspend line

- The easiest method of checking the suspend line is to simulate a home sequence of the RCU10 without activating the drives. The suspend line is asserted before the axis is homed and removed after it is homed.
- Ensure the drives are inactive, and that they will not become active during the test procedure.
- Power up the RCU10 system to place it into compensation mode.
- Clear the initial error asserted at start-up by sending a **Reset** signal to the RCU10.
- Check on the machine control that the **Suspend** line is active.
- Activate the Seek Ref line on J7 – Auxiliary I/O port.
- Manually activate the reference switch to reference the RCU10 (note that the reference mark will only be registered in combination with quadrature, i.e. the axis is moving).

- Deactivate the Seek Ref line on J7 – Auxiliary I/O port.
- Check that the **Suspend** line is inactive.

Warning line

In order to check the warning line, the easiest method is to briefly disconnect an unallocated environmental sensor (not assigned to any compensation process).

- Ensure that the drives are inactive, and that they will not become active during the test procedure.
- Power up the RCU10 system to place it into compensation mode.
- Clear the initial error asserted at start-up by sending a **Reset** signal to the RCU10.
- Check on the machine control that the Warning line is inactive.
- Disconnect one of the environmental sensors that is either directly connected to the RCU10 or assigned across the network.
- Check on the machine control that the Warning line is active (other error lines may be asserted).
- Reconnect the environmental sensor.
- Check on the machine control that the Warning line is inactive.

NOTE: If the allocated sensor is removed for longer than one second and the RCU10 has been referenced, then the **Suspend** and **Error** lines will also be asserted to indicate the failure of a compensation algorithm. These can be cleared by issuing a **Reset** signal to the RCU10 to clear the **Error** line and by referencing the axis again to clear the **Suspend** line.

5.2.3 Testing environment sensors

In order for the RCU10 to function correctly, it is important to ensure that all the environmental sensors are working properly. It is not necessary to perform a calibration on each sensor, as this is done before they are despatched from Renishaw. However, it is important to ensure that each sensor is working as expected and assigned to the correct function.

Checking the sensors:

- Open the sensor window on the RCU CS software display and check that the temperature readings displayed on the screen are sensible. A failed sensor, a short circuit wiring or a misconnection will generally cause an obviously incorrect reading.
- Warm each sensor in turn by either holding it or breathing on it, and watch for the correct response on the screen (note that artificially heating the sensor in this way may cause a rate of change error).

- Disconnect the sensor from its cable to ensure that the RCU10 recognises the failure. Reconnect to restore communication.
- Repeat for all sensors.

NOTE: The pressure sensor cannot be tested in this way, but ensure that it is reading the correct barometric pressure (note that the true local barometric pressure is not the same as that reported on weather maps; these show sea level pressures).

5.2.4 Auxiliary I/O connector input functions

If Auxiliary I/O is being used, it must be tested at this stage to ensure that it is functioning correctly.

- Ensure that the drives are inactive, and that they will not become active during the test procedure.
- With reference to the Auxiliary I/O wiring diagrams in Appendix B and the machine controller inputs, connect the RCU10 Auxiliary I/Os to the machine controller.
- Activate the inputs sequentially on the machine control and ensure that the RCU10 has recognised all inputs correctly on the RCU CS compensation screen (see Appendix D, section D.3.1).
- To test the outputs from the RCU10, simulate the error conditions as described in sections 5.2.1, 5.2.2 and 5.2.3. Ensure that the controller recognises the input and responds as detailed in Table 5.1.

Table 5.1 – Auxiliary I/O connector functions

Pin	Input/ Output	Function	Notes
Pin 1	–	Internal 5 V supply	Can be linked to Pull (pin 7) to set the signal level to 5 V for all auxiliary I/O signals (except 24 V Error). 5 V must also be selected in the **Controller Logic** parameter in the system configuration (see section 4.2.3).
Pin 2	–	General 0 V signal reference level.	May be linked to other pins to provide a permanent active low signal.
Pin 3 – /Workpiece compensation enable	Input	User selectable 5 V or 24 V active low signal.	Allows workpiece compensation to be enabled at a user specific point. Requires that **Controller Signal** is selected in the selected parameter table in the system configuration (see Appendix F).
Pin 4 – /Workpiece compensation temperature freeze	Input	User selectable 5 V or 24 V active low signal.	Freezes the value of the workpiece temperature sensor that is used in the workpiece compensation algorithm. Workpiece compensation is applied using this fixed value when asserted. Requires that the **Workpiece Compensation** algorithm is selected in the system configuration (see Appendix F).

Table 5.1 – Auxiliary I/O connector functions *continued*

Pin	Input/ Output	Function	Notes
Pin 5 – /Seek reference	Input	User selectable 5 V or 24 V active low signal.	Activates the seek reference function of the RCU10. This allows the reference mark signal from either the encoder or reference mark port to reset the position counter of the RCU10 and restart any compensation processes. The system must be referenced to enable any compensation processes. It may be linked permanently low to the **0 V** line (pin 2) to remain permanently active. Any subsequent reference mark signal received will reset the position counter. Therefore, it is advisable only to use this function if the working area is away from the machine reference positions to prevent inadvertent position counter resets.
Pin 6 – 24 V /Error	Output	24 V active low signal.	Error output signal. Indicates any error conditions in the RCU10. This line is for information only and is not safety critical.
Pin 7 – Pull up	Input	User selectable reference input level.	Must be linked to pin 1 or 11 in order to provide pull up of signals to 5 V or 24 V, depending on the machine control requirements. Ensure that the relevant reference level is selected in the **Controller Logic** parameter in the system configuration.
Pin 8 – Not used			
Pin 9 – /Suspend	Output	User selectable 5 V or 24 V input level.	Suspend output signal. This signal can be used in advanced mode to indicate when the machine may not be accurately positioned. The controller can use the signal to suspend machining and hence prevent inaccurate parts. Suspend is also asserted temporarily before referencing, during recovery from compensation buffering, during pulse injection and when enabling workpiece compensation.
Pin 10 – /Warning	Output	User selectable 5 V or 24 V input level.	Warning output signal. Indicates any warning conditions in the RCU10 when using advanced error signal monitoring. Must be monitored by machine control to respond correctly to indicate to the operator that there is a maintenance condition existing that will require attention after finishing the current operation. Warning conditions indicate conditions that require attention, but will not compromise the safety of external operation.
Pin 11 – 24 V	_	Internal 24 V supply	Can be linked to Pull (pin 7) to set the signal level to 24 V for all auxiliary I/O signals (except 24 V Error). 24 V must also be selected in the **Controller Logic** parameter in the system configuration. (See section 4.2.3).
Pin 12 – Parameter table select 1	Input	User selectable 5 V or 24 V input level.	Used in conjunction with **Parameter table select 2** input to select between four user configurable parameter tables defined in the system configuration for each RCU10. (See section F.1.5).
Pin 13 – Parameter table select 2	Input	User selectable 5 V or 24 V input level.	Used in conjunction with **Parameter table select 1** input to select between four user configurable parameter tables defined in the system configuration for each RCU10. (See section F.1.5).

Table 5.1 – Auxiliary I/O connector functions *continued*

Pin	Input/ Output	Function	Notes
Pin 14 – /Compensation buffer enable	Input	User selectable 5 V or 24 V input level.	Enables the compensation buffering function. This puts the RCU10 into a state where the axis position is monitored and any compensation required is stored in a buffer (whilst drives are disabled). On disabling this function, any stored compensation is introduced into the feedback loop to re-establish position (see Section F.1.6).
Pin 15 – /Reset	Input	User selectable 5 V or 24 V input level.	Resets the RCU10 output error latch. Reset signal must be held active for a minimum of 100 ms to ensure correct operation. Must be used to reset all errors and allow normal operation of the RCU10. It may be linked permanently low to the **0 V** line (pin 2) to act as an auto reset function. The error signal will be asserted for a minimum of 1 second before automatically resetting.

5.2.5 Reference mark connector function

The reference mark function must be tested at this stage to ensure that it is behaving correctly.

- Ensure that the drives are inactive, and that they will not become active during the test procedure.
- With reference to the reference switch port wiring diagrams in Appendix B and the machine controller inputs, connect the reference switch port to the machine controller.
- If it is being used, activate the seek reference input on the machine control (the seek reference pin can be linked permanently low to the 0 V line to remain permanently active).
- Operate the reference switch manually and ensure that it has been registered by the RCU10 by monitoring the RCU CS software compensation screen (note that the reference mark will only be registered in combination with quadrature, i.e. the axis is moving); the reference light should turn green and the counter return to zero. You must also ensure that the controller recognises the input and responds correctly.

NOTE: The reference signal must always be produced at exactly the same position on the machine axis, to provide a stable and repeatable axis home position.

5.2.6 Encoder considerations

There are usually two different types of encoder configuration encountered when integrating the RCU10 system in a closed-loop application:

- **Dual encoder systems:** Each machine axis has a basic (secondary) encoder system that is separate to the encoder being used with the RCU10 system. This may be the motor rotary encoder or a pre-existing tape scale etc. This enables the machine to be moved safely and independently by the machine control whilst ignoring the RCU10 system.

- **Single encoder systems:** Each machine axis has only one encoder system to control motion. This is the encoder that is to be integrated through the RCU10 system. Therefore, non-closed-loop motion is only available by hand.

The dual encoder system is easier, because the system integrator is able to move the machine under closed-loop control whilst setting up the RCU10 system.

The single encoder system is a little more difficult because it makes the process of ensuring that the resolution and direction of count are correct for feedback purposes more difficult. It will be necessary to move the machine by hand.

CAUTION: The process of closing the machine’s feedback loop is the point in the installation where there is the most potential to cause problems if the operations are not carried out correctly. Therefore it is essential that great care is taken at this stage, and that the installer understands fully the operation of both the RCU10 and the machine control. Before progressing, check all settings associated with feedback direction and resolution both within the feedback system and the motion controller.

It should also be noted that during the integration process certain safety features might not be fully operational, hence the machine should only be operated by personnel who are aware of this, and able to take appropriate action in the event of a problem. During the integration process the machine should be kept clear of untrained personnel until all functions have been enabled and tested.

5.2.7 Integration procedure

At this stage the machine must be moved to verify that the quadrature supplied to the machine is correctly configured. One of the following two procedures should be followed depending on the presence of a secondary encoder system, as described in section 5.2.6. Method 1 should be used for a dual encoder system and method 2 for a single encoder system.

Method 1 (dual encoder systems): Dummy axis monitoring

- Connect the RCU10 system to "dummy" axis inputs. This enables the machine to be moved under the control of the secondary feedback system.
- Configure the user interface such that the position readout of this "dummy" axis is visible on the user console.
- Move the machine and verify that the RCU10 feedback system provides movement of the expected magnitude and direction to the "dummy" axis. This should be checked on **both** the RCU10 compensation display and the controller's "dummy axis".
- If the movement is not what you expected continue to section 5.2.8.
- Repeat for all axes.

Method 2 (single encoder systems): Single axis monitoring

If an additional "dummy" axis is not available, the axis must be moved manually:

- Configure the user interface such that the position readout of the axis to be moved is visible on the user console.
- Manually move the machine and verify that the RCU10 feedback system provides movement to the axis of the expected magnitude and direction. This should be checked on both the RCU10 compensation display and the controller readout.
- If the movement is not what you expected continue to section 5.2.8.
- Repeat for all axes.

5.2.8 Making corrections

If the system doesn't behave as expected, corrections must be made – the following section details these.

Incorrect direction

If you are experiencing an incorrect direction, a check of the input and output directions is necessary:

- Using RCU-CS, return the RCU10 to configuration mode.

- Open the system **Configuration** and under the **Compensation** tab reverse the input and/or output settings as required.

Incorrect magnitude

If you are experiencing an incorrect magnitude, you must check the input and output resolutions:

- Using RCU-CS, return the RCU10 to configuration mode.

- Open the system **Configuration** and under the **Compensation** tab check the **Resolution** and **Sample Rate** setting in the **Encoder Input** section. Also check the **Resolution** and **Update Rate** setting in the **Output To Controller** section.

5.2.9 Closing the control loop

Once you are satisfied with the direction, resolution and integrity of the feedback signals, complete the integration by converting all axes concerned to take feedback directly from the RCU10 system.

With the machine feedrate turned down (<1%), move all axes and ensure that the machine responds correctly.

Repeat all safety tests described in Section 5.2 to ensure that the machine responds correctly to all error conditions.

5.2.10 Motor drive tuning

It is often found that, when an encoder and compensation system is installed on to an existing machine (a retrofit), or a machine that has already had its motors tuned according to a rotary encoder, then a different tuning set-up is required.

This may happen for two reasons:

- The laser encoder or tape scale feedback resolution is much higher than the existing system's rotary encoders.

- A machine fitted with laser encoders or tape scales has a different mechanical feedback characteristic to that of a motor rotary encoder. This difference is due to the fact that an encoder mounted in the machine's gearbox or on the motor shaft itself will have very little backlash or lag characteristics. The laser encoder or tape scale, however, is measuring the real linear machine position that has to be controlled by the motors through this different mechanical chain.

It will be necessary to tune the motor drives after the integration has taken place, and it is common to see vibration in axis movement until tuning has been done.

NOTE: The subject of control loop/motor drive tuning is not a simple one, and is beyond the scope of this manual. It is recommended that a qualified and experienced engineer, who is familiar with the type of drive being used, perform the tuning operation.

5.2.11 Referencing the system

The final stage of controller integration is to confirm the correct operation of the machine home (or reference) cycle; once the system is correctly homed, compensated feedback can begin.

- Perform a normal machine home operation, if possible setting the feed rate to a low value.
- Ensure that the machine controller registers the reference and that it responds correctly.

Section 6

Operation

Contained in this section

6.1 Standard operation

The RCU10 is normally operated in compensation mode. When power is applied to an RCU10 (either singularly or as part of a network), it will automatically start into compensation mode. This is the RCU10's normal mode of operation and requires no additional input to operate the system apart from any Auxiliary I/O control lines.

Note: If the system is operating in configuration mode, pressing the Mode button in the RCU CS software may also activate compensation mode.

When compensation mode is first activated, the error line on the RCU10 will be active. This **must** be cleared by applying a reset signal to the Reset line on the Auxiliary I/O connector before operation.

WARNING: Restarting the RCU10 units whilst the RCU CS status displays are active may prevent the RCU10 from successfully entering compensation mode.

6.2 RCU CS status during operation

RCU CS software is not required for normal operation, however it may be used to display information about the RCU10's status.

To use RCU CS software as an informational tool, connect the RS232 from the PC/laptop with RCU CS software installed on it to any of the RCU10s in the network.

Start the RCU CS software and log in as either a system configurator or a system user. The software will automatically establish communication with the RCU10 network.

Note: If the software is already running, press the **Receive** button from the button bar to establish communication with the RCU10 network before proceeding.

The standard display screen has a button bar at the top of the screen. On the button bar, three main control buttons can be used to display operational information: **Compensation**, **Sensors** and **Diagnostics**. These buttons are toggle buttons. One press will activate the window, another press will deactivate the window.

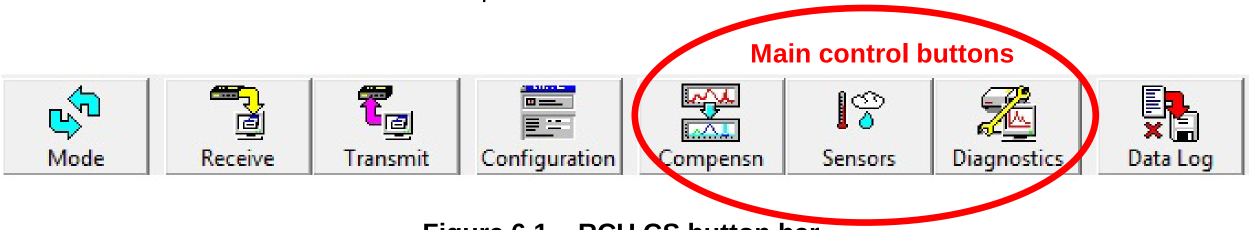


Figure 6.1 – RCU CS button bar

6.2.1 Compensation display

Pressing the **Compensation** button displays the main system compensation screen, as in Figure 6.2.

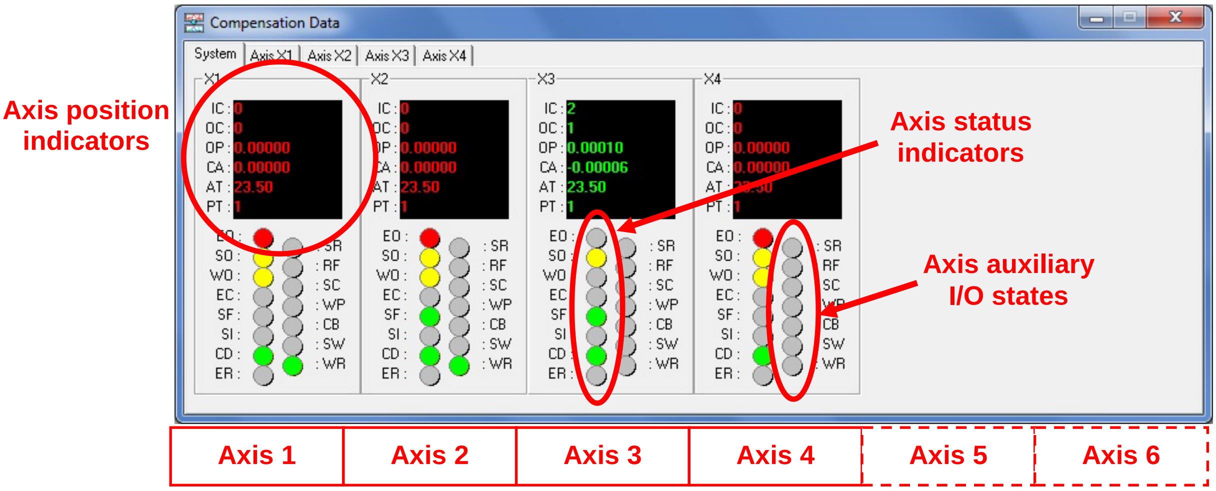


Figure 6.2 – System compensation screen

This displays the status of all RCU10 units in the system: general axis information and system status indicators.

By selecting the individual axis required from the displayed tabs in this window, this summary information may be displayed in a clearer, single screen (shown in Figure 6.3).

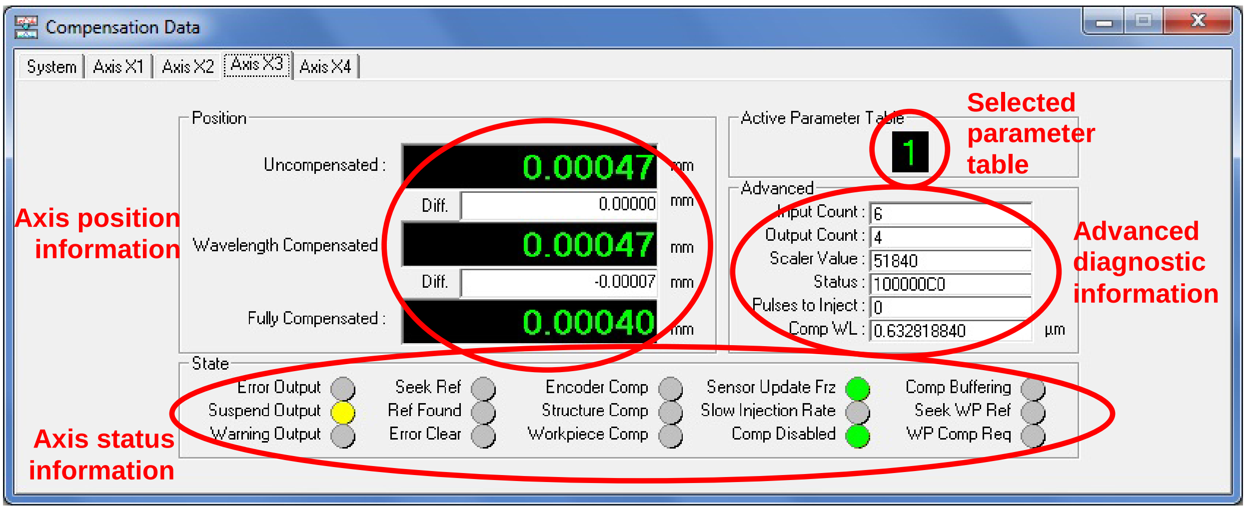


Figure 6.3 – Axis compensation screen

Note: For a full description of each indicator and status lights refer to Appendix D.

6.2.2 Sensor display

Pressing the **Sensors** button displays the sensor overview screen (shown in Figure 6.4).

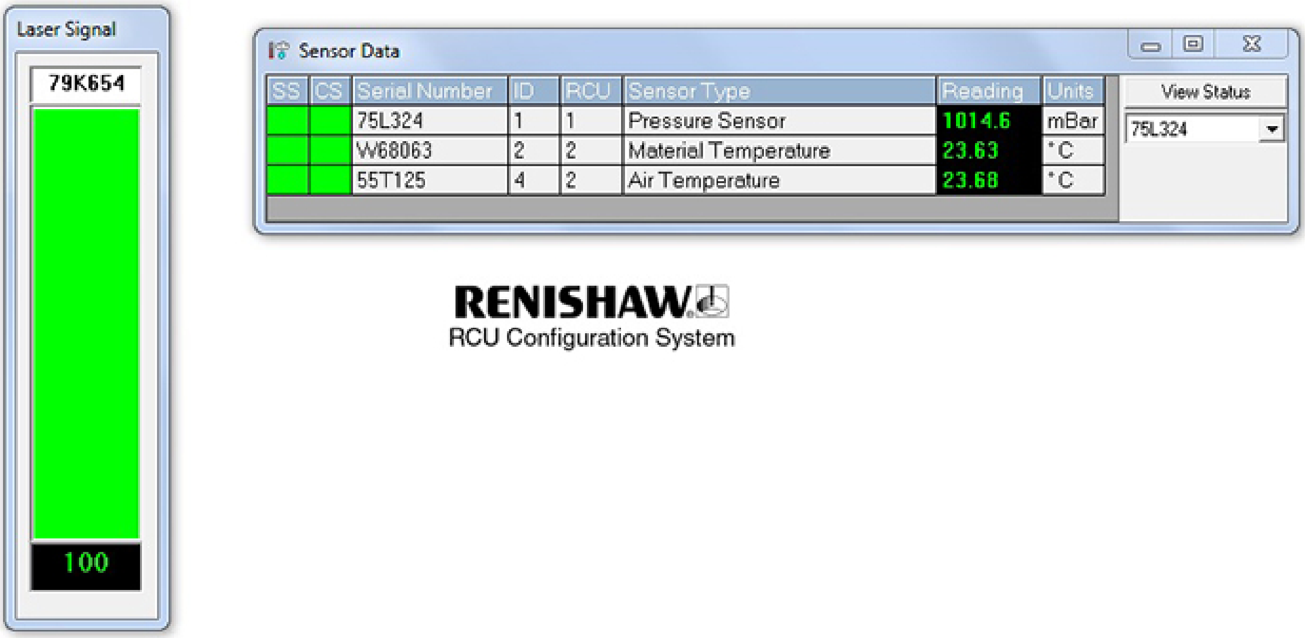


Figure 6.4 – Sensor information screen

This displays an overview of all sensors configured in the RCU10 network. It displays operational and communication status, as well as a real-time display of the reported readings.

If the system is functioning correctly, all readouts should be green.

Laser signal strength monitoring functionality is only available when using a HS20 laser that is wired into the sensor network.

Note: For a full description of each indicator and status lights refer to Appendix D.

6.2.3 Diagnostics display

Pressing the **Diagnostics** button from the button bar will display the diagnostics bar along the bottom of the display screen.

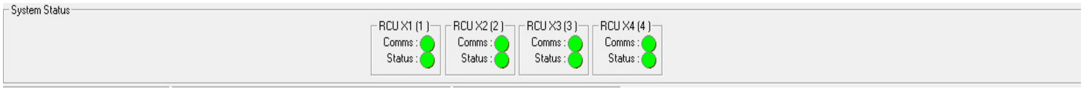


Figure 6.5 – System status bar

This displays a basic overview of each RCU10's communications status and operational status. These status lights will display any problems on any of the individual RCU10s within the network.

For a more detailed description of the fault condition, double-click the axis name to open up the individual axis's diagnostic screen.

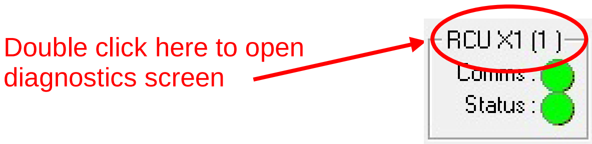


Figure 6.6 – Axis diagnostics screen selection

This screen details most of the functional, configuration and start-up errors that can occur inside the RCU10, grouped into four main categories.

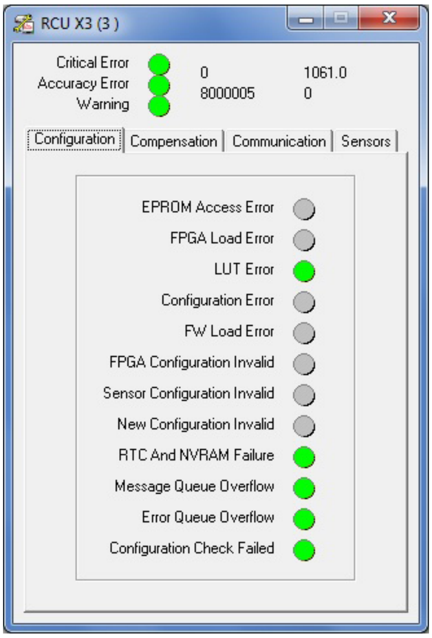


Figure 6.7 – Axis diagnostics Configuration tab

If everything is functioning correctly, all status lights will be green (non-applicable error states will be greyed out).

Note: For a full description of each indicator and status lights refer to Appendix D.

6.3 General maintenance

The RCU10 system requires no routine maintenance. If any fault is present in the system, it will normally be indicated by one of the error status signals which may be monitored via the machine control or the RCU CS software display.

It is recommended, however, to periodically verify the correct operation of the system and environmental sensors, as any fault here may cause an inaccuracy in the feedback system. The frequency of this verification is dependent on the nature of the application.

Note: The RCU10 contains a lithium metal battery. Please contact Renishaw for details of battery replacement. (The customer must not change the battery). Typical battery life is ten years. At end of life the RCU10 must be disposed of in accordance with local regulations.

The use of this symbol on the batteries, packaging or accompanying documents indicates that used batteries should not be mixed with general household waste. Please dispose of the used batteries at a designated collection point. This will prevent potential negative effects on the environment and human health which could otherwise arise from inappropriate waste handling. Please contact your local authority or waste disposal service concerning the separate collection and disposal of batteries. All lithium and rechargeable batteries must be fully discharged or protected from short circuiting prior to disposal.

Appendix A

RCU10 system specifications

Contained in this appendix

A.1 RCU10 system performance

Input resolutions	Laser encoder:	10 nm*, 20 nm*, 40 nm, 79 nm, 158 nm, 316 nm and 633 nm (digital format) * RLE laser only
	Encoder:	0.1 µm, 0.5 µm, 1µm and 5 µm (digital format)
Output resolutions	Digital	10 nm to 5 µm
	Analogue	20 µm, 25 µm, 40 µm, 50 µm and 100 µm (Actual resolutions available depend upon encoder input resolution.)

NOTE: Valid input/output resolution combinations are pre-defined (refer to section 2.4.2 for further details).

Accuracy

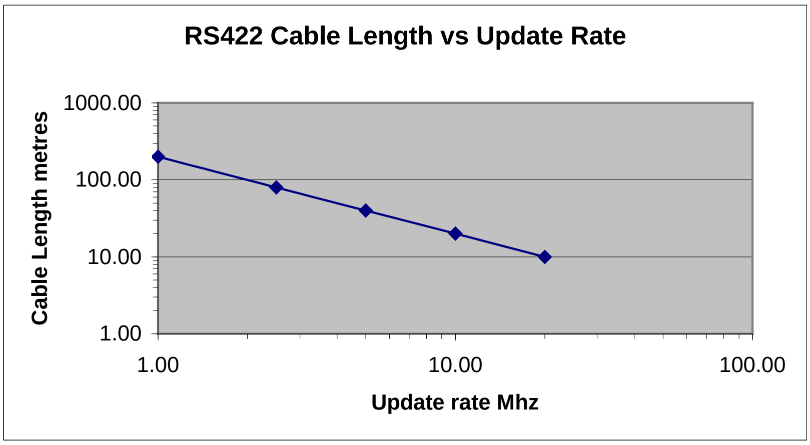
±1 ppm ** (refractive index compensation only)
This assumes a working environment that falls within:
- Temperature range = 0° C to 40° C
- Pressure range = 650 mB to 1150 mB
- Relativity humidity (%RH) = entered within ±20%.

±2 ppm ** (with 10 ppm/°C material compensation)
This assumes a working environment that falls within:
- Temperature range = 0° C to 40° C
- Pressure range = 650 mB to 1150 mB
- Relativity humidity (%RH) = entered within ±20%.

** plus the greater of ±3 input counts and ±1 output counts for digital ouputs and a velocity-dependent following error for analogue outputs.

Maximum velocity	5 m/s	at resolutions >400 nm
	0.2 m/s	at 10 nm resolution
Compensation update rate	200 µs	
Delay through compensator	<1 µs (digital output) <2 µs (analogue output)	

Output update rate (digital) (selectable)	20 MHz (50 ns) (minimum edge-edge separation) 10 MHz (100 ns) 5 MHz (200 ns) 2.5 MHz (400 ns)



Output update rate (analogue)	10 MHz (100 ns)
Input sample rate (selectable)	40 MHz / 20 MHz / 10 MHz / 5 MHz/ 2.5 MHz **Note:** Minimum quadrature edge to edge separation 50 ns (i.e. 20 MHz) The quadrature decode logic contains a digital filter which is used to remove noise spikes from the incoming signals. This filter is only operational for input sample clocks of 10 MHz and below.

NOTE: RCU10 performance specifications are only guaranteed in a working environment that falls within a 0 °C to 40 °C temperature range, 650 mbar to 1150 mbar and a relative humidity entered to within ±20% of actual. Individual component specifications are detailed in section A.2.

A.2 Component performance

A.2.1 Compensation unit

Dimensions

Length	350 mm (13.8 in) including mounting brackets
Width	42 mm (1.65 in)
Depth	135 mm (5.31 in) not including connectors (RCU10-P)
Weight	1.2 kg (RCU10-P)

Power supply

Voltage	24 V ±2 V
Current	<0.25 A
Maximum power	6 W (with 8 sensors connected)

The 24 V power supply should be single fault tolerant certified to EN (IEC) 62368-1:2014+A11:2017

Operating environment

Pressure	Normal atmospheric (650 mbar – 1150 mbar)
Humidity	0-95% RH (non-condensing)
Temperature	Storage -20 °C to 70 °C
Operating	0 °C to 50 °C

NOTE: RCU10 system performance specifications are only guaranteed over a 0 °C to 40 °C temperature range.

Standards compliance

CE EMC	BS EN 61326
FCC	47 CFR PART 15

A.2.2 Air sensor

Accuracy *	± 0.2 °C (k=2)
Measurement range	0 °C – 40 °C
Update rate	1 Hz

A.2.3 Material sensor

Accuracy *	± 0.1 °C (k=2)
Measurement range	0 °C – 55 °C
Update rate	1 Hz

A.2.4 Pressure sensor

Accuracy	± 2 mbar (k=2)
Measurement range	650 mbar to 1150 mbar
Operating temperature	0 °C – 60 °C
Update rate	1 Hz

* Sensors calibrated over operating temperature range by immersion in a temperature controlled fluid bath.

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Appendix B

Connector pinout and hardware installation details

Contained in this appendix

B.1 Introduction

The following pages give the connection pinouts and hardware installation details for each connector in the system.

NOTE: All genders are specified for the cable connector. All pinouts are shown from the connector wiring side (RCU10 front panel).

B.2 24 V dc power (J1)

B.2.1 Connector pinout

4-way binder 680 series, female. The connector is viewed from the wiring side.

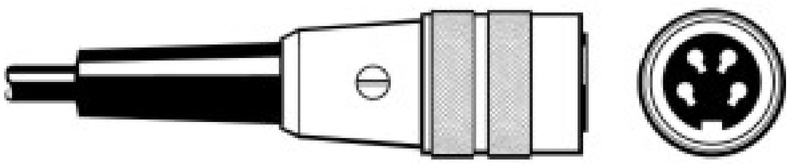


Table B.1 – J1 connector pinouts (24 V dc power)

Pin	Standard PSU	PSU with remote sense
1	+24 V supply	+24 V supply
2	-	+ Sense
3	0 V	0 V
4	Case (screen)	Case (screen)
Chassis	Case (screen)	Case (screen)

B.2.2 Wiring requirements

The supply does not require a shielded cable. A filter is employed at the supply inlet and is effective on both 24 V and 0 V from the power supply unit (PSU) – the system 0 V and case / ground are connected at the other end of this filter (see Figure B.1). The system 0 V may also be connected to PSU 0 V but the benefit of the inlet filter may be reduced.

For longer cable runs, a 24 V-sense line is available on the connector for remote sensing (see Figure B.1).

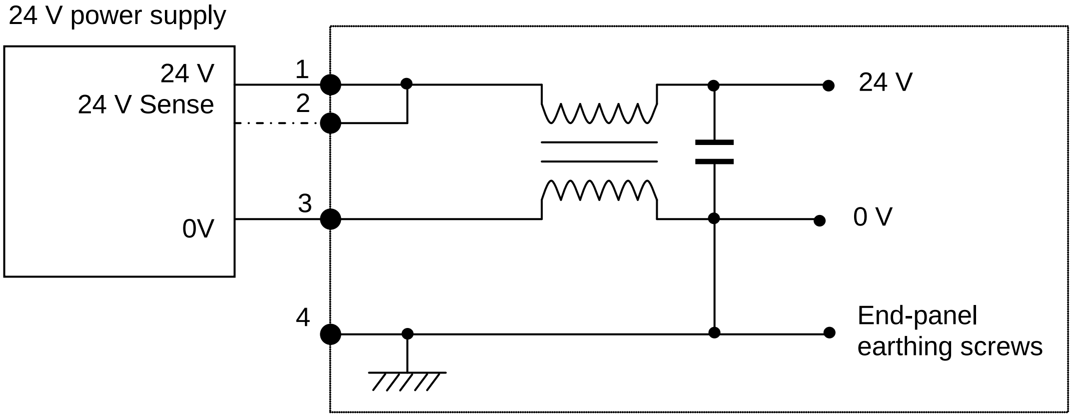


Figure B.1 – Power supply wiring with optional sense connection

The RCU10 will operate between 22 V and 26 V and has reverse and overvoltage protection.

The supply is reverse voltage protected and, if the supply is taken above its normal operating range, will be protected by means of an inline thermal fuse and Crowbar circuit, which shorts the 24 V supply and causes the fuse to set. To reset the fuse, the power must be completely removed from the unit for a number of seconds and then re-applied. The protection circuit will allow safe operation up to ±35 V across the supply terminals, but operation above these levels will result in damage.

NOTE: The action of the fuse is to remove power from the RCU10 unit. Until the fuse has tripped, the supply will be short-circuited.

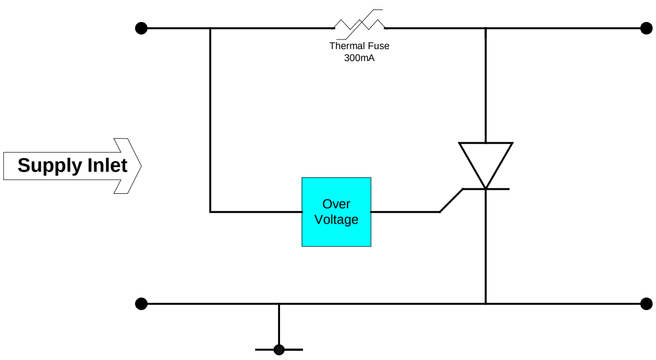


Figure B.2 – Inline thermal fuse

B.3 Controller output (J2)

The RCU10 can be configured to provide digital or analogue position feedback signals.

B.3.1 Digital feedback signals

B.3.1.1 Connector pinout

15-way D-type female (controller port for RS422 interface). The connector is viewed from the wiring side.

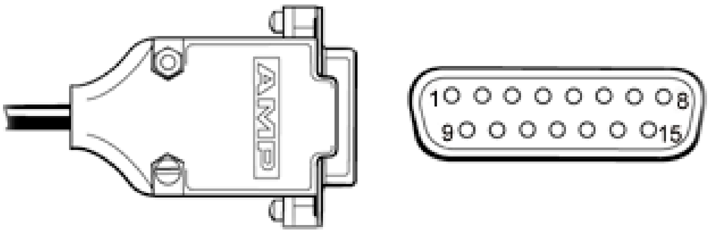


Table B.2 – J2 connector pinouts
(controller output – digital feedback signals)

Pin	Function
1	Error – open collector +24 V
2	0 V – signal ground
3	/Error – error output RS422
4	/Z – reference output RS422
5	/B Quad – RS422
6	/A Quad – RS422
7	5 V encoder supply (see Note 1)
8	5 V sense line (see Note 1)
9	0 V sense line (see Note 1)
10	-
11	Error – error output RS422
12	Z – reference output RS422
13	B Quad – RS422
14	A Quad – RS422
15	Inner screen (see Note 2)
Shell	Case

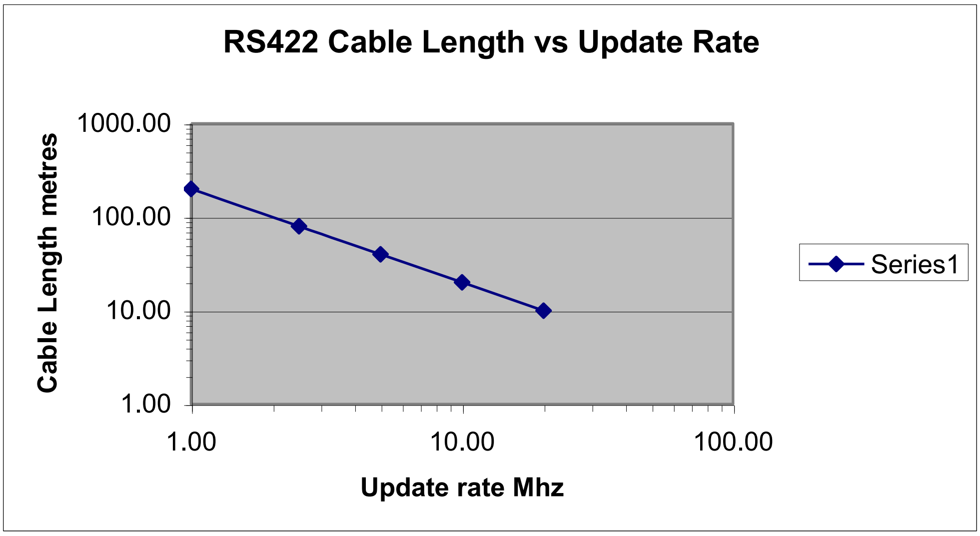
- **Note 1**: Pins 2, 7, 8 and 9 are provided as a method of providing power to encoders which require a 5 V supply (with remote sense if required). The connections simply 'pass through' to the encoder connector. This 5 V supply must be provided by the controller or an external PSU – it is not supplied by the RCU10. Pin 2 is 0 V which is connected to the internal RCU10 0 V line.

- **Note 2:** When used with an RLE or tape/glass encoder, pin 15 may be used to 'pass through' the internal cable screens. This must be connected to the screens at the controller end – it is not grounded inside the RCU10. **IMPORTANT:** When HS10 or HS20 is used, this pin must not be connected.

B.3.1.2 Wiring requirements

A cable with twisted pairs and overall shield is recommended for the digital quadrature interface between the RCU10 and the controller, as specified in EIA RS 422 (e.g. Belden 8107).

Maximum cable length is dependent on the update rate of the quadrature signals; recommendations are shown in the graph below:



Termination

Quadrature, Reference and Error signals may be terminated using an ac or dc termination strategy. Recommendations for termination of the differential pairs at the controller are:

- All pairs may be dc terminated with a 100 Ω to 120 Ω resistor.
- The quadrature and reference pairs may be ac terminated with a series combination of 100 Ω to120 Ω resistor and 1 nF capacitor. For cable lengths less than 1 m, a smaller 100 pF capacitor is recommended.
- The Error line pair should be ac terminated with a series combination of 100 Ω to 120 Ω resistor and 1 nF or 10 nF capacitor.

The quadrature can also be set to tristate when the system experiences an error. The tristate condition is a means of signalling an error to a controller without the use of an extra error line. In the event of an error, the drive is removed from all quadrature lines resulting in a differential output, i.e. A-/A or B-/B, which falls below a given threshold level i.e. it not a high or a low, it is in an undefined state.

B.3.2 Analogue feedback signals

B.3.2.1 Connector pinout

15-way D-type female (controller port for analogue interface). The connector is viewed from the wiring side.

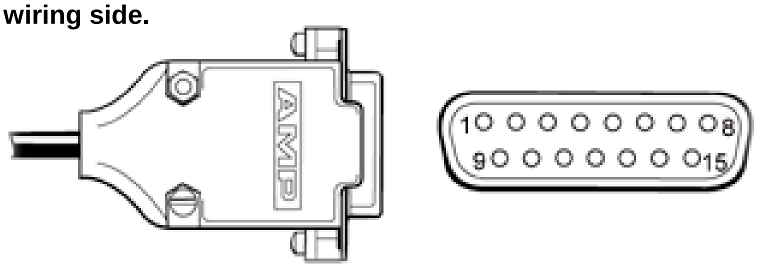


Table B.3 – J2 connector pinouts
(controller output – analogue feedback signals)

Pin	Function
1	Error – open collector +24 V
2	0 V – signal ground
3	/Error – error output RS422
4	/Z – reference output 1 V analogue
5	/Sine – 1 V analogue (see Note 1)
6	/Cos – 1 V analogue (see Note 1)
7	5 V encoder supply (see Note 2)
8	5 V sense line (see Note 2)
9	0 V sense line (see Note 2)
10	-
11	Error – error output RS422
12	Z – reference output 1 V analogue
13	Sine – 1 V analogue (see Note 1)
14	Cos – 1 V analogue (see Note 1)
15	INSCR – inner screen (see Note 3)
Shell	Case

Note 1: Under error conditions the quadrature signal level will drop to 100 mV peak-to-peak.

Note 2: Pins 2, 7, 8 and 9 are provided as a method of providing power to encoders which require a 5 V supply (with remote sense if required). The connections simply ‘pass through’ to the encoder connector. This 5 V supply must be provided by the controller or an external PSU – it is not supplied by the RCU10.

Note 3: When used with an RLE or tape/glass encoder, pin 15 may be used to ‘pass through’ the internal cable screens. This must be connected to the screens at the controller end – it is not grounded inside the RCU10. **IMPORTANT:** When HS10 or HS20 is used, this pin must not be connected.

B.3.2.2 Wiring requirements

A cable with twisted pairs and overall shield is recommended for the analogue quadrature interface between the RCU10 and the controller (e.g. Belden 8107).

Analogue quadrature is fully short-circuit protected.

Termination

A dc termination resistor, which has a nominal value of 120 Ω, should be connected across the differential pairs. This should be applied to the quadrature and reference lines only.

- When correctly terminated, the amplitude of the differential Sine and Cosine signals is specified to be 1 V ±5% peak-to-peak superimposed on 2.5 V ±5% dc common mode.
- When correctly terminated, the amplitude of the differential reference signals is specified to be ±1 V ±5% superimposed on 2.5 V ±5% dc common mode.

In analogue mode, an error is depicted via a drop in the signal level of the quadrature output to 10% or 100 mV peak-to-peak. However, the RS422 Error differential pair is still active and can be used.

B.4 Encoder input (J3)

B.4.1 Connector pinout

15-way D-type male. The connector is viewed from the wiring side.

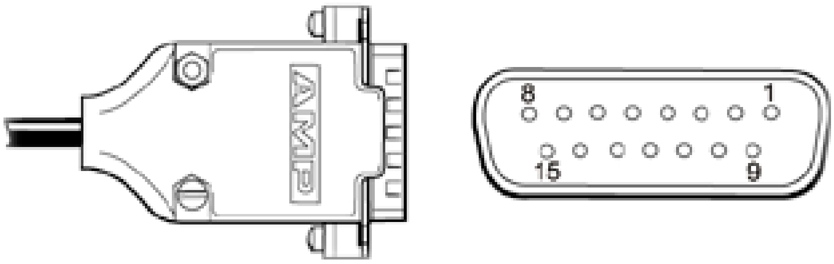


Table B.4 – J3 connector pinouts (encoder input)

Pin	Function – RLE	Function – HS20	Function – RGH
1	Do not connect	Do not connect	Do not connect
2	0 V – signal ground	0 V – signal ground	0 V – signal ground
3	/Error	/Overspeed	/Error
4	/Z	/Unstable	/Z
5	/B quad *	/B quad *	/B quad *
6	/A quad *	/A quad *	/A quad *
7	Do not connect	Do not connect	5 V
8	Do not connect	Do not connect	5 V Sense
9	Do not connect	Do not connect	0 V Sense
10	Do not connect	Do not connect	Do not connect
11	Error	/Beam blocked	Error
12	Z	/Beam low	Z
13	B quad *	B quad *	B quad *
14	A quad *	A quad *	A quad *
15	Do not connect	/Reset	Inner screen (pass through)
Shell	Case	Case	Case

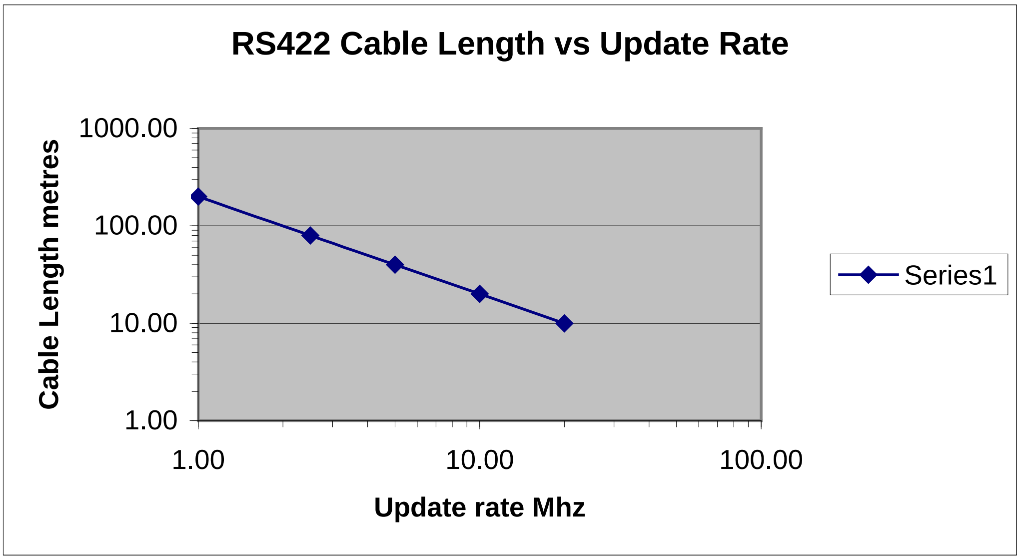
* Float detection will sense most combinations of local disconnection on this interface.

WARNING: The reference port uses the same connector configuration as the sensor. If a reference switch or other device is accidentally connected to the RLE10 sensor ports, the sensor network operation may become disrupted. This may cause errors on the RCU10 system but no damage will be caused. Always ensure that nothing is connected to the RLE10 sensor ports when not in use.

B.4.2 Wiring requirements

A cable with twisted pairs and overall shield is recommended for the digital quadrature interface between the RCU10 and the encoder, as specified in EIA RS 422 (e.g. Belden 8107).

Maximum cable length is dependent on the update rate of the quadrature signals; recommendations are shown in the graph below. For encoders where the quadrature state transition is asynchronous in nature, the update rate applies to a minimum transition (minimum edge to edge separation between the quadrature signals)



The quadrature, reference and error lines are all terminated inside the RCU unit:

- The quadrature line differential pair is dc terminated with a 120 Ω resistor.
- The reference line differential pair is ac terminated with a series connected 120 Ω resistor and 1 nF capacitor.
- The error line differential pair is ac terminated with a series 120 Ω resistor and 10 nF capacitor. In addition, the line is pulled active in the event of a disconnection to either signal.

All the encoder port terminals are protected from wiring faults that would be expected when used with HS10, RLE10 and linear encoders powered from 5 V. Where a short circuit could flow, PCB tracks are rated to 0.5 A.

A method is employed to sense disconnection of one or more of the quadrature lines in addition to the standard EIA–RS422 line receivers. A circuit monitors the difference voltage across each quadrature pair and reports a fault if the level falls below a given voltage threshold (< +0.75 V or > -0.75 V).

NOTE: To ensure that a false disconnection alarm does not occur during normal operation, it is important that the encoder complies with the minimum drive level of 2 V and is within the maximum cable length for the signal bandwidth.

B.5 Reference switch port (J4)

B.5.1 Connector pinout

4-way binder 712 series. The connector is viewed from the wiring side.

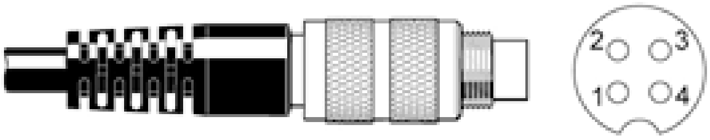


Table B.5 – J4 connector pinouts (reference switch port)

Pin	Function
1	Input return
2	0 V
3	+5 V supply – thermal fuse protection
4	Input
Shell	Case

B.5.2 Wiring requirements

A multi-conductor cable with overall shield is recommended for the reference switch port interface e.g. Belden 9925.

The interface is isolated and consists of four terminals; the power and its return and the signal and its return. To make the reference activate, the interface should to be used with a reference switch that allows the current to flow when at reference. A transistor switch may also be used – this includes P or N type devices arranged as open collector or open drain.

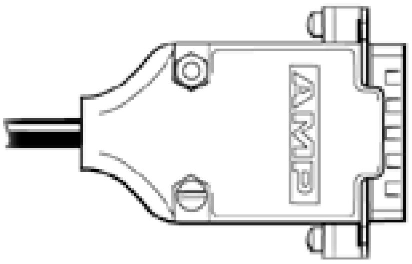
A bipolar driver may also be used **–** in this instance, the thresholds are ON by 3 V and OFF by 1 V (these are not TTL thresholds).

When driven by an external supply voltage, the reference port is protected to ±10 V dc.

B.6 Auxiliary I/O (J7)

B.6.1 Connector pinout

15-way high-density D-type male. The connector is viewed from the wiring side.



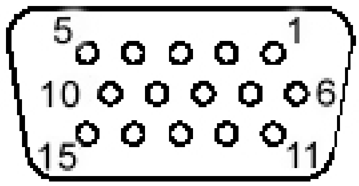


Table B.6 – J7 connector pinouts (Auxiliary I/O)

Pin	I/O	Function
1	O	5 V (output)
2	-	0 V
3	I	/Workpiece compensation enable
4	I	/Workpiece comp temperature freeze
5	I	/Seek reference
6	O	/Error - open collector 24 V
7	I	Pull
8	-	-
9	O	/Suspend – open collector 24 V
10	O	/Warning – open collector 24 V
11	O	24 V (output)
12	I	Parameter table select 1
13	I	Parameter table select 2
14	I	/Buffer enable
15	I	/Reset
Shell		Case

B.6.2 Wiring requirements

The operating threshold for the auxiliary I/O port inputs is set in the configuration of the unit and can be either:

- 5 V: ON by 2 V, OFF by 0.8 V (TTL)
- 24 V: ON by 14.5 V, OFF by 5.8 V

Thermal fuses protect the 24 V and 5 V supply outputs – to reset a fuse, remove the power from the RCU10 unit for a number of seconds. All signal pins (both input and output) are fully protected against a direct connection of an external supply, up to ±30 V.

All the auxiliary I/O signals are connected to the 24 V supply using a weak pull-up. If any of the signals are to be wired to an external interface, the weak pull-ups must be overridden by connecting the terminal PULLUP to either the 5 V or 24 V terminals. The onboard pull-ups are only 20 kΩ in value and will be insufficient in applications where the controller I/O card is an open collector type and sinks a large residual current. In this situation, it is recommended that the user fits external pull-ups of 2K2 in parallel to each signal.

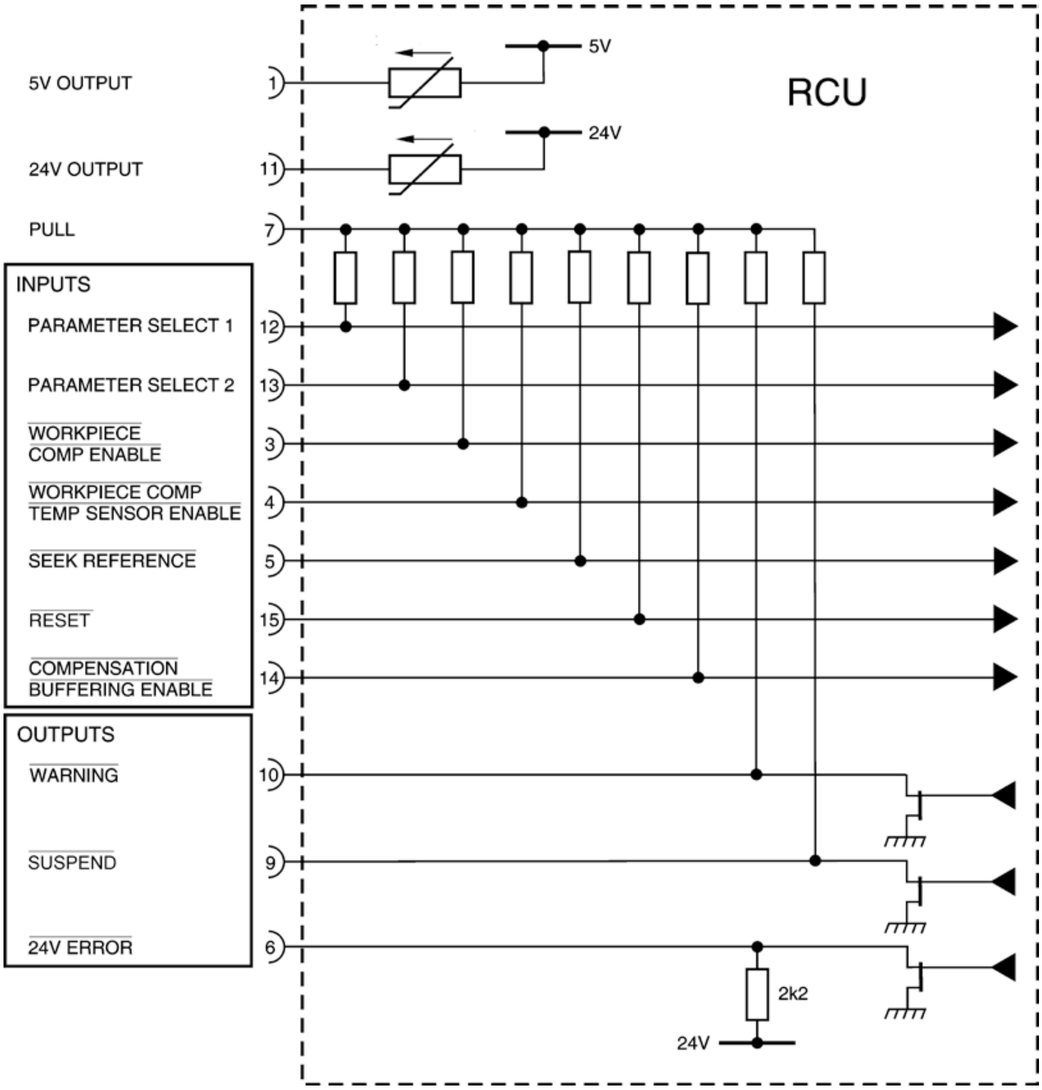


Figure B.3 – Auxiliary I/O port circuit

NOTE: For HS20 applications the RCU10 system should <u>not</u> be wired to automatically reset errors.

NOTE: In applications where the RCU10 is not connected to the controller via the Aux I/O port, another method of clearing the error must be used. Using a 15-way high density D-type female connector, link pin 2 to pin 5, link pin 7 to pin 11 and connect a push to make switch across pins 2 and 15. Pressing the push button will send a reset signal to the RCU10. A separate switch will be required for each RCU10 in the network.

B.7 PC port (J8)

B.7.1 Connector pinout

5-way female binder 712 series. The connector is viewed from the wiring side.

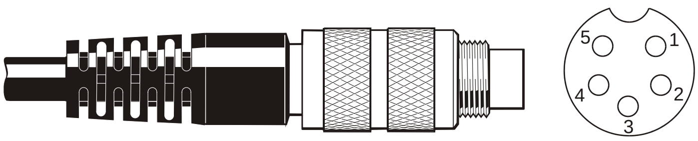


Table B.7 – J8 connector pinouts (PC port)

Pin	Function	
	RS232	RS422/485
1	RXD	
2	0 V	0 V
3		Data
4		/Data
5	TXD	
Shell	Case	Case

B.7.2 Wiring requirements

The PC interface uses an asynchronous serial data format with a data rate of 19.2 kbaud. The PC port may be used with either a standard RS232 interface or an RS485 interface – all terminals are protected against a single fault short circuit to another terminal.

The RCU10 is supplied with a standard RS232 PC cable assembly (A-9904-1456) of 1 m in length. If the standard cable is too short, custom RS232 cables should be constructed using multi-conductor cable with an overall shield e.g. Belden 9925.

If the interface is longer than 10 m, it is recommended that the RS485 interface be used instead of the RS232 interface (maximum cable length of 50 m). These should be constructed using a twisted pairs cable that has an overall shield e.g. Belden 8102 or Belden 8132. For a simple network with one RS485 controller and one RCU10, a cable as specified in EIA RS 422 would be suitable. For a more complex RS485 network, then follow the guidelines in EIA RS485.

The RCU10 terminates one end of the interface. In most cases this should be sufficient, however, for fault-free communication over very long runs, the user may need to terminate the other end. Either of the following terminations may be used:

- An ac termination using a 100 Ω – 120 Ω resistor in series with a 1 nF capacitor.
- A dc termination using a 100 Ω – 120 Ω resistor.

B.8 Fastlink port

To ensure correct operation of the RCU10 network, the Fastlink cable assembly provided by Renishaw must be used.

Fastlink cable termination should be applied to the physical end units of the network during the configuration stage.

Set the network up without termination. Run the configuration software and select termination on the two end units only. Remove and re-apply power or reset the system to activate the termination.

NOTE: The configuration software only allows 0 or 2 units to be terminated.

B.9 Sensors (J5, J6)

B.9.1 Connector pinout

4-way binder 712 series. The connector is viewed from the wiring side.

Cable connectors: Male at RCU10 end
Female at sensor end

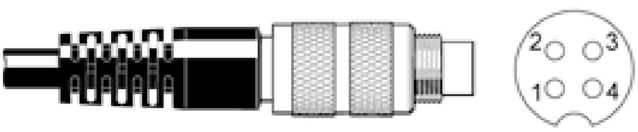


Table B.8 – J5 and J6 connector pinouts (sensors)

Pin	Function
1	/Data
2	0 V
3	+ 5 V supply – thermal fuse protection
4	Data
Shell	Case

B.9.2 Wiring requirements

Standard cable

The RCU10 is supplied with a standard sensor cable assembly (P-CABS-0005-RT) that is recommended for a single run, where the total cable length is up to 15 m (see Figure B.4). It may also be used for connection to a number of sensors through a distribution box – in this instance a single cable run of 5 m to the distribution box and to each sensor is permitted (see Figure B.4).

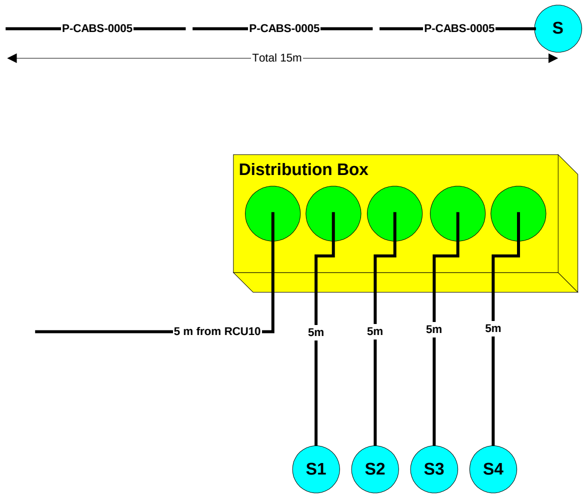


Figure B.4 – Standard cable

The sensor supply lead is fitted with an inline thermal fuse **–** if activated, then power must be removed from the RCU10 unit so that it can reset. The Data and /Data lines are protected from short-circuit to each other and to either supply line.

Custom cable recommendations

In applications where more than five meters is required, it is recommended that a custom cable is manufactured. This should be manufactured from the following specification cable:

- 24 AWG EcoMini 2 pair
- Nominal diameter 4.22mm (0.166")

An example of this cable is **'Aplha Wire'** – Mfr. Part No. 78172

This cables nominal diameter correctly fits the recommended Binder cable back shell clamp (max allowed dia. 5mm)

A maximum allowable voltage drop of 1.25 V from the RCU10 to the sensor governs the maximum allowable cable run. The specification for peak current drawn by any one sensor is 20 mA, which means that for a single run of cable, the power lead resistance must be less than 31.25 Ω. Two examples utilising Belden 88102 are shown below:

- For a single run: Belden 88102 has 24AWG cores that give a resistance of 76 Ω per km, which means a maximum single run of 400 m (see Figure B.5).
- A common network with three equally spaced sensors (see Figure B.5): the cable to sensor S1 is conveying 60 mA, the cable to sensor S2 is conveying 40 mA and the last cable to S3 is conveying 20 mA. The total voltage drop is (0.06 + 0.04 +0.02) * (2 * 203/3) * (76/1000) = 1.24, which gives a maximum run of 203 m in this configuration.

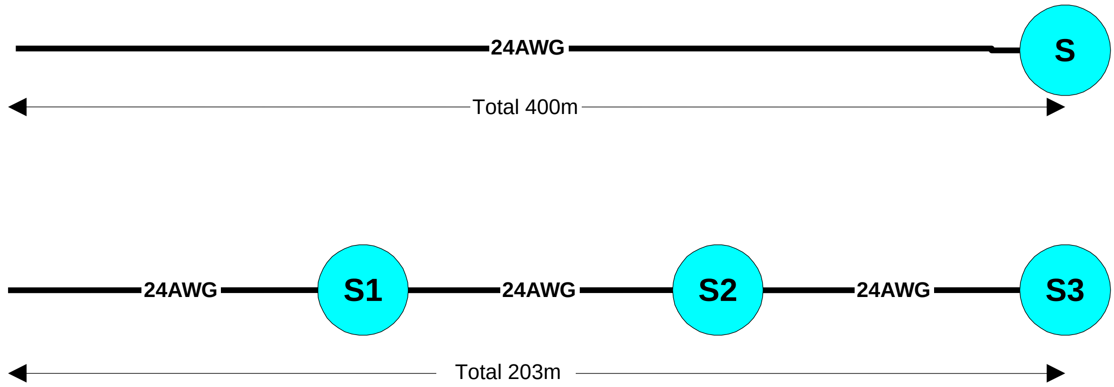


Figure B.5 – Custom cables

Appendix C

RCU CS

Contained in this appendix

C.1 RCU CS

C.1.1 Overview

Before the RCU10 may be used, it must be configured using the RCU10 configuration software (RCU CS). This package allows all the parameters and operational modes to be configured and also provides an operational display to monitor the compensation process, environment and error status. The following sub-sections describe the requirements for and operation of the RCU CS package.

C.1.2 Access levels

The RCU CS has been implemented with three levels of user access.

Each level has password protection (apart from the **User** level). This password protection is included to prevent possible misconfiguration by untrained persons, or corruption of the system firmware.

User

This level only allows the user to view the operation and existing configuration of the system. No changes can be made to the system configuration or the current operating mode.

This level is intended for the base level end-user. Access at this level does not require a password.

System configurator

This level provides access to all user-configurable parameters and fields within the system. Full access to all functions is provided.

This level is designed for use by the OEM, system installer or trained maintenance staff.

The default password is **config** in lower case.

System upgrade

This level is reserved for Renishaw use only. It provides the facility for system firmware upgrades.

Table C.1 – Access levels

Access level	User	System configurator	System upgrade
View configuration/operation displays	✓	✓	✓
Change parameter data	×	✓	✓
Configure system	×	✓	✓
Upgrade firmware	×	×	✓

This manual describes the use of **User** and **System Configurator** access levels. If you do not have rights to some of the areas described in this manual, the option may not appear or it may be greyed out.

CAUTION: It is recommended that the system configurator level password is changed from the default since this level allows access to parameters that can affect system safety.

In the event that an access password is forgotten, contact a Renishaw support representative who will restore access by supplying a recovery password.

C.1.3 Operating modes

The RCU10 has two main modes of operation:

Configuration This mode is used to configure the RCU10(s) individually or as part of a network.

WARNING: In this mode the RCU10 hardware is essentially ‘offline’. The machine or axis should not be enabled. In this mode the RCU10 error output signal (24 V error) is asserted so that the controller can disable motion.

Compensation This is the normal operating mode once configuration has been completed.

The RCU CS software is used to switch between these modes using the **Mode** button on the button bar. The current operating mode can be seen on the status bar at the bottom of the RCU CS screen, and the RCU10 will display the following on the front panel display:

Table C.2 – Operating modes

Configuration mode	Compensation mode	Description
CONF		Configuration mode. Compensator is ‘offline’.
	ERR	Compensation mode, with error(s) present.
	RDY	Ready for referencing (homing).
	CMP	Compensation mode. System operating.

Note: The button cannot be used to change modes if 'Inhibit compensation' is set.

C.1.4 Configuration data

The RCU10 compensator unit stores configuration data in an internal (non-volatile) memory. Since a multi-axis system is made up of individual single-axis units that communicate along a multi-axis communication bus, some of the configuration data will be common to the system (global) and some data will apply to each axis only (local).

The diagram below shows the data organisation for a multi-axis system.

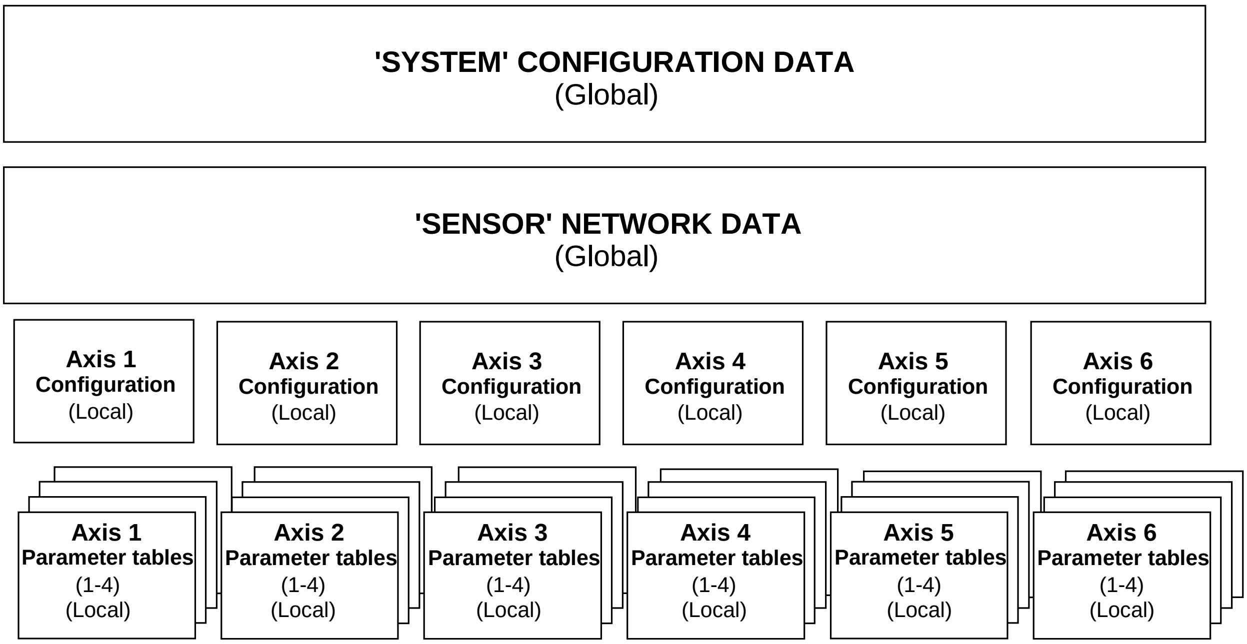


Figure C.1 – Configuration data summary

Global configuration data

Global configuration data comprises settings that are common to a whole system. This data is stored in all RCU10s in a system and comprises all the settings and data on the **System** and **Sensors** tabs of the configuration screen (detailed in sections 4.2.1 and 4.2.2).

Local configuration data

Local configuration data comprises settings that are unique to each axis of the system. This data is stored only in the relevant RCU10 unit and comprises all the settings and data in the **Compensation** and **Parameters** tabs of the configuration screen (detailed in sections 4.2.3 and 4.2.4).

Parameter table data

The parameter table data is also unique to each axis, but there can also be multiple tables per axis, depending on the configuration. A single RCU10 unit may contain up to four parameter tables. This data is stored only in the relevant RCU10 unit.

The parameter data table comprises all the settings and data in the **Parameters** tab of the configuration screen (detailed in sections 4.2.4 and Appendix F.1.7.2).

C.2 RCU CS installation

C.2.1 System requirements

RCU CS requires a PC-based system with the following specifications:

- 40 MB free hard drive space (minimum)
- Windows 7 and Windows 8 (32 bit or 64 bit)
- 800 x 600 screen resolution (minimum); 1024 x 768 (preferred)
- DVD-ROM
- At least one free serial port - either RS232 or USB used with an RS232 to USB converter (available from Renishaw)
- See Renishaw website for more details on current system requirements

C.2.2 Installation procedure

- Insert the installation CD into a drive. The installation program should run automatically. If this does not happen, manually run the program **setup.exe** by selecting **Run** from the **Start** menu and typing “d:\setup.exe”, where “d” is the letter relating to the CD-ROM drive being used.
- Click **Next** to acknowledge the welcome screen.
- Read the Software Licence Agreement and press **Yes** if you accept its terms.
- Select the destination location and press **Next** to start installing the software.
- Select “**Yes, I want to restart my computer**” and click on **Finish** to complete the installation.

Note: Full instructions for the installation and removal of the RCU CS software can also be found in a text file (readme.txt) in the software’s installed directory. This file will also contain any updates on the latest version of RCU CS.

This program will install the RCU CS software and associated files in the default folder: *C:\Program Files\Renishaw\RCU CS (if using a Windows 64-bit PC then C:\Program Files (x86)\Renishaw\RCU CS).*

A shortcut named RCU CS will be created on the Start menu, desktop, and also under the group:

Start -> Programs -> Renishaw RCU10

Uninstalling the software

To uninstall the software, use the **Uninstall** option.

Start -> Programs -> Renishaw RCU10 -> Uninstall RCU CS

If the software fails to fully uninstall, the likeliest cause is that the RCU CS folder cannot be deleted as it still contains files. The reason for this may be that data log files have been automatically stored there.

NOTES:

1. Previous versions of Renishaw RCU-CS software must be uninstalled before installing an upgrade.
2. The removal of any shared files may affect other applications installed on your PC.
3. Prior to uninstalling or upgrading RCU-CS it is recommended that the RCU10 configuration is backed up in accordance with section F2.1.1.

C.2.3 Screen layout

The screen layout for the RCU CS is shown in Figure C.2. Any commands that require user input will be marked in **bold**.

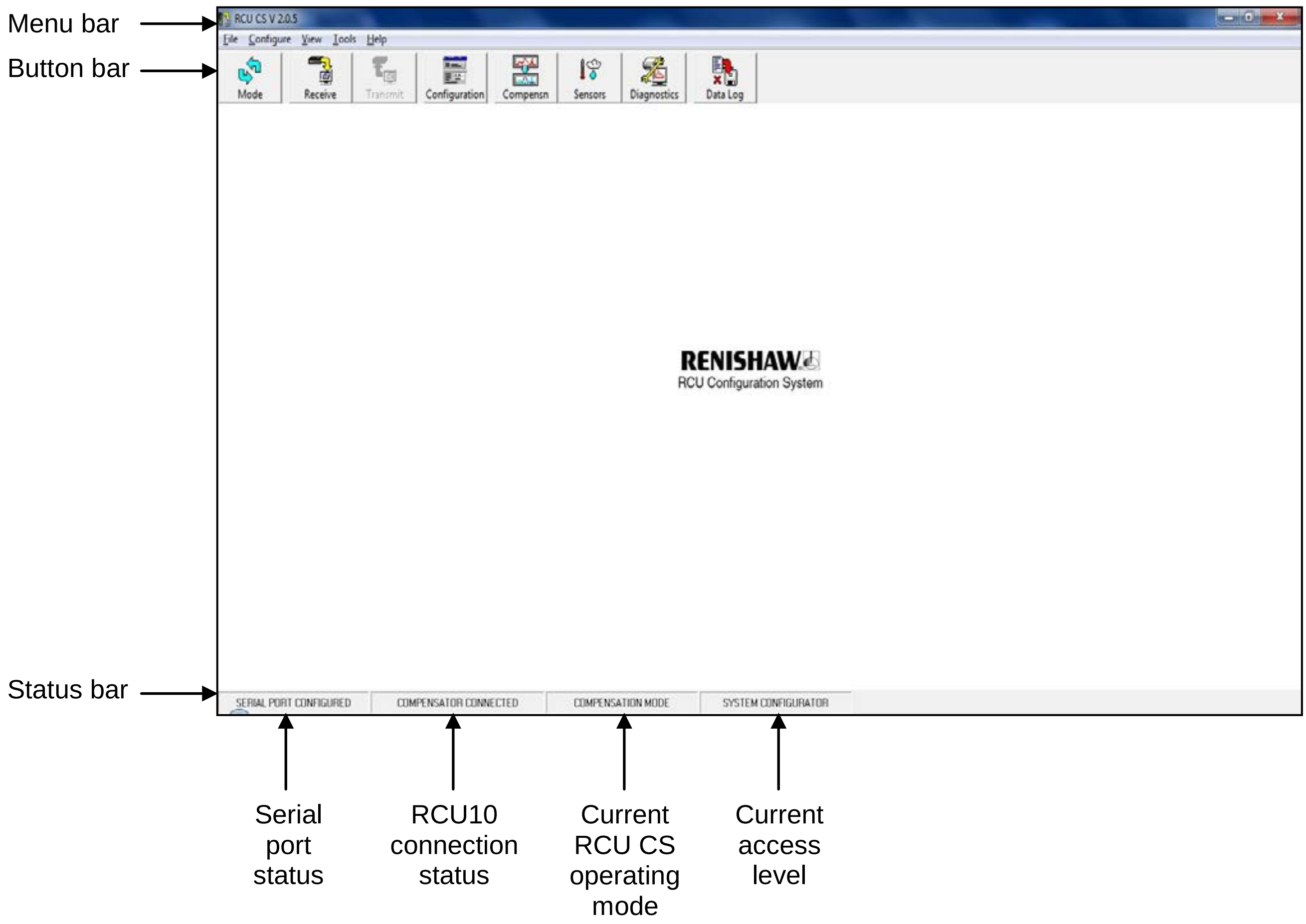


Figure C.2 – RCU10 status display

Menu bar

The menu bar lists all the RCU CS functions in five different menus: File, Configure, View, Tools and Help.

- ## File menu

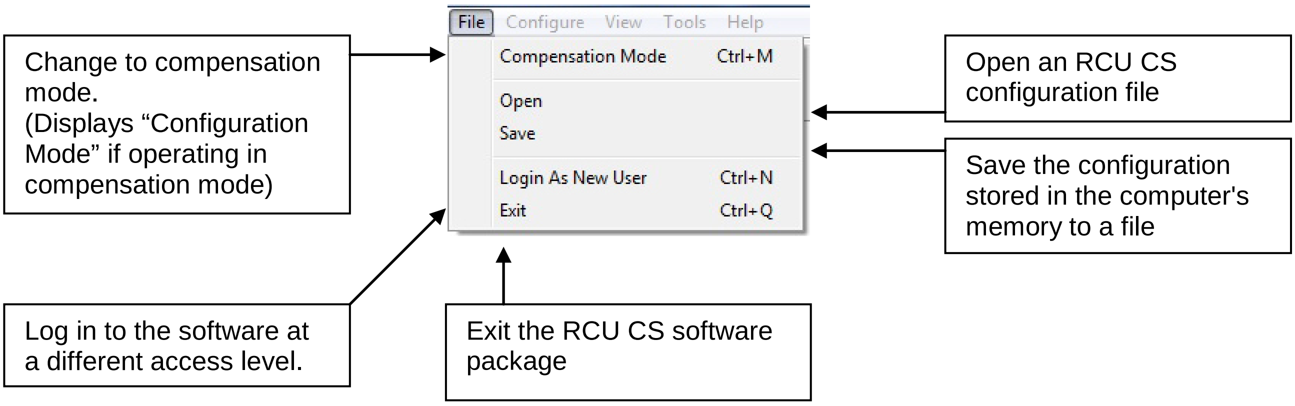


Figure C.3 – File menu functions

- ## Configure menu

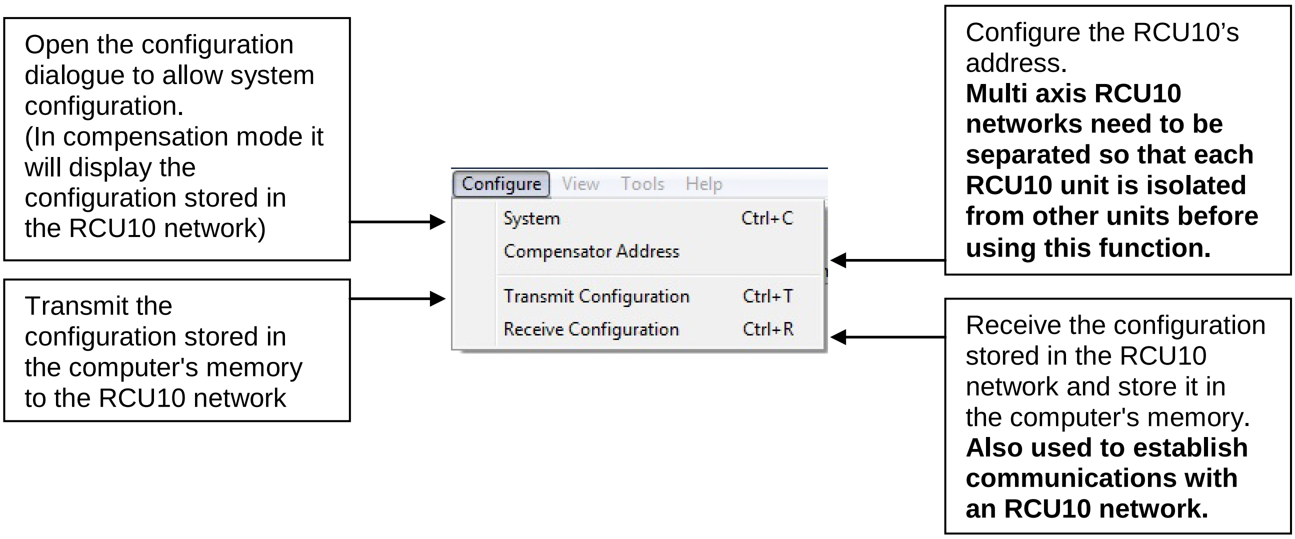


Figure C.4 – Configure menu functions

• View menu

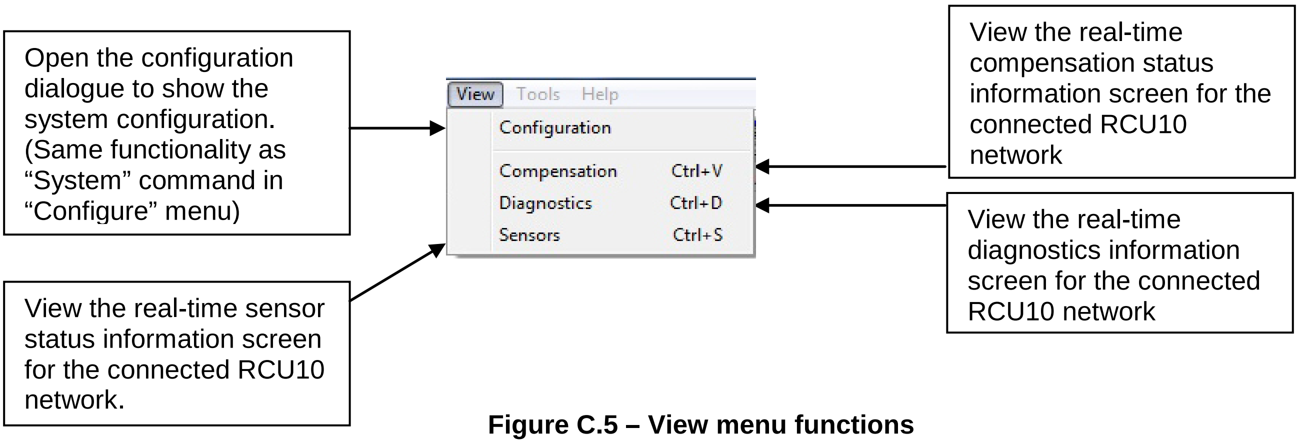


Figure C.5 – View menu functions

Note: Do not leave diagnostics or sensors windows open if the RCU10 system hardware needs to be powered down. Doing so may prevent the RCU10 powering up correctly.

• Tools menu

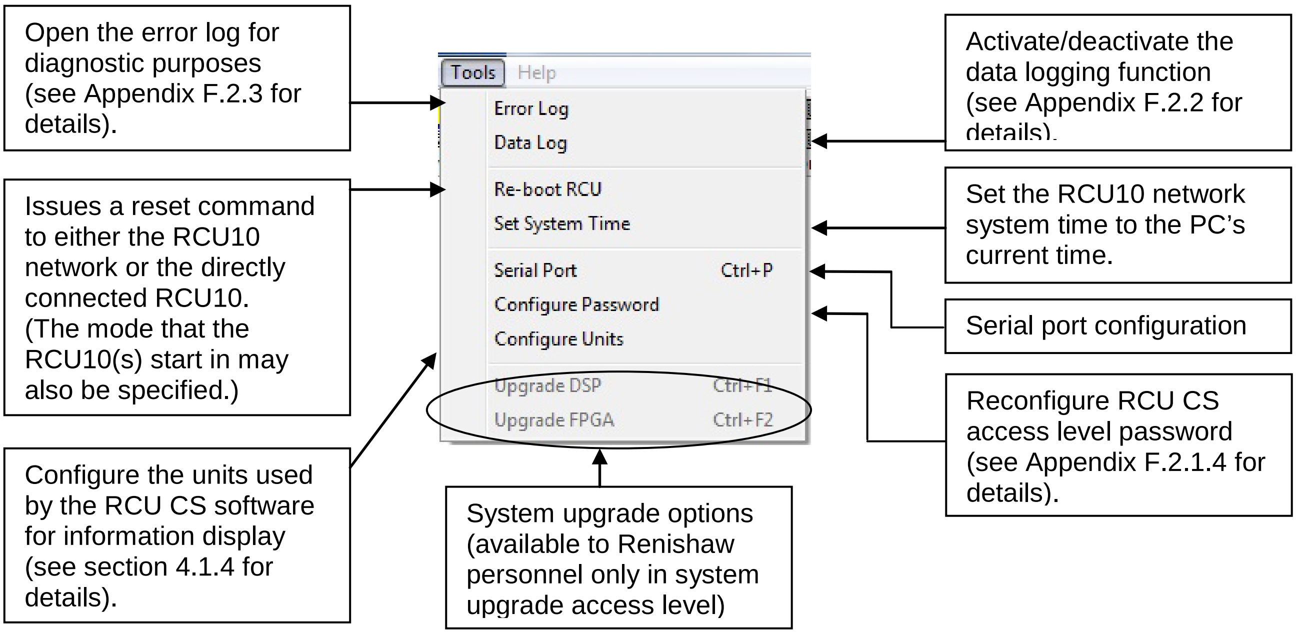


Figure C.6 – Tools menu functions

• Help menu

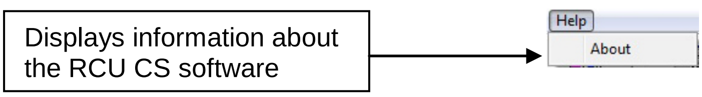


Figure C.7 – Help menu functions

Button bar

The button bar offers easy access to commonly used functions.

Figure C.8 – Button bar

- **Mode** – Change current operating mode (Configuration ↔ Compensation).
- **Receive** – Connect to RCU10 network and receive all configuration data.
- **Transmit** – Transmit all configuration data stored in the computer's memory to the RCU10 network.
- **Configuration** – Display the configuration stored in the computer's memory.
- **Compensation** – Display the real-time RCU10 network compensation status screen.
- **Sensors** – Display the real-time RCU10 network sensor status screen.
- **Diagnostics** – Display the real-time RCU10 diagnostics status screen.
- **Data Log** – Enable/disable the data logging function.

Status bar

The status bar shows the following information:

- Serial (COM) port status.
- RCU10 connection status.
- Current operating mode (configuration/compensation).
- Current access level (user/system configurator/system upgrade).

Note: Do not leave diagnostics and sensors windows open if the RCU10 system hardware needs to be powered down. Doing so may prevent the RCU10 powering up correctly.

Appendix D

Compensation system status information and diagnostics

Contained in this appendix

D.1 Diagnostics

The RCU10 is a powerful system with in-built fault diagnosis/logging to determine the cause of any system errors that may occur. This section aims to give an overview of each of the various warning indicators available across the RCU CS software. This will provide the user with a basic understanding of the fault being exhibited and will aid the diagnosis process should the user need to contact Renishaw for further support.

D.1.1 Process overview

There should be a sequential approach to diagnosing problems on the RCU10 compensation system.

- Refer to the RCU CS diagnostics screens.
- Identify the source of the problem(s) indicated.
- Refer to the sensor status screen if necessary.
- Refer to section D.3 of this guide to identify the course of corrective action.

The general procedure for dealing with most errors is to remove the source of the error and then apply a reset by taking pin 15 of the Auxiliary I/O connector low. If this fails to clear the condition, then it may be necessary to apply a total system reset (power cycle) to restart the RCU10(s).

D.2 Error descriptions

There are four levels of error supported by the RCU10 firmware. These are, starting with the most critical:

1. System errors (SE)
2. Errors (E)
3. Warnings (W)
4. Sensor failure

System errors (SE) indicate a critical system failure. It cannot be cleared by asserting the **Reset** line on the Auxiliary I/O connector. These errors indicate a loss of firmware integrity and safe operation cannot be reliably restarted. System errors can only be cleared by a system reset (power cycling).

Errors (E) indicate any critical failure that does not affect the RCU10 firmware integrity, or the safety of internal operations. Errors can be cleared by removing the source of the fault and then asserting the **Reset** line on the Auxiliary I/O connector to allow normal operation to be restarted. After a single error event is detected, the error condition is latched until the **Reset** signal is asserted, and the condition that caused the error has disappeared.

Suspend conditions indicate states where the compensator has not fully completed the compensation adjustment, such as waiting to reference the axis, injecting pulses after a compensation process or a compensation failure. Error clear or system reset is not required to deactivate the **Suspend** line.

A **Warning** (W) condition indicates any other error condition that requires attention, but will not compromise the safety or the accuracy of the feedback signals. The warning condition is not persistent and will disappear when the reason for causing it is cleared. Error clear or system reset is not required to deactivate the **Warning** line.

A **Sensor failure** condition indicates real-time problems with a specific sensor. It will create a **Warning** output signal in the advanced mode of error operation. Sensor failure will only propagate to an Error if the sensor is assigned a role in a compensation process. As the sensor network is shared between all RCU10 units in a specific installation, sensor failures may be indicated on every unit (dependent upon allocation).

D.3 RCU CS information screens

RCU CS offers a number of information screens providing a full range of positional and status information. All are accessible by using the toggle buttons in the button bar.

D.3.1 Compensation system screen

This screen (shown in Figure D.1) displays the complete compensation system's status in a simple, clear format. It is accessible by pressing **Compensation** on the button bar.

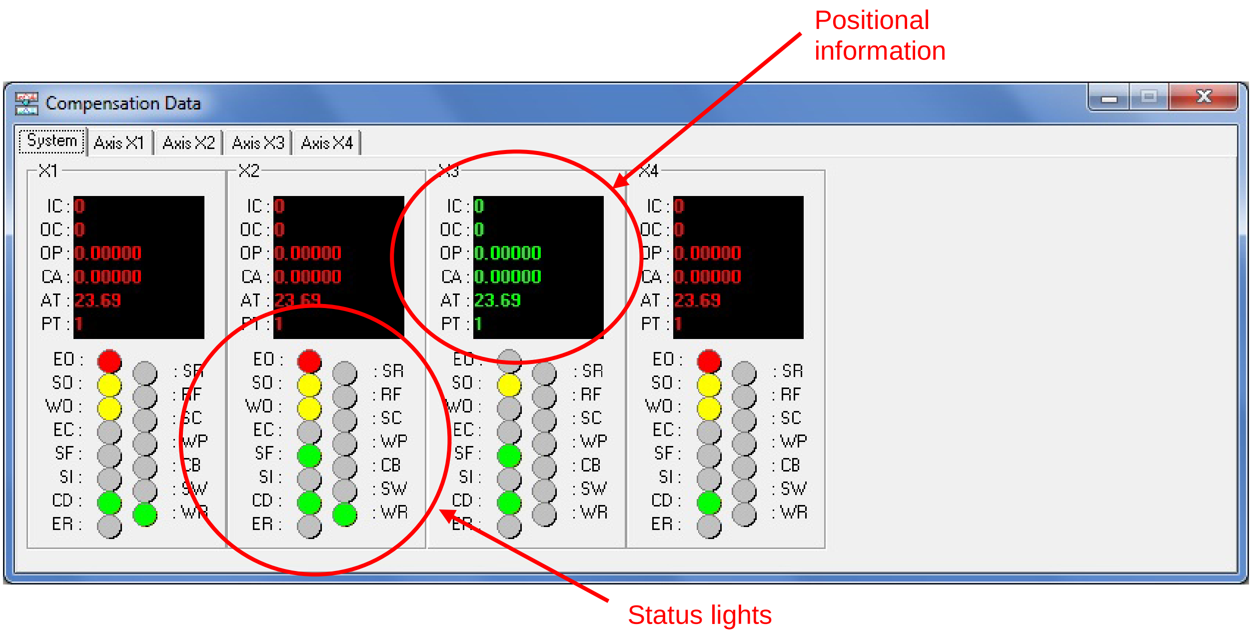


Figure D.1 – Compensation system screen

Table D.1 – Positional information (compensation system screen)

Acronym	Meaning	Description	Displays
IC	Input count	Uncompensated input count from the encoder. Count size depends upon the selected encoder input resolution and amount of movement since referencing the axis.	Single counts
OC	Output count	Fully compensated output count from the RCU10. Count size depends upon the selected output resolution and on movement since the axis was referenced.	Single counts
OP	Output position	Fully compensated output position in mm/inches.	in/mm/m
CA	Compensation applied	Total amount of compensation applied to the system. Sum of the applied encoder, workpiece and structure compensations. Displays in mm/inches.	in/mm/m
AT	Air temperature	Air temperature reading of the sensor assigned to that axis for refractive index compensation. When linear encoders selected, value is greyed out and shows default value of 20 °C or 68 °F.	°C/°F
PT	Parameter table	Selected parameter table.	Integer 1-4

Table D.2 – Status lights (compensation system screen)

Acronym	Meaning	States	Description/cause	Corrective action (if necessary)
EO	Error out	OFF	Axis is functioning without error.	None required.
		RED	Axis has registered an error.	Refer to other status light to identify cause.
SO	Suspend out	OFF	**Suspend** line is inactive (high) on the Auxiliary I/O connector. Axis is in a normal operational state.	None required.
		AMBER	**Suspend** line is active (low) on the Auxiliary I/O connector. This may be due to a number of factors: The axis has not been referenced. A compensation algorithm has failed. A positional count is being injected.	 Change the state of the compensator by referencing the axis. Check compensation process for errors or sensor errors in Diagnostics window. Wait for positional counts to be injected.
WO	Warning out	OFF	**Warning** line is inactive (high) on the Auxiliary I/O connector. Axis is in a normal operational state.	None required.
		AMBER	**Warning** line is active (low) on the Auxiliary I/O connector.	Check compensation process for errors or sensor errors in Diagnostics window.
EC	Encoder compensation	OFF	Axis is not applying refractive index or linear encoder compensation to the output count.	Reference axis to activate compensation. Check configuration to ensure that compensation algorithm has been selected.
		GREEN	Refractive index or linear encoder compensation is being applied to correct the output count.	None required.
SF	Sensor update freeze (workpiece)	OFF	**Workpiece comp temperature freeze** line is inactive (high) on the Auxiliary I/O connector. Workpiece temperature sensor will update in real time.	Freeze sensor reading if required by taking **Workpiece comp temperature freeze** line active (low) on Auxiliary I/O connector.
		GREEN	**Workpiece comp temperature freeze** line is active (low) on the Auxiliary I/O connector. Workpiece temperature sensor has been frozen at a fixed temperature.	Unfreeze sensor when required by taking **Workpiece comp temperature freeze** line inactive (high) on Auxiliary I/O connector.

Table D.2 – Status lights (compensation system screen) *continued*

Acronym	Meaning	States	Description/cause	Corrective action (if necessary)
SI	Slow injection rate	OFF	Axis is in a normal operational state. (Axis may or may not be applying compensation.)	None required.
		AMBER	Axis is currently injecting pulses to recover from a change of compensation state, e.g. deactivation of workpiece compensation at a distance down the axis.	Wait for injection process to complete by monitoring the suspend line.
CD	Compensation disabled	OFF	Refractive index or linear encoder compensation is being applied to correct the output count.	None required.
		GREEN	Axis is not applying refractive index or linear encoder compensation to the output count.	Reference axis. Check for compensation failure errors in diagnostics window.
ER	Error clear	OFF	**Reset** line is inactive (high) on the Auxiliary I/O connector. Errors will latch.	Take **Reset** line active (low) on the Auxiliary I/O connector.
		GREEN	**Reset** line is active (low) on the Auxiliary I/O connector. Errors will register in error log and on error line for one second before auto resetting.	Take **Reset** line inactive (high) on Auxiliary I/O connector, (if using, basic or extended operation). No action required if the line is tied low.
SR	Seek reference	OFF	**Seek reference** line on the Auxiliary I/O connector is inactive (high). Axis is in a normal operational state.	Take **Seek reference** line on Auxiliary I/O connector active (low) to enter seek reference state.
		GREEN	**Seek reference** line on the Auxiliary I/O connector is active (low). Axis is in seek reference state and is waiting for a reference mark signal from either the encoder or RCU reference mark port.	Take **Seek reference** line high after referencing is completed (see RF light) to return to a normal operational state.
RF	Referenced	OFF	Axis is not referenced.	Machine will operate but RCU10 will not apply compensation.
		GREEN	Axis is referenced.	None required.
SC	Structure compensation	OFF	Structure compensation is disabled.	If this function is required then activate compensation in axis configuration by ticking the check box for structure compensation on the **Axis** tab. Add an expansion offset value and an expansion coefficient to the parameter table settings.
		GREEN	Structure compensation is enabled.	None required.

Table D.2 – Status lights (compensation system screen) *continued*

Acronym	Meaning	States	Description/cause	Corrective action (if necessary)
WP	Workpiece compensation	OFF	Workpiece compensation is not being applied.	Activate compensation by moving the machine to the point of origin of structure expansion and taking the **Workpiece compensation enable** line on the Auxiliary I/O connector active (low).
		GREEN	Workpiece compensation is being applied.	Deactivate by taking the **Workpiece compensation enable** line on the Auxiliary I/O connector not active (high).
CB	Compensation buffering	OFF	**Compensation Buffer Enable** line on the Auxiliary I/O connector is inactive (high). Compensation buffering is disabled.	To activate take **Compensation Buffer Enable** line active (low) on the Auxiliary I/O connector.
		AMBER	**Compensation Buffer Enable** line on the Auxiliary I/O connector is active (low). Compensation buffering is enabled	To deactivate take **Compensation Buffer Enable** line inactive (high) on the Auxiliary I/O connector.
SW	Seek workpiece reference	OFF	Either the Material reference has already been established or Material compensation is not selected in system configuration	None required.
		GREEN	The machine has already passed the reference mark switch (or expansion origin if they are different) and is waiting for the command from the controller to activate the **Workpiece compensation**. It is possible to offset the **Workpiece compensation** origin from the reference mark point by typing an offset distance into the RCU CS parameter table.	Send command to activate **Workpiece compensation**.
WR	Workpiece compensation request	OFF	**Workpiece compensation enable** line on the Auxiliary I/O connector is inactive (high).	Activate the **Workpiece compensation enable** line on the Auxiliary I/O connector (active low).
		GREEN	**Workpiece compensation enable** line on the Auxiliary I/O connector is active (low).	None required.

D.3.2 Compensation axis screen

This screen (shown in Figure D.2) is the individual axis tab from the complete compensation status display. It displays the same information as the system compensation screen, but in a clearer manner. It is accessible by pressing **Compensation** on the button bar and then selecting the desired axis from the tabs at the top.

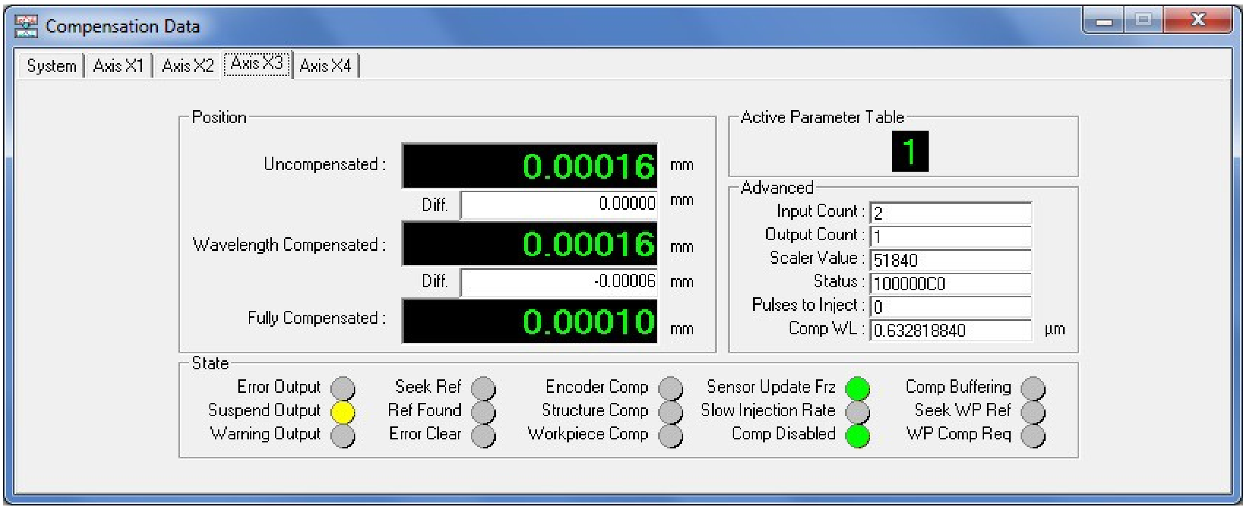


Figure D.2 – Compensation axis screen

Table D.3 – Position box (compensation axis screen)

Display	Description	Displays
Uncompensated	Encoder input position without any compensation.	in/mm/m
Diff. (top)	Difference between uncompensated position and wavelength compensated position.	in/mm/m
Wavelength Compensated	Axis position with air refractive index compensation applied. (Greyed out in encoder compensation mode.)	in/mm/m
Diff. (bottom)	Difference between wavelength compensated and fully compensated position.	in/mm/m
Fully Compensated	Axis position with all selected compensation applied.	in/mm/m

Table D.4 – Advanced box (compensation axis screen)

Display	Description	Displays
Input Count	Encoder input position without any compensation.	Single counts
Output Count	Axis position with all selected compensation applied.	Single counts
Scaler Value	Scale coefficient used in compensation equations. Value dependent upon axis configuration.	Integer
Status	Status word for diagnostic use.	32-bit hex word
Pulses to Inject	Pulses left to inject into the output count.	Single counts
Comp WL	Refractive index compensated laser wavelength. (Greyed out in encoder compensation mode.)	Microns

Table D.5 – Active parameter table box (compensation axis screen)

Meaning	Description	Displays
Parameter table	Selected parameter table currently in use.	Integer 1-4

Table D.6 – State box (compensation axis screen)

Acronym	Meaning	States	Description/cause	Corrective action (if necessary)
The lights in the State box are duplicates of the status lights on the compensation system screen (see Table D.2).				

D.3.3 Sensor data screen

This screen (shown in Figure D.3) displays all the real-time status and data information from the sensor network. It offers an overview of the entire sensor network as well as offering individual sensor status information. It is accessible by pressing **Sensors** on the button bar.

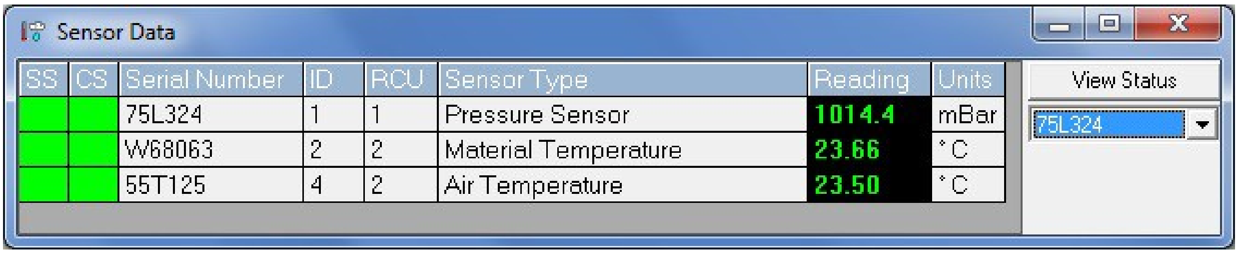


Figure D.3 – Sensor data screen

Table D.7 – Sensor data screen status information

Acronym	Meaning	State	Description	Corrective actions
SS	Sensor status (how the sensor reports its own operational status).	GREEN	Fully functional.	None required.
		RED	Sensor is faulty.	Select sensor serial number from drop-down list and click on **View Status** to check the individual sensor for a possible cause.
CS	Compensator status (how the compensator reports the sensor's operational status).	GREEN	Fully functional.	None required.
		RED	Sensor is faulty.	Select sensor serial number from drop-down list and click on **View Status** to check the individual sensor for a possible cause.

Table D.8 – Sensor data screen sensor information

Field	Meaning	Description	Displays
Serial Number	Sensor serial number	Unique number on the sensor body and input into the system during configuration. Required for communication purposes.	Serial number
ID	Sensor identification number	The unique number the system has allocated to the sensor for communication purposes.	Integer 1-32
RCU	RCU connection	The RCU unit that the sensor is physically connected to.	Integer 1-6
Sensor Type	Sensor type	One of three variants – air temperature sensor, material temperature sensor and air pressure sensor.	Text
Reading	Sensor reading	Current sensor reading.	°C / °F
Units	Display units	Selected display units - Temperature	°C / °F
		Selected display units - Pressure	mBar / “Hg

D.3.3.1 Individual “View status” screen

This screen will display error and warning conditions for an individual sensor. It is accessible by selecting the required sensor from the drop-down list on the sensor data screen, and then pressing **View Status**.

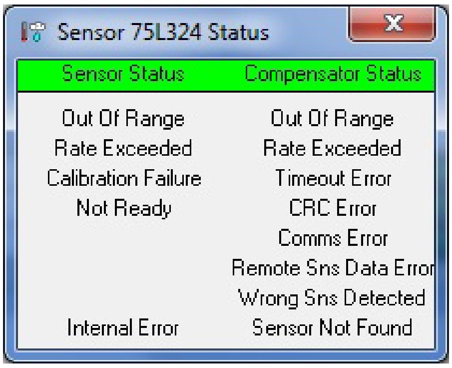


Figure D.4 – Individual sensor status display

Table D.9 – Sensor status errors/warnings

Error	State	Description	Corrective action (if necessary)
Out Of Range	OFF	Sensor is operating within its normal range of operation.	None required.
	RED	Sensor is reading outside its normal operating range. Sensor failure.	Move sensor to a more suitable environment. Replace sensor.
Rate Exceeded	OFF	Sensor is operating within its normal rate of change.	None required.
	RED	Sensor is changing value at a quicker rate than its normal setting. Sensor failure.	Move sensor to a more suitable environment. Replace sensor
Calibration Failure	OFF	Sensor is operating within its calibrated specification.	None required.
	RED	Sensor data is out of calibration.	Return sensor to Renishaw for recalibration.
Not Ready	OFF	Sensor is operating normally.	None required.
	RED	Sensor's operational accuracy is not ready. Sensor is still initialising.	Wait for sensor to finish initialising procedure. Disconnect sensor, wait a few seconds, and then reconnect sensor.
Internal Error	OFF	Sensor is operating without error. Sensor is operating with any number of the above errors present (non-conflicting).	None required. Check other sensor status error conditions.
	RED	More than one of the above errors occurring simultaneously are conflicting. Sensor failure.	Check other sensor status error conditions. Replace sensor

NOTE: Sensor Status and **Compensator Status** titles will display with a red or green background depending upon whether an error/warning has been indicated.

Table D.10 – Compensator status errors/warnings

Error	State	Description	Corrective action (if necessary)
Out Of Range	OFF	Compensator is receiving data within the configured range of operation.	None required.
	RED	Compensator is receiving a value outside the configured range of operation.	Change configured limit values on Sensors tab in compensator configuration.
Rate Exceeded	OFF	Compensator is receiving data that is changing within the configured rate of change limits.	None required.
	RED	Compensator is receiving data that is changing outside the configured rate of change limits.	Change configured rate of change values on Sensors tab in compensator configuration.
Timeout Error	OFF	Compensator is receiving data within the specified communications timeout limit.	None required.
	RED	Sensor did not reply within a specified time.	Check sensor is connected correctly. Check sensor is configured correctly. Check sensor is wired correctly. Replace sensor.
CRC Error	OFF	Compensator is receiving data correctly.	None required.
	RED	Cyclic Redundancy Code error. Data integrity check failed on sensor bus.	Check sensor is connected correctly. Check sensor is configured correctly. Check sensor is wired correctly. Replace sensor.
Comms Error	OFF	Compensator is communicating with the sensor correctly.	None required.
	RED	Communications error. Parity, overrun or framing error.	Check sensor is connected correctly. Check sensor is configured correctly. Check sensor is wired correctly. Replace sensor.
Remote Sns Data Error	OFF	Compensator is receiving data correctly from a remotely connected sensor.	None required.
	RED	Remote sensor data error. Sensor data corrupted when transferred across the network.	Check fast serial link cables are connected correctly. Check sensor is connected correctly. Check sensor is configured correctly. Check sensor is wired correctly. Replace sensor.
Wrong Sns Detected	OFF	Compensator is communicating with the correct sensor.	None required.
	RED	Wrong sensor detected. A sensor with a different serial number replied.	Check sensor is connected correctly. Check sensor is configured correctly. Check sensor is wired correctly. Replace sensor.
Sensor Not Found	OFF	Compensator is communicating with sensor without error. Compensator is communicating with sensor with any number of the above errors present (non-conflicting).	None required. Check other compensator status error conditions.
	RED	Sensor not responding. Sensor failure.	Check sensor is connected correctly. Check sensor is configured correctly. Check sensor is wired correctly. Replace sensor.

D.3.4 Diagnostics

These screens display all the various axis-specific errors that a system may be displaying. They may all be accessed from the System status screen that is available by pressing the **Diagnostics** button on the button bar.

D.3.4.1 System status screen

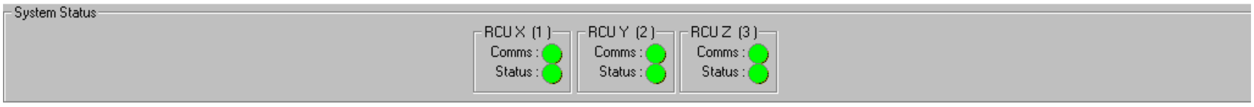


Figure D.5 – System status screen

Table D.11 – System status screen (diagnostics)

Error	State	Description	Corrective actions (if necessary)
Comms	GREEN	Axis is communicating correctly with other compensators.	None required.
	RED	RCU communication error	As there are no communications, relevant data cannot be displayed. Check network communications and connections.
Status	GREEN	Axis is operating correctly	None required.
	AMBER	RCU status WARNING asserted.	See individual axis diagnostics screen for cause. Double-click axis name to bring up individual axis diagnostic screen.
	RED	RCU status ERROR asserted	See individual axis diagnostics screen for cause. Double-click axis name to bring up individual axis diagnostic screen.

In order to access the extended diagnostics functions of each individual axis, the user may double-click the **Axis name** to reveal the **Diagnostics** screen.

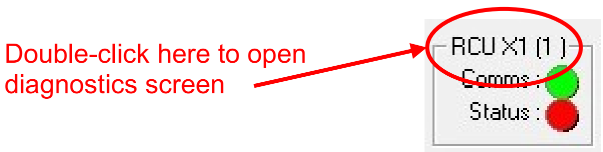


Figure D.6 – Individual axis status

D.3.4.2 RCU diagnostics screen (top display)

At the top of the axis diagnostics screen is a range of information that is available across all the diagnostics tabs. In general, it provides a basic overview of the system and its functionality.

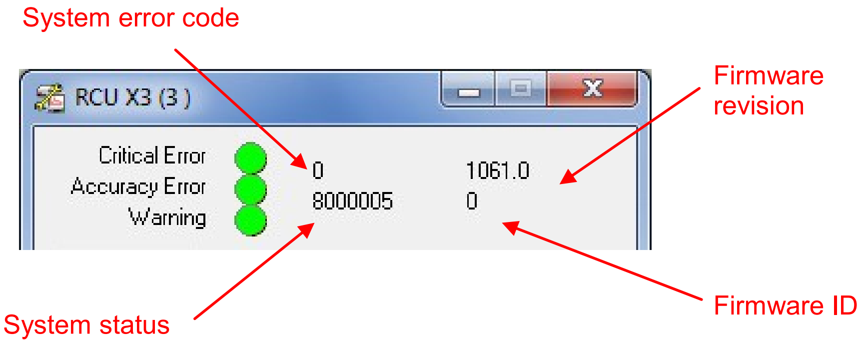


Figure D.7 – Axis diagnostics screen (top display)

Table D.12 – RCU diagnostics screen (errors)

Error	State	Description	Corrective action
Critical Error	GREEN	Axis is functioning without an error state being asserted.	None required.
	RED	Axis is in **Error** state. **Error** output line on Auxiliary I/O connector is asserted.	Check individual tabs in axis diagnostics screen to locate cause.
Accuracy Error	GREEN	Axis is functioning without a warning state asserted.	None required.
	AMBER	Axis is in a **Warning** state. **Warning** output line on Auxiliary I/O connector is asserted (or **Error** in simple error reporting mode).	Check individual tabs in axis diagnostics screen to locate cause.
Warning	GREEN	Axis is functioning without a suspend state asserted.	None required.
	AMBER	Axis is in a **Suspend** state. **Suspend** output line on Auxiliary I/O connector is asserted (or **Error** in simple error reporting mode).	Check individual tabs in axis diagnostics screen to locate cause.

Table D.13 – RCU diagnostics screen (information)

Information	Description
System error code	32-bit hex code describing system errors and warnings.
System status	32-bit hex code describing system status.
Firmware revision	Revision/release number of the firmware module in use.
Firmware ID	Hex identification bit of the firmware module in use: 0 = combined laser/scale compensation module or laser only 1 = scale compensation only module 2–7 = Not currently used, reserved for future released compensation modules F = configuration module

D.3.4.3 RCU diagnostics – Configuration tab

This screen details most of the functional, configuration and start-up errors that can occur inside the RCU10.

NOTE: In the following tables, System Reset refers to a power cycle of the RCU10 unit. This enables the unit to start up again, perform all functional self-check tests and load the compensation modules again.

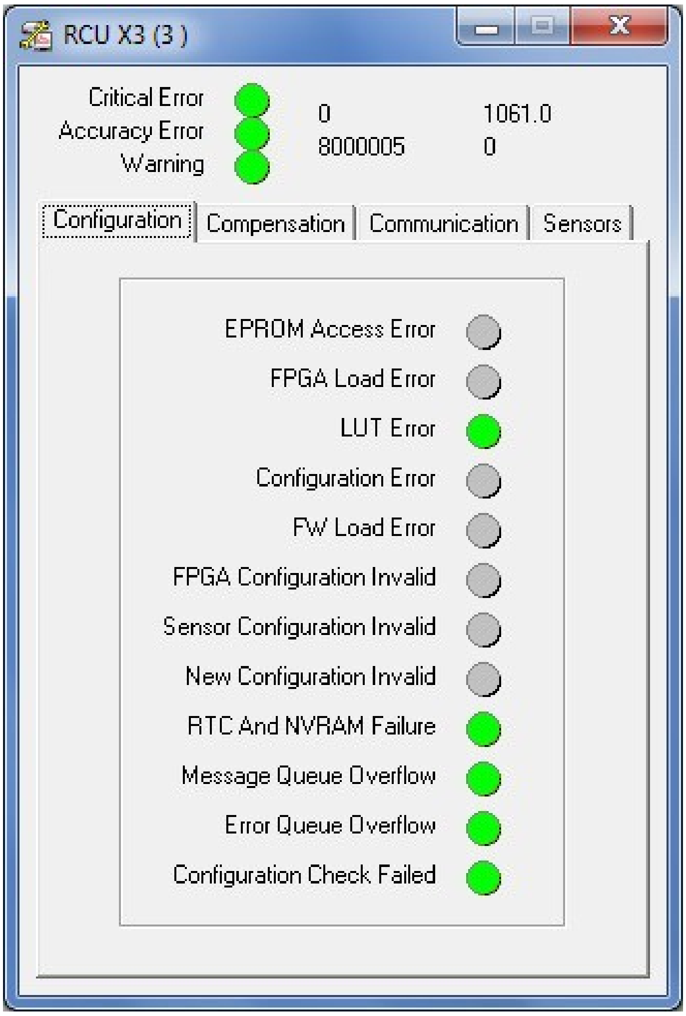


Figure D.8 – Axis diagnostics Configuration tab (Compensation mode)

Table D.14 – Axis diagnostics (Configuration tab)

Error	Description	Configuration mode	Compensation mode	
			Advanced	Simple
EPROM Access Error	Erasable Programmable Read Only Memory access error. EPROM write/erase/ read operation failed.	**ERROR** Assert **Reset** line on Auxiliary I/O connector.	—	—
FPGA Load Error	Field Programmable Gate Array load error. FPGA code corrupted or FPGA load failed.	**SYSTEM ERROR** System Reset. Contact Renishaw.	—	—
LUT Error	Look Up Table error. LUT data corrupted, LUT load failed or LUT incorrect.	**SYSTEM ERROR** System Reset. Contact Renishaw.	**ERROR** System Reset.	
Configuration Error	Axis configuration error. Configuration data inconsistent.	**SYSTEM ERROR** Check configuration and re-send to unit.	—	—
FW Load Error	Firmware load error. Compensation module load failure.	**SYSTEM ERROR** System Reset. Contact Renishaw.	—	—
FPGA Configuration Invalid	Field Programmable Gate Array configuration invalid. Configuration data targeted at FPGA is invalid.	**SYSTEM ERROR** System Reset. Check configuration and re-send to unit.	—	—
Sensor Configuration Invalid	Sensor configuration is invalid. Configuration data targeted at one or more sensor(s) is invalid.	**SYSTEM ERROR** System Reset. Check configuration and re-send to unit.	—	—
New Configuration Invalid	New configuration loaded is invalid. Newly specified configuration integrity check failed.	**ERROR** Assert **Reset** line on Auxiliary I/O connector. Check configuration and re-send to unit.	—	—
RTC and NVRAM Failure	Real Time Clock and Non-Volatile Random Access Memory failure. Battery low. NVRAM contents lost.	**SYSTEM ERROR** Contact Renishaw	**WARNING** Contact Renishaw	
Message Queue Overflow	Too many event messages. RCU10 state machine damaged. Internal diagnostics function.	**SYSTEM ERROR** System Reset.		
Error Queue Overflow	Too many errors. RCU10 error tracking is damaged. Internal diagnostics function.	**SYSTEM ERROR** System Reset.		
Configuration check failed	For safety reasons two copies of the system configuration file are held within the RCU10. Periodically these files are compared to check that they are identical.	Not applicable	**ERROR**	

D.3.4.4 Axis diagnostics – Compensation tab

This screen details the errors that can occur to prevent the RCU10 compensating correctly.

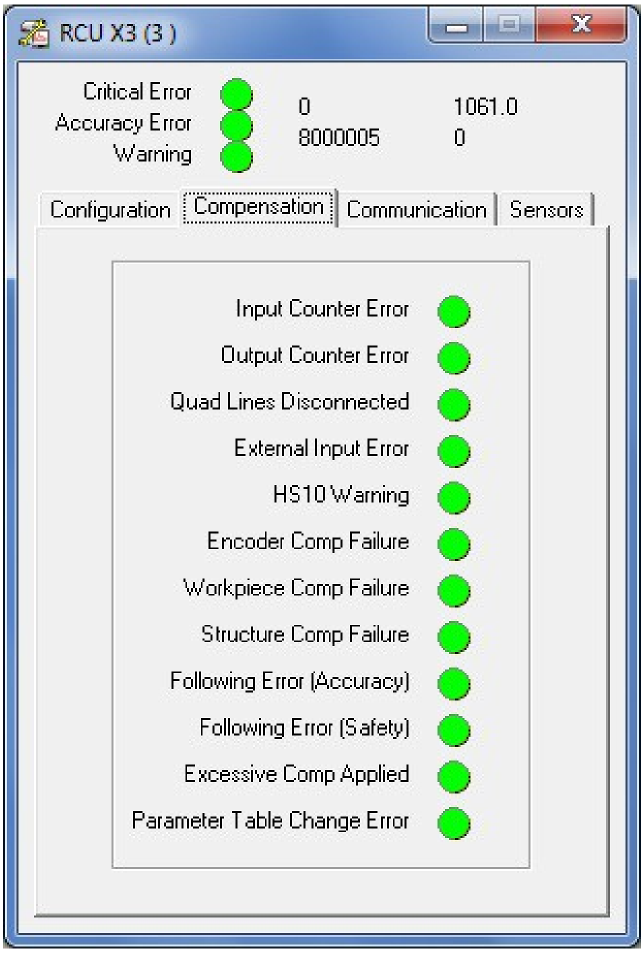


Figure D.9 – Axis diagnostics Compensation tab (Compensation mode)

Table D.15 – Axis diagnostics (Compensation tab)

Error	Description	Configuration mode	Compensation mode: Advanced	Compensation mode: Simple
Input Counter Error	Coincidence of edges on A and B quadrature indicating an overspeed condition on the input counter.	**WARNING**	**ERROR**	
		Check encoder connector.	Check encoder connector. Assert **Reset** line on Auxiliary I/O connector. Re-reference axis.	
Output Counter Error	Coincidence of edges on A and B quadrature indicating an overspeed condition on the output counter.	**WARNING**	**ERROR**	
			Assert **Reset** line on Auxiliary I/O connector. Re-reference axis.	
Quad Lines Disconnected	Axis input quadrature lines are disconnected.	**WARNING**	**ERROR**	
		Check encoder connector.	Check encoder connector. Assert **Reset** line on Auxiliary I/O connector.	
External Input Error	The encoder is producing an error. This also freezes the compensation process/internal counters.	**WARNING**	**ERROR**	
			Assert **Reset** line on Auxiliary I/O connector. Re-reference axis.	
HS10 / HS20 Warning	HS10 laser head warning line active.	**WARNING**		
		Check HS10 for stability and signal strength.		
Encoder Comp Failure	Encoder compensation algorithm failure. A sensor allocated to this process has failed or is in error.	—	**SUSPEND**	**ERROR**
			Check **Sensors** diagnostic tab for errors. Check **Sensors** screen for errors.	Assert **Reset** line on Auxiliary I/O connector.
Workpiece Comp Failure	Workpiece compensation algorithm failure. A sensor allocated to this process has failed or is in error.	—	**SUSPEND**	**ERROR**
			Check **Sensors** diagnostic tab for errors. Check **Sensors** screen for errors.	Assert **Reset** line on Auxiliary I/O connector.
Structure Comp Failure	Structure compensation algorithm failure. A sensor allocated to this process has failed or is in error.	—	**SUSPEND**	**ERROR**
			Check **Sensors** diagnostic tab for errors. Check **Sensors** screen for errors.	Assert **Reset** line on Auxiliary I/O connector.
Following Error (Accuracy)	The accuracy following error limit has been exceeded.	—	**WARNING**	
			Wait for Warning to disappear to achieve full accuracy	
Following Error (Safety)	The safety following error limit (8.192 mm) has been exceeded. Indicates that the compensation buffer limit has been exceeded if compensation buffering is active.	—	**ERROR**	
			Assert **Reset** line on Auxiliary I/O connector.	
Excessive Comp Applied	More than 25 mm of compensation has been requested by the RCU10.	—	**ERROR**	
			Assert **Reset** line on Auxiliary I/O connector.	
Parameter Table Change Error	An undefined parameter set has been selected for use in the compensation process.	—	**SUSPEND**	**ERROR**
			Re-reference axis.	Assert **Reset** line on Auxiliary I/O connector. Re-reference axis.

D.3.4.5 Axis diagnostics – Communication tab

This screen details the systems communication status. This may be the sensor communications, RCU10 network communications or PC communications.

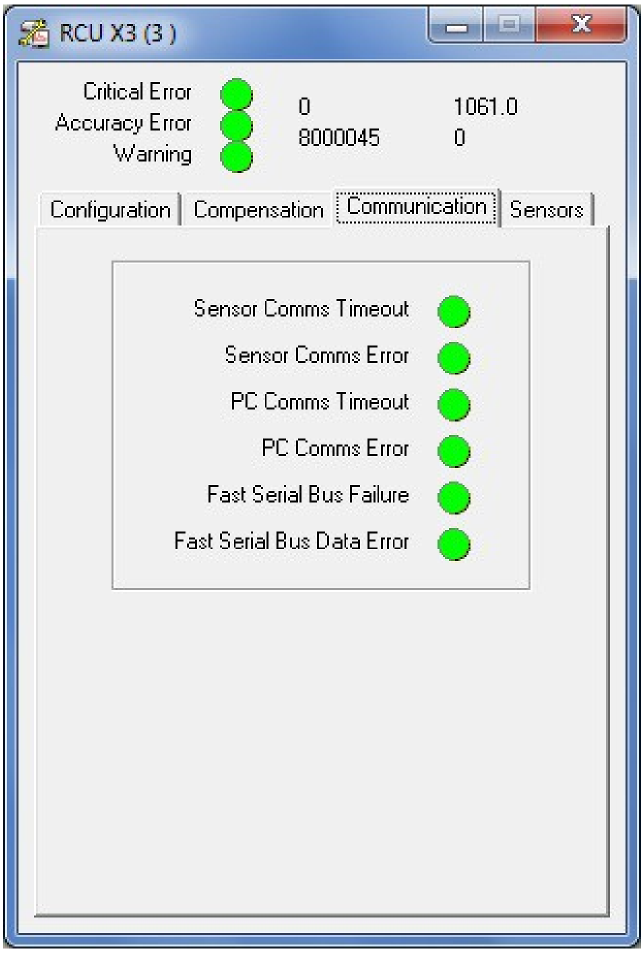


Figure D.10 – Axis diagnostics Communication tab

Table D.16 – Axis diagnostics (Communication tab)

<table>
<tr><th rowspan="2">Error</th><th rowspan="2">Description</th><th rowspan="2">Configuration mode</th><th colspan="2">Compensation mode</th></tr>
<tr><th>Advanced</th><th>Simple</th></tr>
<tr><td rowspan="2">Sensor Comms Timeout</td><td rowspan="2">No reply from a sensor. One or more sensors timed out.</td><td colspan="2">WARNING</td><td>ERROR</td></tr>
<tr><td colspan="3">Check sensor connections.
Check Sensor screen for errors.
Check individual sensor errors.</td></tr>
<tr><td rowspan="2">Sensor Comms Error</td><td rowspan="2">Sensor communications error. Framing, over run, parity or UART IC error.</td><td>WARNING</td><td>SUSPEND</td><td>ERROR</td></tr>
<tr><td colspan="3">Check sensor connections.
Check Sensor screen for errors.
Check individual sensor errors.
Assert Reset line on Auxiliary I/O connector (Error condition only).</td></tr>
<tr><td rowspan="2">PC Comms Timeout</td><td rowspan="2">Communication from PC interrupted.</td><td colspan="3">WARNING</td></tr>
<tr><td colspan="3">Check connection to PC.</td></tr>
<tr><td rowspan="2">PC Comms Error</td><td rowspan="2">Personal Computer communications error. Framing, over run, parity or UART IC error.</td><td colspan="3">WARNING</td></tr>
<tr><td colspan="3">Check connection to PC.</td></tr>
<tr><td rowspan="2">Fast Serial Bus Failure</td><td rowspan="2">Unrecoverable network error. No master connected. Includes timeout errors.</td><td colspan="3">SYSTEM ERROR</td></tr>
<tr><td colspan="3">System Reset.</td></tr>
<tr><td rowspan="2">Fast Serial Bus Data Error</td><td rowspan="2">Data corruption on sensor information passed over fastlink.</td><td colspan="3">ERROR</td></tr>
<tr><td colspan="3">Assert Reset line on Auxiliary I/O connector.</td></tr>
</table>

D.3.4.6 Axis diagnostics – Sensors tab

Compensation mode

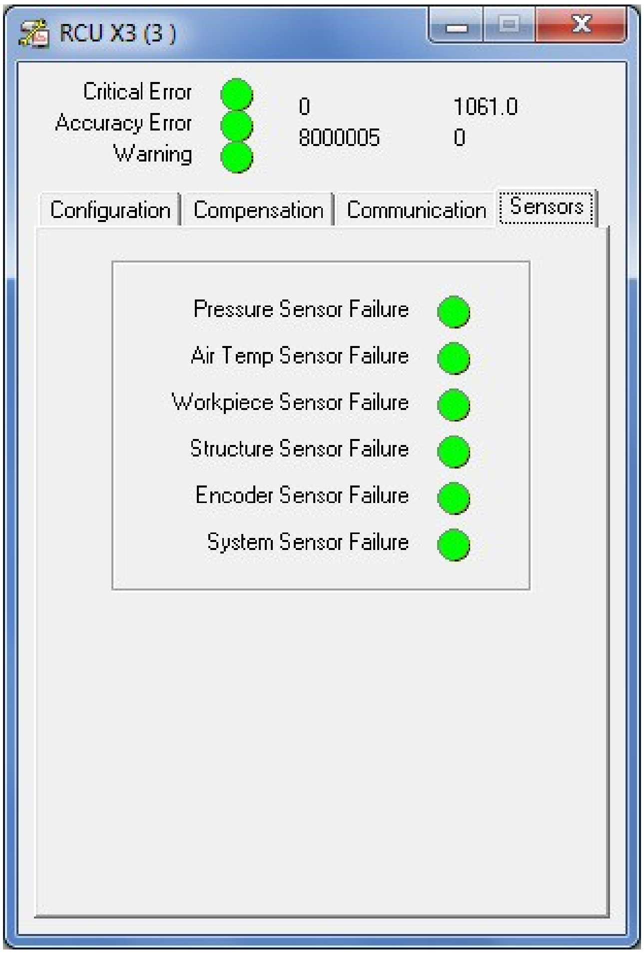


Figure D.11 – Axis diagnostics Sensors tab

Table D.17 – Axis diagnostics (Sensors tab)

Error	Description	Configuration mode	Compensation mode	
			Advanced	Simple
Pressure Sensor Failure	Allocated pressure sensor has failed.	**WARNING**	**SUSPEND**	**ERROR**
		Check sensor connections. Check **Sensor** screen for errors. Check individual sensor errors. Assert **Reset** line on Auxiliary I/O connector (Error condition only).		
Air Temp Sensor Failure	Allocated air temperature sensor has failed.	**WARNING**	**SUSPEND**	**ERROR**
		Check sensor connections. Check **Sensor** screen for errors. Check individual sensor errors. Assert Reset line on Auxiliary I/O connector (Error condition only).		
Workpiece Sensor Failure	Allocated material temperature sensor has failed.	**WARNING**	**SUSPEND**	**ERROR**
		Check sensor connections. Check **Sensor** screen for errors. Check individual sensor errors. Assert **Reset** line on Auxiliary I/O connector (Error condition only).		
Structure Sensor Failure	Allocated material temperature sensor has failed.	**WARNING**	**SUSPEND**	**ERROR**
		Check sensor connections. Check **Sensor** screen for errors. Check individual sensor errors. Assert **Reset** line on Auxiliary I/O connector (Error condition only).		
Encoder Sensor Failure	Allocated material temperature sensor has failed.	**WARNING**	**SUSPEND**	**ERROR**
		Check sensor connections. Check **Sensor** screen for errors. Check individual sensor errors. Assert **Reset** line on Auxiliary I/O connector (Error condition only).		
System Sensor Failure	Sensor connected to but not used by RCU unit under interrogation has failed.	**WARNING**	**WARNING**	**WARNING**
		Check sensor connections. Check **Sensor** screen for errors. Check individual sensor errors. Assert **Reset** line on Auxiliary I/O connector (Error condition only).		

Note: If mode is simple, any rate of change errors are treated as a warning.

Appendix E

Commissioning tests

Contained in this appendix

E.1 System performance testing

There are a number of calibration tests that may be performed on the installed RCU10 compensation system. Not all tests will be required, depending upon the configuration of the installation and the functions being used. The majority of tests are designed to test the operation of workpiece thermal compensation.

NOTE: These tests are designed to confirm the operation and accuracy of the encoder and RCU10 quadrature compensation system, NOT the machine as a whole.

E.1.1 Prerequisites

The following equipment is required to carry out the tests:

- Desktop or laptop PC installed with LaserXL and RCU CS software.
- Renishaw XL-80 calibration laser. (If a gantry axis with two independent scales is being measured, then two XL-80s are desirable to obtain simultaneous measurements, but not essential.)
- Renishaw linear optics kit. (If measuring an axis over 30 m in length, then the long-range linear optics kit is required.)
- Renishaw XC-80 environmental compensation unit.
- Renishaw XC-80 air temperature sensor.
- Renishaw XC-80 material temperature sensor.

Each set of tests should be conducted for each axis before moving on to the next axis. This will allow multiple tests to be conducted for one optical set-up. Before commencing testing, ensure that the following has been carried out:

- Connect an XC-80 unit to the XL-80 to compensate for measurement errors due to environmental effects.
- Connect the XC-80 air temperature sensor to the XC-80 system. This must be mounted close to the air sensor for the axis under test. (If tape/glass scale encoders are being used, then the air sensor must be placed close to the material temperature sensor being used to provide encoder compensation for the axis under test.)
- Connect the XC-80 material temperature sensor to the XC-80 system. This must be mounted close to the material temperature sensor being used for workpiece thermal compensation on the axis under test.
- Connect the XL-80/XC-80 system to a desktop or laptop PC with LaserXL software installed.
- Ensure that any error compensation is disabled in the machine controller.

- Start the LaserXL linear measurement software.
- Set up and align the XL-80 on the axis under test.

NOTE: If using laser encoders, it is very important that the XL-80 laser should be aligned close to the optical path of the encoder or through the same optics. If using tape/glass scale encoders, then the XL-80 should be aligned close to the encoder measurement path.

If the XL-80 is aligned with some vertical or horizontal offset from the encoder, then differences between the two readings may be introduced owing to discrepancies in the machine geometry, rather than due to any faults in the RCU10 quadrature compensation system.

E.1.2 Test 1 – Linear compensation (air refractive index or encoder scale compensation)

The first test checks that the air refractive index compensation (or encoder scale compensation) is operating correctly. An XL-80 laser must be used to accurately measure the machine's position and compare it with the compensated position of the machine:

- Set up the XL-80 and XC-80 as described in section E.1.1 on the axis under test.
- Disable any workpiece compensation on the XC-80 by setting the expansion coefficient to zero in the LaserXL software.
- Ensure that the RCU10 controlling the axis under test has been referenced. This will automatically activate air refractive index compensation in the RCU10.
- Move the axis under test to a position near the axis reference position.
- Datum the XL-80 (inputting an offset, if required, to allow the XL-80 and RCU10 to display the same position).
- Ensure that workpiece compensation for the RCU10 is turned off for the axis under test. This may be done by ensuring that the **workpiece compensation line** on the Auxiliary I/O line is taken high by the controller, to make it inactive. Check that the '**WP**' light on the RCU CS compensation window is off for the axis under test.

WARNING: If the machine is at the far end of travel, away from the workpiece reference position, then the machine may move slightly when workpiece compensation line is taken inactive. This is when it injects or removes pulses to establish the correct position. Before taking the control line high, ensure that it is safe to move the machine.

- Move the machine axis under test sequentially to capture data from the XL-80 laser using the Renishaw LaserXL calibration software. Use the recommendations in ISO230-2 for machine calibration. Ensure that up to five runs of data are captured.

- Use the Renishaw XCal-View data analysis software to calculate the accuracy and repeatability of the machine according to ISO230-2.

Under ideal conditions the accuracy should be 2 ppm ± 5 µm (0.0002 in) or better for both HS20 and RLE20. The repeatability should be 2.5 µm (0.0001 in) or better.

NOTE: Analysis should be conducted with a full understanding of additional error sources due to alignment of the XL-80. Errors such as cosine error and Abbé offset error should be approximated and subtracted from any overall system accuracy value obtained from XCal-View.

E.1.3 Test 2 – Workpiece thermal expansion compensation

This is a repeat of test 1, with workpiece compensation enabled on both the RCU10 compensation system and on the XC-80 calibration system. This will test that workpiece thermal compensation is operating correctly.

- Set up the XL-80 and XC-80 as described in section E.1.1 on the axis under test.
- Ensure that the RCU10 controlling the axis under test has been referenced. This will automatically activate air refractive index compensation in the RCU10.
- Move the axis under test to a position near the axis reference position.
- Datum the XL-80 (inputting an offset, if required, to allow the XL-80 and RCU10 to display the same position).
- Open the **Configuration** screen in RCU CS and select the **Parameters** tab. Ensure that a valid value for workpiece expansion compensation has been set in the active parameter table. Make a note of this value for the axis under test (close the display screen afterwards).
- Activate workpiece compensation for the RCU10 by taking the workpiece compensation line on the Auxiliary I/O connector low using the machine controller. Check that the '**WP**' light in the RCU CS **Compensation** screen is on (this indicates a successful activation).
- Activate compensation on the XL-80 laser by setting the expansion coefficient to the same coefficient as set in the compensator unit (noted above).
- Perform the ISO230-2 test as per test 1, noting the accuracy and repeatability figures. This test should be compared against the machine's specification, as this is testing the features of the RCU10 compensation system that are normally used. (If using structure compensation, repeat the test with structure compensation enabled to obtain true operational results.)

NOTE: Analysis should be conducted with a full understanding of additional error sources due to alignment of the XL-80. Errors such as cosine error and Abbé offset error should be approximated and subtracted from any overall system accuracy value obtained from XCal-View.

It is also advisable to test against a set of angular pitch and yaw measurements from the XL-80 system. This can be done using the same laser set-up, but changing the optics used. This comparison will allow the machine builder to understand any additional machine error sources that may contribute to the positional accuracy and repeatability of the RCU10 quadrature compensation system.

E.1.4 Test 3 – Workpiece thermal expansion at higher temperatures

Test 2 was performed at ambient workpiece temperature. It is important to also test the performance of the system at a higher temperature.

Repeat test 2, but raise the temperature of both the RCU10 material temperature sensor and the XC-80 material temperature sensor artificially to a constant temperature.

Repeat the ISO230-2 accuracy check as previously outlined. The accuracy and repeatability figures should be unchanged from test 2.

NOTE: The XL-80 calibration laser is being compensated at the higher temperature in order to track the performance of the compensator unit at this higher temperature. The response times of the XC-80 and RCU10 material sensors are not the same, so it is important to maintain as constant a temperature as possible throughout the testing period so that performance differences do not introduce additional errors.

E.1.5 Test 4 – Workpiece temperature change at material reference position

This is a static test intended to ensure that no workpiece thermal compensation is applied at the reference (expansion origin) position in response to a change in workpiece temperature:

- Place the workpiece material temperature sensors on a suitable, ambient temperature substrate. Allow the sensors to settle to ambient temperature fully.
- Set up the XL-80 and XC-80 as described in section E.1.1 on the axis under test.
- Disable any workpiece compensation on the XC-80 by setting the expansion coefficient to zero in the LaserXL software.

- Move the axis under test to the workpiece reference position. At this position, the workpiece offset is zero. Any changes in workpiece temperature should have no effect at all on the position of the axis under test.
- Activate workpiece compensation for the RCU10 by taking the workpiece compensation line on the Auxiliary I/O connector low using the machine controller. Check that the ‘**WP**’ light in the RCU CS **Compensation** screen is on (this indicates a successful activation).
- Datum the XL-80 (inputting an offset, if required, to allow the XL-80 and RCU10 to display the same position).
- Artificially elevate the RCU10 material temperature sensor allocated to workpiece thermal compensation. Allow the system to stabilise at the higher temperature. Throughout the test, monitor the XL-80 reading. As the temperature changes, there should be no change in the axis position, as indicated by the XL-80 reading.
- Remove the sensor from the artificial heat source and allow it to return to ambient temperature. Throughout the test, monitor the XL-80 reading. As the temperature changes, there should be no change in the axis position, as indicated by the XL-80 reading.

E.1.6 Test 5 – Static workpiece temperature change at distance

This is a static test intended to ensure that workpiece thermal compensation is applied at a position away from the expansion origin position.

- Place the workpiece material temperature sensors on a suitable, ambient temperature substrate. Allow the sensors to settle to ambient temperature fully.
- Set up the XL-80 and XC-80 as described in section E.1.1 on the axis under test.
- Disable any workpiece compensation on the XC-80 by setting the expansion coefficient to zero in the LaserXL software.
- Activate workpiece compensation for the RCU10 by taking the workpiece compensation line on the Auxiliary I/O connector low using the machine controller. Check that the ‘**WP**’ light in the RCU CS **Compensation** screen is on (this indicates a successful activation).
- Move the machine to the workpiece reference position.
- Move the machine to a position away from the workpiece reference position, near the end of axis travel.
- Datum the XL-80 (inputting an offset, if required, to allow the XL-80 and RCU10 to display the same position).

- Artificially elevate the RCU10 material temperature sensor allocated to workpiece thermal compensation. Allow the system to stabilise at the higher temperature. Throughout the test, monitor the XL-80 reading. As the temperature changes, the XL-80 reading will be observed to change as compensation is applied.

- Check that the change in the axis position is of the order of magnitude expected using the XL-80.

NOTE: During this test, the RCU10 quadrature compensation system will provide correction to the controller. The machine will move physically to compensate for the temperature change. This change in position will not be reflected in the machine position in the controller, but can be observed with the calibration laser (with workpiece compensation disabled).

To calculate the movement, use the following formula:

Distance = distance from workpiece reference X change in temperature X EC

(where EC = expansion coefficient).

Example:

With an offset of 2500 mm, a coefficient of expansion of 20 ppm/°C and a temperature rise of 2 °C, the machine will move by 100 µm. (In imperial, with an offset of 100 in, an expansion coefficient of 11.11 ppm/°F and a temperature change of 4 °F, the machine will move by 0.00444 in.)

- Record the workpiece temperature and the machine position at a number of different points over a temperature range of around 7 °C.

- Plot this data on to a graph of position against temperature. Check that the slope of the data equates to the expected slope calculated from the expansion coefficient.

Example:

If the expansion coefficient is 20 ppm/°C and the offset is 2500 mm, then the growth rate should be 50 µm per °C (slope of the graph). (In imperial, if the offset is 100 in and the expansion coefficient is 11.11 ppm/°F, then the growth rate is 0.001111 in per °F [slope of the graph].)

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Appendix F

Extended capability

Contained in this appendix

F.1 Extended RCU10 system capability

F.1.1 Extended system capability

The RCU10 system includes a number of features that enable the basic performance of the system (detailed in section 1) to be extended. These optional features include:

- Extended system status monitoring capability through three output lines (per axis).
- Ability to control the material compensation feature through a combination of input lines to the RCU10 compensator.
- Parameter tables that enable the user to have up to four different sets of compensation parameters. These parameter tables are selected through two input lines to the RCU10 system.

Full details of each of these features are provided in this appendix.

F.1.2 Extended system status monitoring

The RCU10 is capable of two different modes of operation with respect to error-handling.

In the simple mode, all errors are indicated by monitoring the **Error** output line.

There is also an extended mode of error-handling (termed Advanced) which allows a greater level of monitoring of the RCU10 status by the machine control. When the extended mode is selected, two lines are available in addition to the standard **Error** line; these are **Warning** and **Suspend**.

WARNING: When the Error line signal is asserted on any axis, the machine control MUST deactivate the entire machine.

F.1.2.1 Extended status monitoring

Extended error line outputs

When the system is configured with extended error line operation enabled, three levels of error are available to the machine control. The advantage of this extended error handling is that the machine will not be 'shut-down' by problems of lesser importance, but they may be indicated in a manner that allows planned maintenance. The three levels are as follows:

Warning Low-level errors which don't affect system accuracy but indicate that maintenance is required.

Suspend Medium-level errors which may affect the accuracy or operation of the machine. Processes/part machining should not be allowed until this error has cleared.

Error Errors which may affect the integrity of the feedback system. The axis must be stopped and disabled immediately.

The resulting machine handling of these extended error functions should be as follows:

Table F.1 – Extended error line outputs

Output line asserted	Causes	Action by control
Warning	• HS20 laser signal strength has reached **Beam low** level. • Unassigned or unallocated sensor detected. • Other minor RCU10 condition.	• Display a message. • Schedule maintenance.
Suspend	• Sensor rate of change exceeded. • Sensor reading out of range. • Following error (Accuracy) detected. • Axis not yet referenced (homed). • Sensor failure. • Compensation failure. • Parameter table select failure. • Compensation buffering enabled. • Currently injecting to re-establish position.	• Stop the machining operation (part program). • Display a message. • Jog movements may be allowed.
Error	• Internal RCU10 error. • Input/output counter errors. • Laser encoder in preheat. • RCU10 in configuration mode. • Error from external input. • System configuration invalid or corrupt. • Axis fast link failure. • Following error safety detected. • Excessive compensation detected	• Stop axis motion immediately and disable drive.

F.1.3 Axis referencing with extended error lines

The axis referencing sequence for applications that use Error, Suspend and Warning lines is shown in Figure F.1.

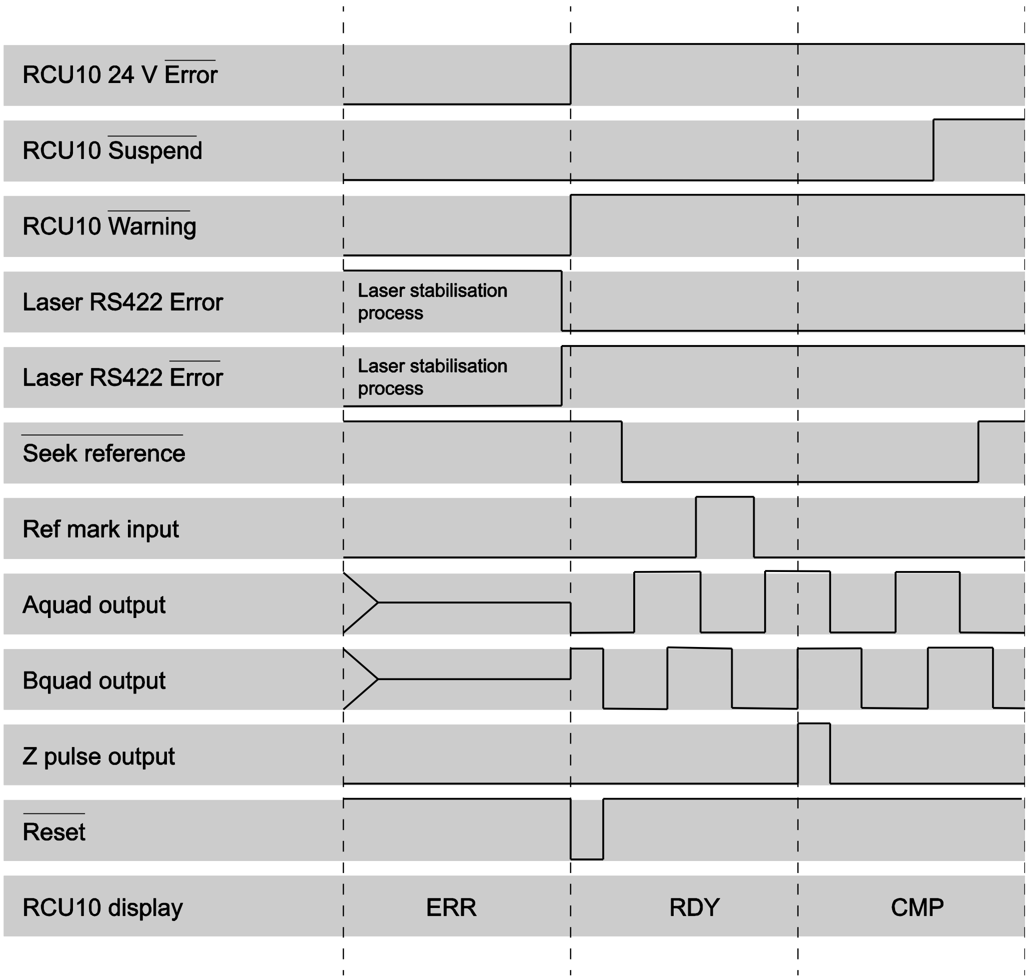


Figure F.1 – Axis referencing sequence using extended error lines (Error, Suspend and Warning)

F.1.4 Controlling workpiece compensation from motion control system output lines

F.1.4.1 Introduction

Depending upon the application, there may be a requirement to enable workpiece compensation at a location other than machine home. To enable this to be achieved, an input to the RCU10 unit called **Workpiece compensation enable** is provided.

Through this line it is possible to both enable and disable workpiece compensation anywhere along the axis.

This function is best operated by programming it as an M-code operation.

Two M-codes are required to enable and disable the function, and these are traditionally programmed as M91 and M90:

M91 Activate/define the workpiece origin (enable workpiece compensation)

M90 Deactivate workpiece compensation

A second related function is the ability to ‘freeze’ the last value read from the workpiece material sensor. A second control line (**Workpiece compensation temperature freeze)** is used to do this. This function can also be implemented as machine M-codes:

M92 Suspend workpiece temperature sensor reading

M93 Resume workpiece temperature sensor reading

F.1.4.2 Enabling workpiece compensation

The workpiece compensation function is enabled when the **Workpiece compensation enable** line is held in a low state. The M91 code should be programmed to set the output line low (off).

Once workpiece compensation is enabled, all moves relative to the workpiece reference position are appropriately compensated for the effects of thermal expansion or contraction. In some applications it is possible to fixture multiple parts on the machine table. In such cases workpiece compensation is enabled at a location (workpiece reference) around which the part is predicted to expand and the part is then machined as normal.

F.1.4.3 Disabling workpiece compensation

Conversely, the workpiece compensation function is disabled when the **Workpiece compensation enable** line is returned to the high state. M90 should be programmed to set this line high (on).

Workpiece compensation is now deactivated. If M90 is used at a machine position which is away from the workpiece origin, the appropriate number of compensation pulses will be re-injected into the machine control to bring the machine back into a position that is compensated only for the effects of wavelength variation (if laser encoders are used). For this reason, a short delay should be programmed in before machining is allowed to continue.

F.1.4.4 Suspending workpiece compensation

The function **Disable material compensation** is included to enable the user to update the reference temperature for material compensation purposes at selected intervals.

This function effectively ‘freezes’ the last reading that has been taken on the material temperature sensor, whilst workpiece expansion compensation remains active.

This is achieved by setting the state of the **Workpiece compensation temperature freeze** line as follows:

High **(M93)** The material temperature is read constantly

Low **(M92)** The material temperature is held at the last reading

F.1.4.5 Multiple fixturing with workpiece compensation

If, because of multiple fixturing, the machine now moves to the next part with workpiece compensation active, then compensation for the total move relative to the workpiece reference of the previous part is applied and will continue to be applied during machining. Clearly this could introduce inaccuracy in the features machined in the second and subsequent parts. In this case it is necessary to disable and then re-enable the workpiece reference at the new parts’ reference position.

The correct way to use workpiece compensation in cases with multiple fixturing capability is detailed below:

1. Home the machine axes (if not already done).
2. Move the machine to the workpiece expansion origin position. When in position, use M91 to enable workpiece compensation.
3. Machine the part.
4. Switch back to wavelength compensation only using M90.
5. Move the machine to the second workpiece expansion origin. When in position, use M91 to enable workpiece compensation.
6. Machine the part.
7. Switch back to wavelength compensation only using M90.
8. Move to the next workpiece origin etc.

F.1.5 Parameter table selection

A number of 'parameter tables' may be available for use during operation. The purpose of these is to allow the easy selection of a number of common options/operations.

The parameters which may be selected are shown below:

- Dead path for laser encoders or reference offset from scale expansion origin
- Workpiece temperature sensor serial number
- Workpiece expansion coefficient
- Workpiece origin offset
- Workpiece origin type

The use of these switchable parameters allows such options as:

- Multiple machine home positions.
- Changing to an alternative machining zone.
- Use of multiple workpiece material sensors (for multiple machine zones or other reasons).
- Changing of the material type (e.g. aluminium/steel)

The values for these parameters may be pre-configured at **System Configurator** level as detailed in sections 4.2.4 and F.1.7.1, and then selected during operation by the machine control or a simple switch.

The number of parameter tables available depends on how the system configurator has programmed the RCU10s. A maximum of four parameter sets may be selected by use of two hardware lines. The selection control is shown in the table below:

Table F.2 – Parameter table selection

Select parameter table	PT select 1	PT select 2
1	HIGH	HIGH
2	LOW	HIGH
3	HIGH	LOW
4	LOW	LOW

(NOTE: If single parameter table operation is selected, there is not a requirement to connect to the parameter table select lines.)

The procedure for use should be as follows:

1. Stop the machine/part program.
2. Change the selected parameter table (by use of the control lines).
3. Re-home the machine or axis. Once this is complete, the new parameter set will be used and displayed in the software. This can be confirmed by looking at the RCU CS status display screen to see which parameter table is shown as active.

F.1.6 Compensation buffering

As described in section 1.4.2, this facility enables the compensation system to calculate and store any required compensation in a buffer within the RCU10 if the machine's E-stop is activated and hence the motion temporarily disabled.

To activate this facility, pin 14 of the Auxiliary I/O port on the RCU10 needs to be taken low; to deactivate the facility, this line should be at the voltage level determined by the pull up voltage selected (either 24 V or 5 V). The status of this mode (i.e. enabled or disabled) is depicted by the CB lamp displayed on the Compensation screen. If compensation buffering is enabled, pin 14 of the Auxiliary I/O connector is low and the lamp beside the CB acronym is amber.

Once the E-stop and hence the compensation buffering is disabled, any stored compensation is injected into the motion feedback loop and compensated position re-established. The rate at which this “stored” compensation is injected into the feedback path is determined by the recovery injection rate configurable within each axis compensation window.

F.1.7 Configuration of advanced features

F.1.7.1 Multiple parameter tables

When multiple parameter tables are selected, each axis has a number of selectable tables of parameters which may be switched during machine operation.

By making the appropriate hardware selection, the parameter tables may be selected on a per axis basis. But it will probably be more common to use the system such that all axes have the same table number selected at any time.

There are a number of operational functions which may be implemented with the parameter tables (this is discussed in section F.1.7.2).

It is possible to step through the available parameter tables using the left and right buttons that appear next to the **Displayed parameter table** box.

Rules for parameter table use:

- Every axis has the number of tables available as set on the **System** tab.
- Each individual axis must have suitable data in every available entry box of every available parameter table.
- Parameter tables are always sequential starting at number 1.
- Data entry boxes will only be shown for applicable functions (e.g. if workpiece compensation is not enabled for a particular axis, then none of the workpiece compensation parameters will be required for that axis).

Appendix E includes parameter table record sheets which may be used to assist in designing the multiple parameter values and recording them. It is best to fill this table out prior to performing the configuration. In this way, by entering the data from the form into the RCU CS, mistakes are easily avoided.

F.1.7.2 Operating with multiple parameter tables

Two of the commonest applications are shown below:

Using parameter tables to change material type

In the case where workpiece expansion compensation is being used and different materials are regularly worked on the same machine, it may be necessary to change the thermal expansion coefficient.

In this case the parameters for each axis would be configured identically. Different material expansion coefficients would be used in each parameter table.

This may be configured as follows.

1. Make the wiring to the parameter table selection lines (Auxiliary I/O connector) common to each axis. This makes all axes change together.

2. On the **System** tab of the **Configuration** window, select **Multiple** parameter tables. Determine how many material types are to be used, and set the number of parameter tables to this number (one for each material type).

3. Go to the **Parameters** tab and enter the required values in each parameter table that is available. Repeat this for each axis. In this case **Expansion coefficient <1>** will be set for one material and **Expansion coefficient <2>** will be set for another, etc.

4. In operation, the appropriate material type may be selected prior to homing the machine by using the parameter selection control lines. These may be given M-codes in the machine controller.

Using a machine with multiple home positions or zones

In this case, the use of the parameter tables is a little more complicated, as each axis and each parameter table will contain differing values.

Consider the case where a machine has multiple home positions. For each home position, the relevant axes could have different values for :

- Air dead path (or scale offset) (If laser encoders are used)
- Workpiece temperature sensor (If a different sensor is required for each zone)
- Workpiece expansion coefficient (If each zone is used for different materials)
- Workpiece origin offset (If a fixed offset from home is being used)
- Workpiece origin type (To select fixed offset or by logic)

In this case only those axes which are to have the multiple home/zones will need to be switched, but all parameter tables in all axes must have valid data entered.

To implement multiple parameter tables:

1. Make the wiring to the parameter table selection lines (Auxiliary I/O connector) only on those axes which are to have multiple home/zones.

2. On the **System** tab of the **Configuration** window, select **Multiple** parameter tables. Determine how many home/zone positions are to be used, and set the number of parameter tables to this number (one for each home/zone).

3. Go to the **Parameters** tab and enter the required values in each parameter table that is available. Repeat this for each axis. Refer to the prepared record sheet in Appendix E to assist.

4. In operation the appropriate home position/zone may be selected prior to homing the machine by using the parameter table control lines. This operation may be programmed as part of the home procedure or by an M-code.

Configuration example

In the following example two parameter tables are used to switch between two working positions on a machine.

Axes X1, X2 and Y use laser encoders and axes Z, W and A use linear tape scales.

Workpiece compensation is used only on axes X and Y, therefore data does not have to be entered for axes Z, W and A.

In parameter table 1 the machine will use home position 1, which has X axis dead path values of 1500 mm and 1475 mm. The material temperature sensor used will be V97307. The workpiece material is aluminium, which has an expansion coefficient of 20 ppm/°C. The workpiece origin is selected by machine control logic lines and the offset is zero.

Scale offset values are entered for axes Z, W and A as scale material expansion compensation is being used on these axes.

Example : Machine home position 1

1	Axis X1	Axis X2	Axis Y	Axis Z	Axis W	Axis A	Units (select)
Air dead path <1> (Scale offset)	1500 -	1475 -	450 -	- 475	- 350	- 50	mm
Workpiece temperature sensor <1>	V97307	V97307	V97307	-	-	-	Serial #
Workpiece expansion coefficient <1>	20	20	20	-	-	-	ppm/°C
Workpiece origin offset <1>	0	0	0	-	-	-	mm
Actuation method	Logic	Logic	Logic	-	-	-	-

In parameter table 2 the machine will use a second home position which is 5 m further down the X axis. For this reason, the dead paths for X1 and X2 are 5500 and 5475. Note the Y does not change, as this uses the same home position as before.

A different material temperature sensor is used in this position, therefore V97308 is entered.

The workpiece will be of steel in this position, so an expansion coefficient of 10 is used.

At this second home position a different method of enabling workpiece compensation is to be used. It is configured to enable workpiece compensation at the same point as the machine home (reference) position. An offset is entered for X and Y to place the workpiece expansion origin at a fixed point 1 m from X home and 2.5 m from Y home positions.

Example : Machine home position 2, steel part

2	Axis X1	Axis X2	Axis Y	Axis Z	Axis W	Axis A	Units (select)
Air dead path <2> (Scale offset)	5500 -	5475 -	450 -	- 475	- 350	- 50	mm
Workpiece temperature sensor <2>	V97308	V97308	V97308	-	-	-	Serial #
Workpiece expansion coefficient <2>	10	10	10	-	-	-	ppm/°C
Workpiece origin offset <2>	1000	1000	2500	-	-	-	mm
Actuation method	At Ref	At Ref	At Ref	-	-	-	-

F.2 RCU CS – Additional functionality

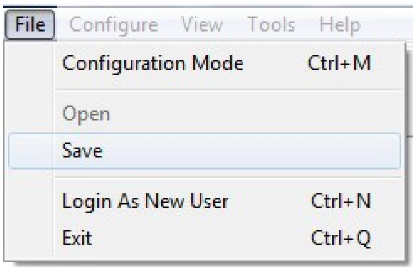
F.2.1 Additional RCU CS configuration functionality

As well as the basic functions described so far, the RCU CS software has a number of additional configuration functions that may be used.

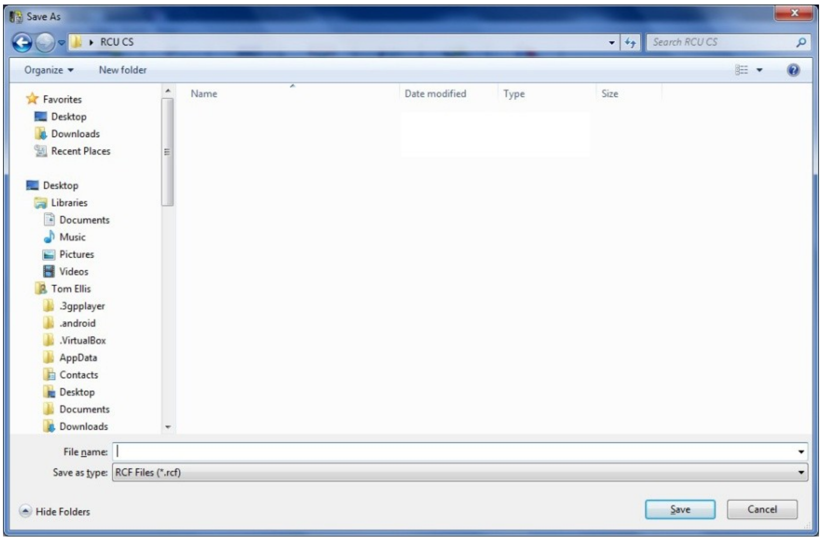
F.2.1.1 Saving the configuration

It is advisable to save the finished configuration to a file that may be kept as a back-up of the system configuration. This may then be used in the event of a fault or a mistake being made.

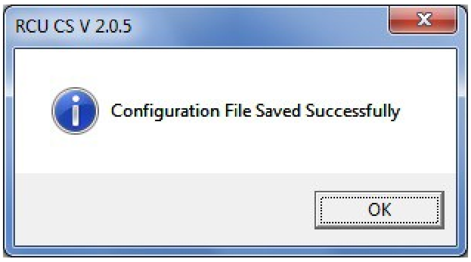
- Select **Save** from the **File** menu.



- A window will appear asking for a file name and location to save to.



- Once this has been entered, the file will be saved in this location.

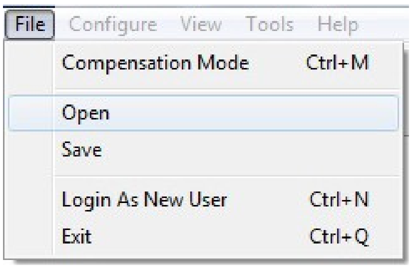


- Press **OK** to continue operating with the system.

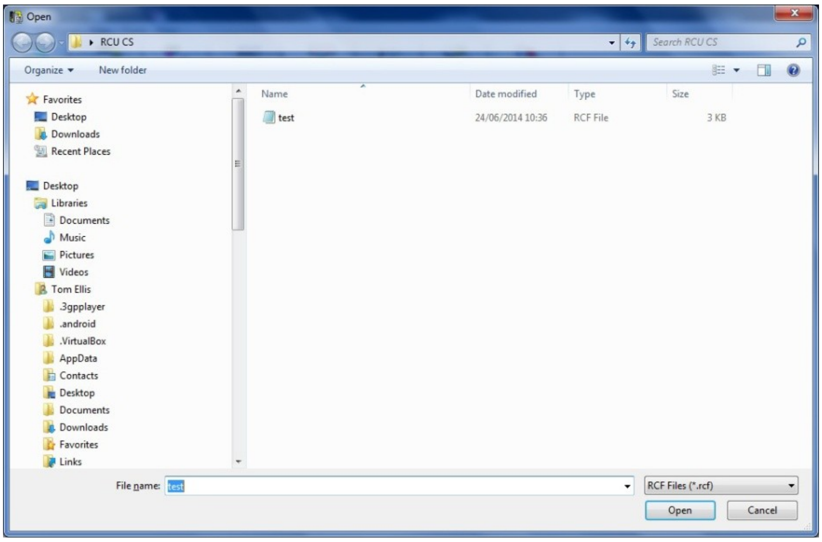
F.2.1.2 Loading a configuration

Saved configuration files can be restored on to the RCU10 hardware if necessary using the following procedure:

- Select **Open** from the **File** menu.



- A window will appear asking for the name and location of the configuration file to load.



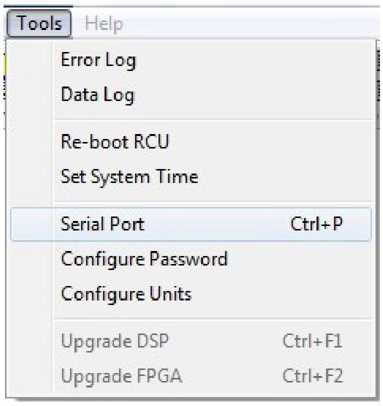
- After selecting the file to open and selecting **Open**, the configuration data is displayed in the configuration window.
- If the contents of the file are correct, press **OK** to overwrite the PC data.
- If the contents are deemed incorrect, press **Cancel** and the data will be discarded.
- Press **OK** to continue operating with the system.
- The configuration screen will open automatically to ensure that the user can check the configuration before transmitting it to the RCU10(s).

NOTE: The RCU CS will also check this configuration when **OK** is pressed. Pressing **Cancel** at this stage will cause the data loaded by the configuration file to be lost.

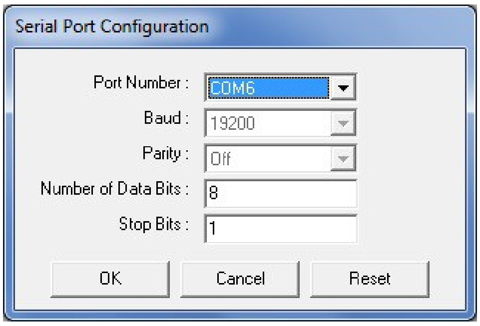
F.2.1.3 Setting the PC communication port

The default setting for the PC communication with the RCU10s is COM 1. If an alternative COM port is to be used, this can be done as follows.

- From the **Tools** menu, select the **Serial Port** option.



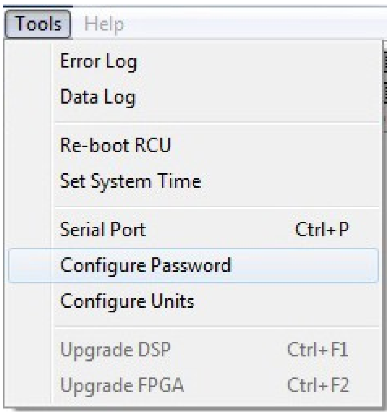
- The COM port may then be selected:



F.2.1.4 Configuring passwords

The system configurator may change the access password required to log in at system configurator access level.

- Select **Configure Passwords** from the **Tools** menu.



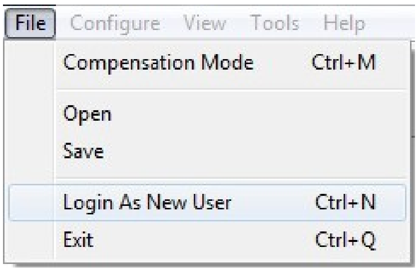
- The following screen will appear:

- Select the password to change and enter the new password into both fields.
- Click **OK** when complete.
- Make a note of the new password. If the user-defined password is forgotten, contact your Renishaw representative who will restore access by supplying a recovery password.

F.2.1.5 Logging in as new user

The current user may return to the start-up screen and log in at a different access level at any time, for example a configurator may wish to return the system to user level access.

- Select **Login As New User** from the **File** menu.

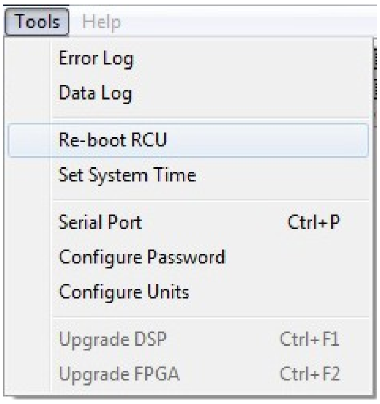


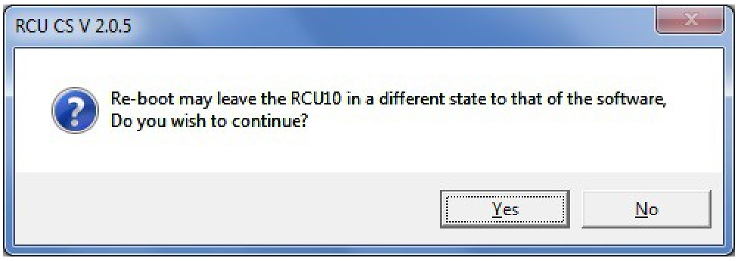
- RCU CS will return to the main log in screen, allowing the user to select the access level required.

F.2.1.6 Rebooting the RCU

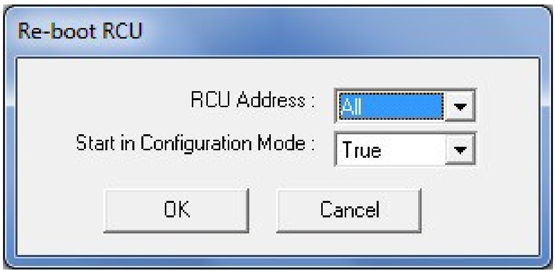
By selecting **Re-boot RCU** from the **Tools** menu, the user may re-start the RCU10 they are connected to, or the entire network. The start-up mode may be selected as either configuration or compensation mode. This can allow the user to force the RCU10(s) into configuration mode if there is a fault, without having to reconfigure the system.

- Select **Re-boot RCU** from the **Tools** menu.





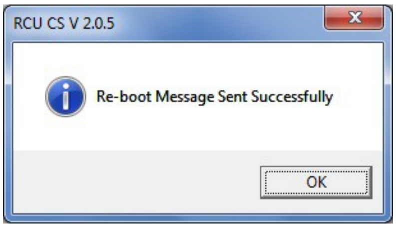
- Select **Yes** to continue.



- Select the RCU10(s) to re-boot from the drop-down list. The user may select either the single RCU10 that RCU CS is connected to, or all RCU10s in the network.
- Select the mode the unit(s) must start up into. **True** will boot the RCU10(s) into configuration mode, **False** will boot the RCU10(s) into compensation mode.

NOTE: If any of the units have **Inhibit Compensation Mode** selected in the axis configuration, they will always boot into configuration mode, regardless of the selection above.

- Click **OK**. The RCU10s will make a click to signify the re-boot. The message below should appear.



- Press **OK** to continue working with RCU CS.

F.2.2 Data logging

The data log is a powerful function that may be used to record the information that is displayed on the RCU CS screen. The data log records all the data displayed on the **Compensation**, **Sensor** and **Diagnostics** displays. It records the data in three text files in a designated directory:

*****_Comp.txt

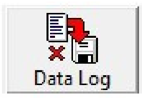
*****_Sens.txt where ***** is the file name entered

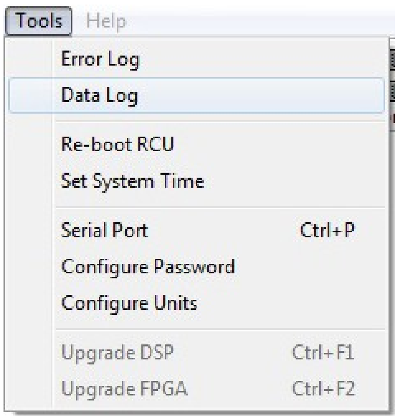
*****_Stat.txt

The data is recorded at the rate at which it is received from the RCU10 network. This is approximately 17-20 readings per second. The number of records created depends upon the number of display screens open:

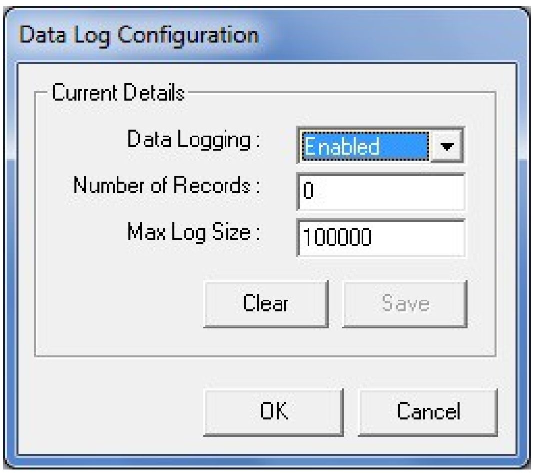
One view open	Approximately 18 records per second per display open
Two views open	Approximately 12 records per second per display open
Three views open	Approximately 6 records per second per display open

- To enable data logging, press the Data Log button on the button bar, or select **Data Log** from the **Tools** menu.



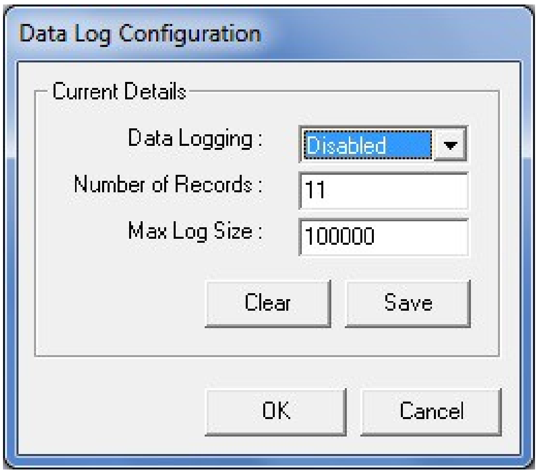


- Select **Enabled** from the drop-down list.

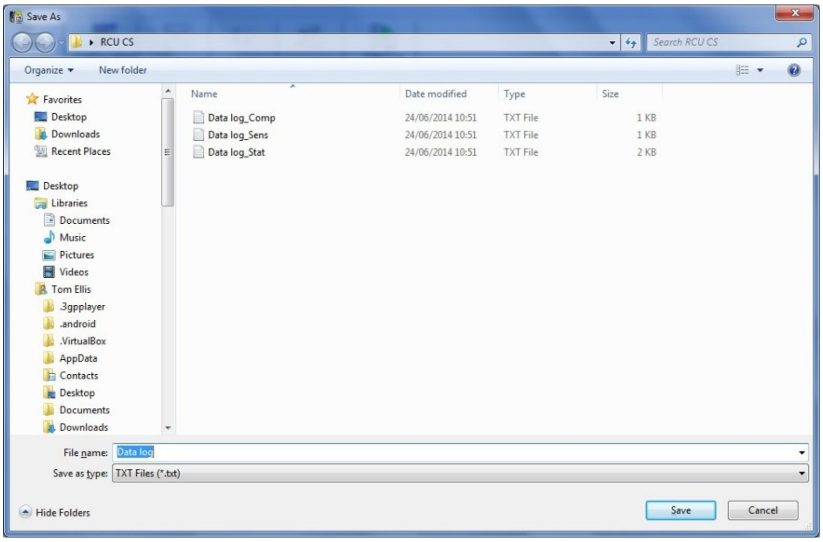


- Click **OK** to begin logging data.

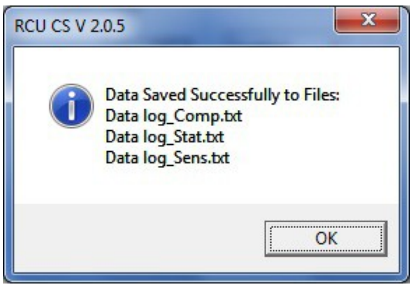
- Open the **Compensation**, **Configuration** and **Diagnostics** information views as required to display the required information.
- To complete the data logging process, press the Data Log button on the button bar, or select **Data Log** from the **Tools** menu.
- Select **Disabled** from the drop-down list.



- Press **Save** to transfer the data log results to a file.



- Define a file name for the data log files.
- A confirmation dialogue will display the names of the saved files.



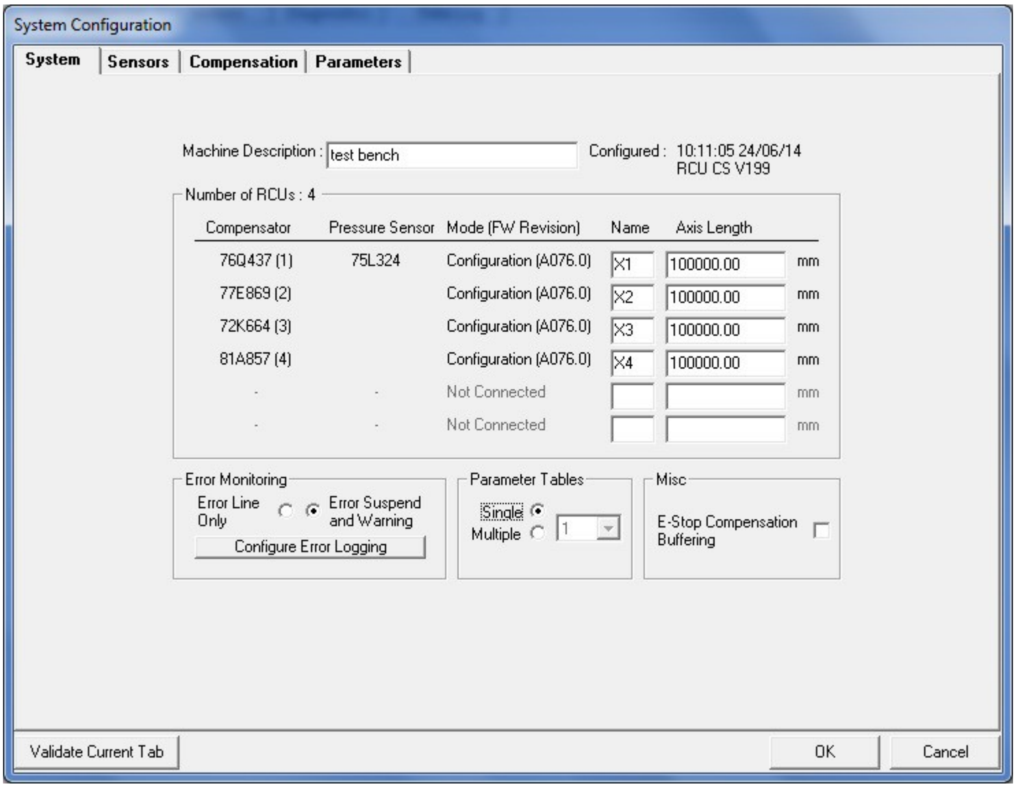
- These files can be viewed in any standard text editor and will display all saved data in delimited text rows.

F.2.3 Error logging

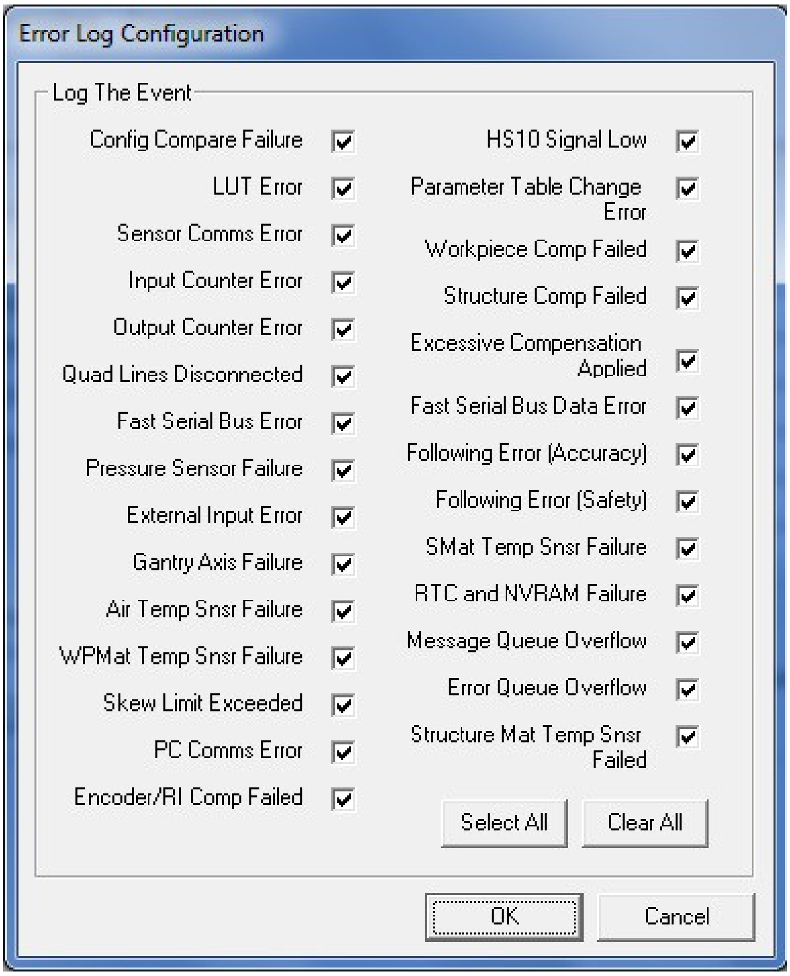
The error log is a powerful diagnostics tool that is provided primarily for Renishaw diagnostics purposes.

To activate the error log, it must be configured in the global system settings:

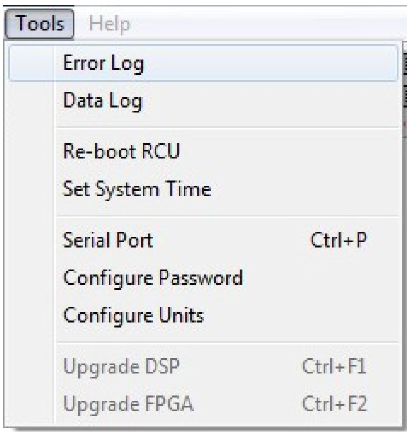
- Ensure that the RCU10 network is in configuration mode.
- Press the Configuration button on the button bar.
- On the **System** tab, press the **Configure Error Logging** button.



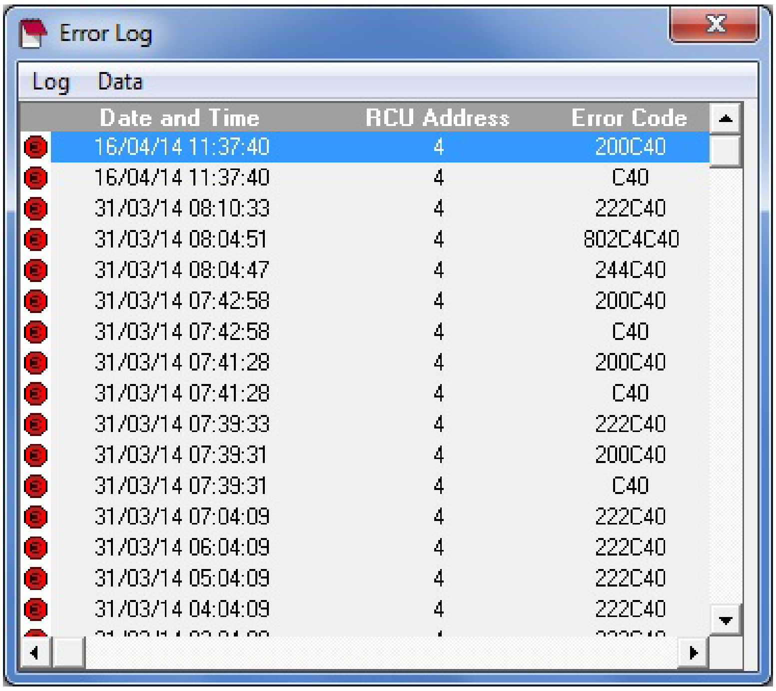
- Press Select All to enable the logging of all errors.



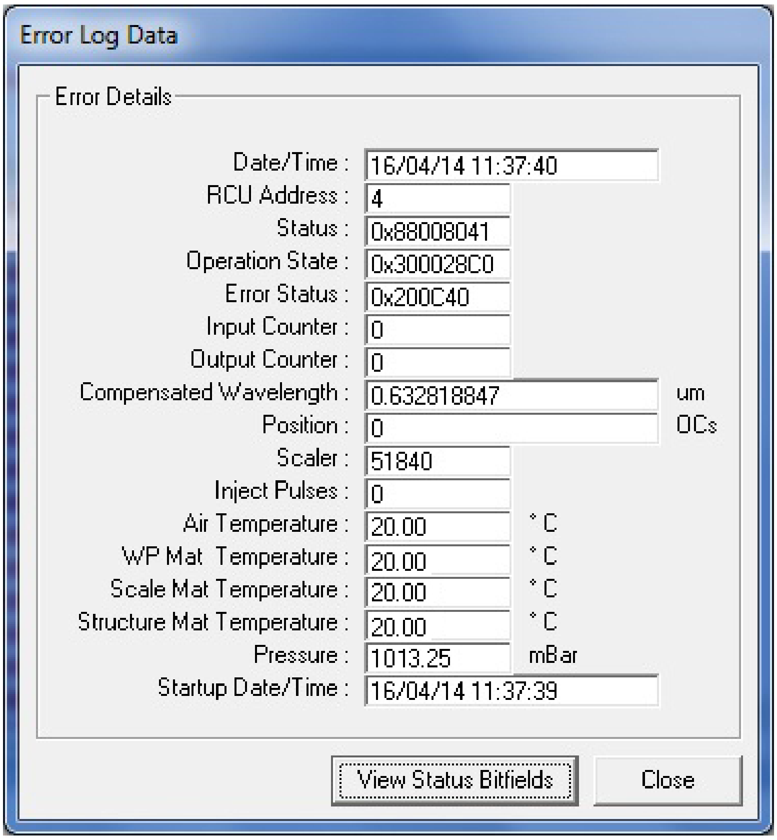
- Press **OK** to continue and transmit the configuration as normal. Each individual unit will now log all errors during operation.
- To access the error log, select Error Log from the Tools menu.



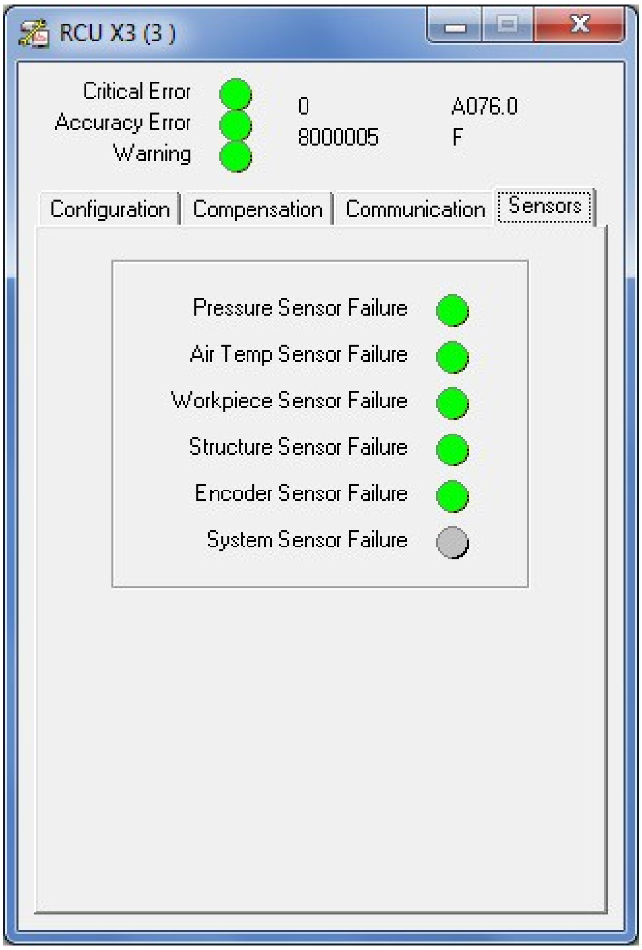
- The screen will show a list of up to the last 32 errors logged in all the RCU10s in the network.



- To look at individual errors, double-click the error to display the full details of that error condition.



- To look at the resulting error conditions as they would appear in the diagnostics window, press the View Status Bitfields button to call up the screen below.



Saving data

The error log may be saved for records or analysis. Select **Save** from the **Log** menu in the error log window. This will allow the data to be stored in a delimited text file.

Sorting data

The error log may be sorted for display by date and time, RCU address or error code. This allows data to be more clearly displayed.

Error log codes

Below is a basic list of codes for reference. These will give a basic overview of the main events occurring in each error log record. For a clearer description, open each log event and press **View Status Bitfields** to view the status lights activated.

0x1	Configuration compare failed
0x2	Reserved
0x4	LUT error
0x8	UARTA access error
0x10	Input counter error
0x20	Output counter error
0x40	Quadrature lines disconnected (float)
0x80	Fast serial bus failure
0x100	Pressure sensor failure
0x200	Parameter set selection error
0x400	External input error
0x800	HS10 signal low warning
0x1000	Reserved
0x2000	Air temperature sensor failure
0x4000	Workpiece material temperature sensor failure
0x8000	Reserved
0x10000	UARTB error
0x20000	Air compensation failed/Encoder compensation failed
0x40000	Workpiece expansion compensation failed
0x80000	Structure expansion compensation failed
0x100000	Excessive compensation applied
0x200000	Fast serial bus data corruption
0x400000	Following limit warning exceeded
0x800000	Following error exceeded
0x1000000	Scale material temperature sensor failure
0x2000000	Reserved
0x4000000	Reserved
0x8000000	Reserved
0x10000000	RTC and NVRAM failure
0x20000000	Message queue overflow – too many messages
0x40000000	Error queue overflow – too many errors
0x80000000	Structure material temperature sensor failure

F.2.3.1 Error log descriptions

The dialog below shows all the errors that can be recognised by the system:

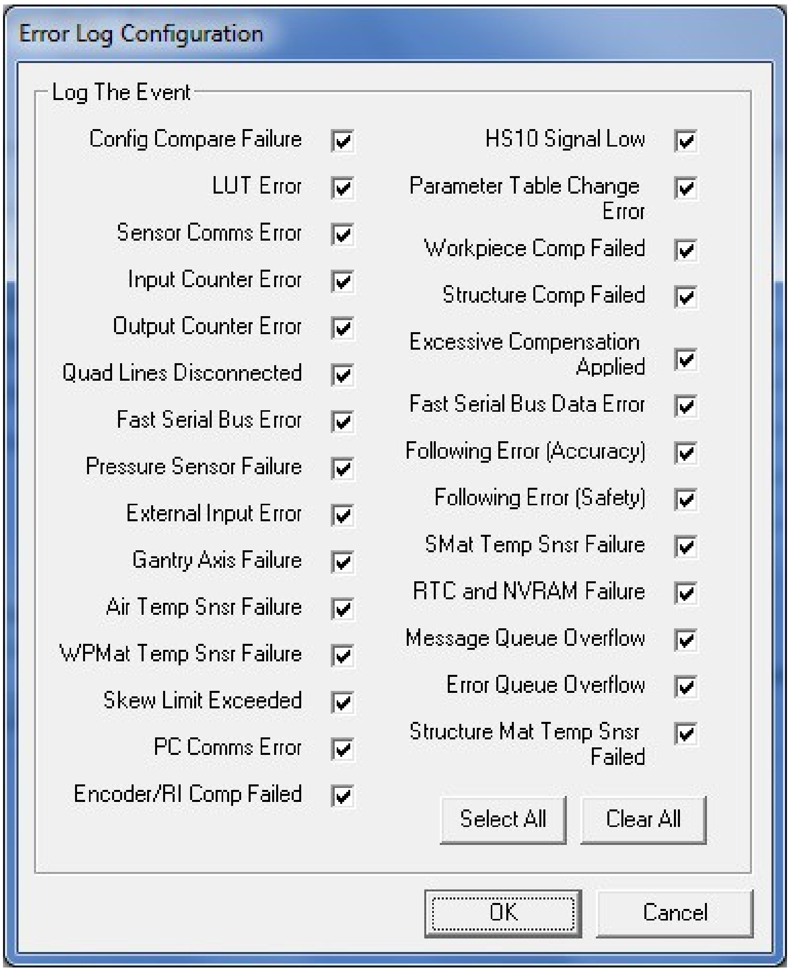


Table F.3 below gives a brief description of each error.

Table F.3 – Error log descriptions

Event	Description	Advanced setting	Simple setting
Config Compare Failure	RCU10s in a network are operating with different configuration modules.	ERROR	ERROR
LUT Error	Look up table (LUT) error. LUT data corrupted, LUT load failed or LUT incorrect.	ERROR	ERROR
Sensor Comms Error	Sensor communications error. Framing, overrun, parity or UART IC error.	SUSPEND	ERROR
Input Counter Error	Coincidence of edges on A and B quadrature indicating an overspeed condition on the input counter.	ERROR	ERROR
Output Counter Error	Coincidence of edges on A and B quadrature indicating an overspeed condition on the output counter.	ERROR	ERROR
Quad Lines Disconnected	Axis input quadrature lines are disconnected.	ERROR	ERROR
Fast Serial Bus Error	Unrecoverable network error. No master connected. Includes timeout errors.	ERROR	ERROR
Pressure Sensor Failure	Allocated pressure sensor has failed.	SUSPEND	ERROR
External Input Error	The encoder is producing an error. This also freezes the compensation process/internal counters.	ERROR	ERROR
Gantry Axis Failure	Not implemented.		
Air Temp Snsr Failure	Allocated air temperature sensor has failed.	SUSPEND	ERROR
WPMat Temp Snsr Failure	Allocated material temperature sensor has failed.	SUSPEND	ERROR
Skew Limit Exceeded	Not implemented		
PC Comms Error	Personal computer communications error. Framing, overrun, parity or UART IC error.	WARNING	WARNING
Encoder/RI Comp Failed	Encoder compensation algorithm failure. A sensor allocated to this process has failed or is in error.	SUSPEND	ERROR
HS10 Signal Low	HS10 laser head warning line active.	WARNING	WARNING
Parameter Table Change Error	An undefined parameter set has been selected for use in the compensation process.	SUSPEND	ERROR
Workpiece Comp Failed	Workpiece compensation algorithm failure. A sensor allocated to this process has failed or is in error.	SUSPEND	ERROR
Structure Comp Failed	Structure compensation algorithm failure. A sensor allocated to this process has failed or is in error.	SUSPEND	ERROR
Excessive Compensation Applied	More than 25mm of compensation (excluding refractive index compensation)has been applied.	ERROR	ERROR

Table F.3 – Error log descriptions *continued*

Event	Description	Advanced setting	Simple setting
Fast Serial Bus Data Error	Data corruption on sensor information passed over fastlink.	ERROR	ERROR
Following Error (Accuracy)	The accuracy following error limit has been exceeded.	WARNING	WARNING
Following Error (Safety)	The safety following error limit has been exceeded. Indicates that the compensation buffer limit has been exceeded if compensation buffering is active.	ERROR	ERROR
SMat Temp Snsr Failure	Allocated material temperature sensor has failed. All four encoder errors fail together when zoning is not available.	SUSPEND	ERROR
RTC and NVRAM Failure	Real-time clock and non-volatile random access memory failure. Battery low. NVRAM contents lost.	WARNING*	WARNING*
Message Queue Overflow	Message queue overflow. RCU10 state machine damaged. Internal diagnostics function.	ERROR	ERROR
Error Queue Overflow	Error queue overflow. RCU10 error tracking is damaged. Internal diagnostics function.	ERROR	ERROR
Structure Mat Temp Snsr Failed	Allocated material temperature sensor has failed.	SUSPEND	ERROR

* Changes to error once system is restarted

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Appendix G

Reference

Contained in this appendix

G.1 Compensation equation overview

This section provides details of the equations which are used by the RCU10 to provide compensation for the following:

1. Encoder thermal compensation
2. Laser compensation
3. Structure thermal compensation
4. Workpiece thermal compensation

G.1.1 Encoder compensation

Axis position (m) = Input position (m)
+ Encoder thermal expansion compensation (µm)
+ Encoder thermal expansion offset compensation (µm)
+ Machine structure thermal expansion compensation (µm)

Output position (m) = Axis position (m)
+ Workpiece thermal expansion compensation (µm)

G.1.1.1 Definition of position terms

Input position (m) = $IQR_{20} . IQC_{er} . 10^{-6}$

This is the uncompensated position, as indicated by the axis encoder, measured in m.

IQR_{20} = Nominal encoder Input Quadrature Resolution at 20 °C (taken from encoder manufacturer's datasheet and expressed in µm).

IQC_{er} = Input Quadrature Count since the encoder was referenced. The input quadrature direction sense must be set so that IQC_{er} becomes more positive when the axis moves in the positive (forward) direction. IQC_{er} is set to zero at the instant the encoder is referenced.

Axis position (m)

This is the true axis position (measured in m). It includes corrections to remove the effects of thermal expansion or contraction of the axis encoder and the machine structure.

Output position (m)

This is the fully compensated position output (measured in m) that is sent to the machine's axis servo-controller. This output compensates the axis position to include additional corrections to remove the effects of thermal expansion or contraction of the workpiece.

G.1.1.2 Definition of compensation terms

Note that a *positive* correction or compensation value causes the servo-control to move the axis in a *negative* (reverse) direction as it holds the demand position.

Encoder thermal expansion compensation (µm) = Input position (m) . α_e . (T_{ec} - 20)

This is the compensation for the linear thermal expansion of the axis encoder in µm.

α_e = Encoder's linear coefficient of thermal expansion (taken from manufacturer's datasheet and expressed in µm/m/°C).

T_{ec} = Current encoder temperature (in °C).

Encoder thermal expansion offset compensation (µm) = EO . α_e . (T_{ec} - T_{er})

This is the additional compensation for the linear thermal expansion of the axis encoder that is required if the encoder expansion origin is not coincident with the encoder reference point.

EO = Distance (in m) between the encoder's reference point and the point about which the encoder expands. EO should be entered as a *negative* value if the axis would have to travel in a *negative* (reverse) direction to move, from the encoder expansion point, to the encoder's reference point.

α_e = Encoder's linear coefficient of thermal expansion (taken from manufacturer's datasheet and expressed in µm/m/°C).

T_{ec} = Current encoder temperature (in °C).

T_{er} = Encoder temperature at instant encoder is referenced (in °C). The use of T_{er} (instead of 20 °C) ensures the axis doesn't jump as it is referenced.

Machine structure thermal expansion compensation (µm) = S . (20 - T_{sc})

This is the compensation for the thermal expansion of some part of the machine's structure, such as the machine's spindle. If T_{sc} is greater than 20 °C, and S is a positive value, this will give a *negative* compensation value which will cause the axis to move in a *positive* (forward) direction.

S = Structure compensation required in µm/°C.

T_{sc} = Current structure temperature (in °C). Because compensation is referenced to 20 °C, enabling structure compensation will make the axis move slightly as it is referenced when the structure is not at 20 °C.

Workpiece thermal expansion compensation (µm) = $(AP_c - AP_{wce} - WO) \cdot \alpha_w \cdot (20 - T_{wc})$

This is the compensation for the linear thermal expansion of the workpiece in µm. It includes the facility to provide additional compensation if the workpiece expansion origin is not coincident with the point at which workpiece expansion compensation was enabled.

AP_c = Current axis position (in m).

AP_{wce} = Axis position (in m) at the instant workpiece compensation was enabled.

WO = Expected distance between the workpiece expansion origin and the cutting tool tip (or processing point), when workpiece expansion compensation is going to be enabled.

WO is measured parallel to the axis of motion and expressed in metres. WO should be entered as a *negative* value if the axis would have to travel in a *negative* (reverse) direction to move the tool tip, from the point at which workpiece compensation is enabled, to the workpiece expansion origin.

If the cutting tool tip is going to be positioned at the workpiece expansion origin when workpiece expansion compensation is enabled, then WO should be set to zero.

α_w = Workpiece's linear coefficient of thermal expansion (in µm/m/°C).

T_{wc} = Current workpiece temperature (in °C).

G.1.2 Laser compensation

Axis position (m)	=	**Input position (m)**
		+ Laser wavelength compensation (µm)
		+ Laser dead path wavelength compensation (µm)
		+ Machine structure thermal expansion compensation (µm)
Output position (m)	=	**Axis position (m)**
		+ Workpiece thermal expansion compensation (µm)

G.1.2.1 Definition of position terms

Input position (m) = $IQR_{ntp} \cdot IQC_{er} \cdot 10^{-9}$

This is the uncompensated position, as indicated by the laser encoder, measured in m.

IQR_{ntp} = Nominal laser encoder Input Quadrature Resolution in nm. This is calculated from λ_{ntp} by taking into account the interpolation factor and interferometer type (single or double pass) selected by the user.

λ_{ntp} = Laser wavelength in air at 20°C, 101,325 Pa, 50%RH, 450ppm CO_2, expressed in nm. Refer to section G.2.

IQC_{er} = Input Quadrature Count since the laser encoder was referenced. The input quadrature direction sense must be set so that IQC_{er} becomes more positive when the axis moves in the positive (forward) direction. IQC_{er} is set to zero at the instant the laser encoder is referenced.

Axis position (m)

This is the true axis position (measured in m). It includes corrections to remove the effects of air refraction on the laser beam and of thermal expansion or contraction of the machine structure.

Output position (m)

This is the fully compensated position output (measured in m) that is sent to the machine's axis servo-controller. This output compensates the axis position to include additional corrections to remove the effects of thermal expansion or contraction of the workpiece.

G.1.2.2 Definition of compensation terms

Note that a ***positive*** correction or compensation value causes the servo-control to move the axis in a ***negative*** (reverse) direction as it holds the demand position.

Laser wavelength compensation (µm) = Input position . 10^6 . (λ_c/λ_{ntp} - 1)

This is the compensation for the effects of the refractive index of air on the laser wavelength.

λ_c = Laser wavelength in air under current conditions. Refer to section G.2.

λ_{ntp} = Laser wavelength in air at 20°C, 101,325 Pa, 50%RH, 450ppm CO_2. Refer to section G.2.

Laser dead path wavelength compensation (µm) = LO . 10^6 . (λ_c/λ_r - 1)

This is the additional compensation for the effects of changes in the refractive index of air on the laser wavelength that is required if the interferometer optics are not close together at the encoder reference point.

LO = Laser dead path. This is the physical separation between the optics at the instant the laser encoder is referenced (expressed in m). If the interferometer is located at the negative extreme of the axis, then LO will be a positive value (see Figure G.1).

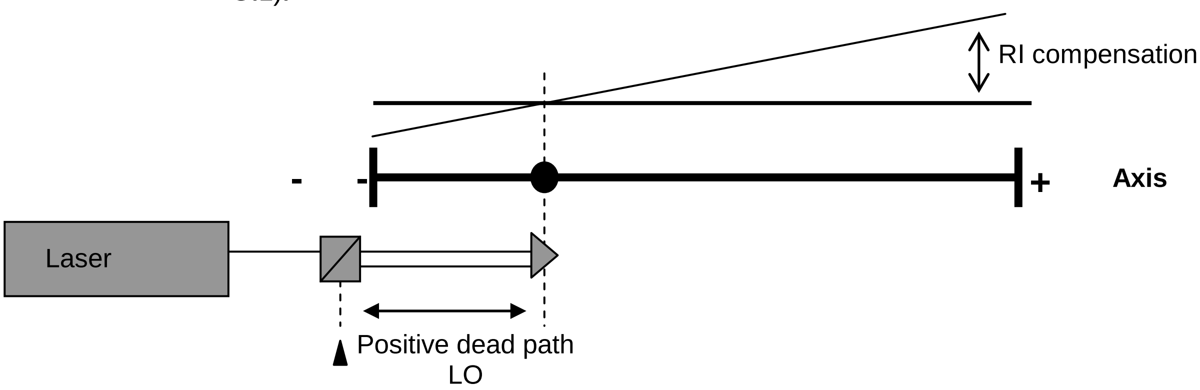

Figure G.1 – Axis configuration where dead path is entered as a positive value

If the interferometer is located at the positive extreme of the axis, then LO will be a negative value (see Figure G.2).

Note: In the case of a double pass plane mirror interferometer system, the dead path value must not be doubled. It is still the physical separation between the optics at the instant the laser is referenced. Care needs to be taken when entering the dead path for a column reference system, since such systems can have positive or negative values for LO, irrespective of where the interferometer is).

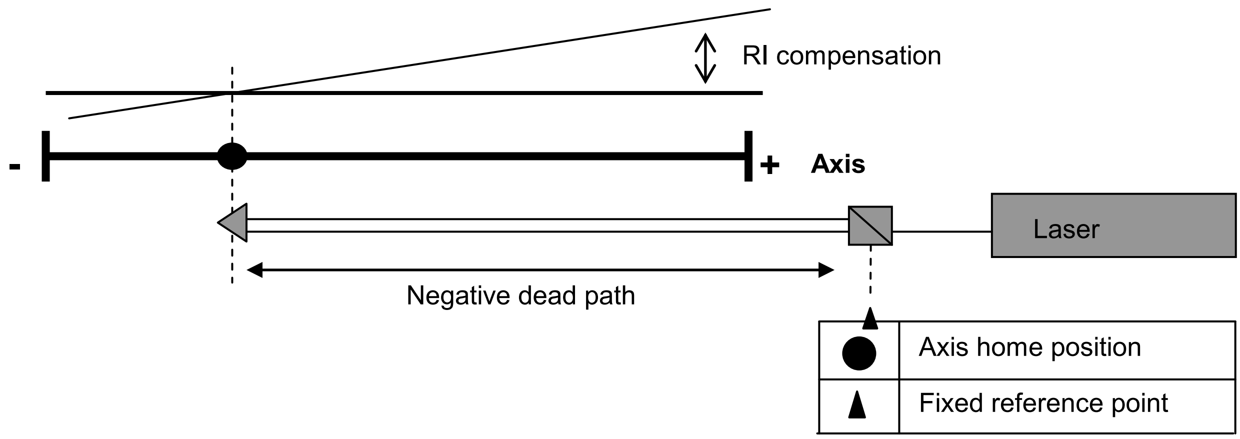

Figure G.2 – Axis configuration where dead path is entered as a negative value

λ_c = Laser wavelength in air under current conditions. Refer to section G.2.

λ_r = Laser wavelength in air at instant the laser encoder is referenced. Refer to section G.2. The use of λ_r (instead of λ_{ntp}) ensures the axis doesn't jump as it is referenced.

Machine structure thermal expansion compensation (µm) = S . (20 - T_{sc})

This is the compensation for the thermal expansion of some part of the machine's structure, such as the machine's spindle. If T_{sc} is greater than 20 °C, and S is a positive value, this will give a ***negative*** compensation value which will cause the axis to move in a ***positive*** (forward) direction.

S = Structure compensation required in µm/°C.

T_{sc} = Current structure temperature (in °C). Because compensation is referenced to 20 °C, enabling structure compensation will make the axis move slightly as it is referenced when the structure is not at 20 °C.

Workpiece thermal expansion compensation (μm) = $(AP_c – AP_{wce} - WO) . \alpha_w . (20 - T_{wc})$

This is the compensation for the linear thermal expansion of the workpiece in μm. It includes the facility to provide additional compensation if the workpiece expansion origin is not coincident with the point at which workpiece expansion compensation was enabled.

AP_c = Current axis position (in m).

AP_{wce} = Axis position (in m) at the instant workpiece compensation was enabled.

WO = Expected distance between the workpiece expansion origin and the cutting tool tip (or processing point), when workpiece expansion compensation is going to be enabled.

WO is measured parallel to the axis of motion and expressed in metres. WO should be entered as a *negative* value if the axis would have to travel in a *negative* (reverse) direction to move the tool tip, from the point at which workpiece compensation is enabled, to the workpiece expansion origin. If the cutting tool tip is going to be positioned at the workpiece expansion origin when workpiece expansion compensation is enabled, then WO should be set to zero.

α_w = Workpiece's linear coefficient of thermal expansion (in μm/m/°C).

T_{wc} = Current workpiece temperature (in °C).

G.2 Air refraction compensation

The equations below define how to calculate the refactive index of air and hence the current laser wavelength. The equations are defined using the T_{90} temperature scale and have been taken from the following reference.

- Tables of Physical and Chemical Constants - 16th Edition
- G.W.C.Kaye & T.H. Laby, Longman (sections 2.5.7 and 3.4.2)

The wavelength of the laser in air (λ_{air}) is related to its wavelength in a vacuum (λ_{vac}) by the equation

$$\lambda_{vac} = n \times \lambda_{air}$$

where n is the refractive index of the air.

For standard air (dry air at 15 °C and 101325 Pa, containing 450 ppm by volume of CO_2) the refractive index n_s is given by the dispersion equation from Birch (1994).

$$(n_s - 1) \times 10^8 = 8\,342.54 + 2\,406\,147\,(130 - \sigma^2)^{-1} + 15\,998\,(38.9 - \sigma^2)^{-1}$$

where $\sigma = 1000 / \lambda_{vac}$ (λ_{vac} is expressed in nm)

For dry air at a temperature of t °C and a pressure of p Pa, the refractivity ($n_{tp} - 1$) is given by

$$n_{tp} - 1 = p\,(n_s - 1)\,[\,1 + p\,(60.1 - 0.972\,t) \times 10^{-10}]\,/\,[\,96\,095.43\,(1 + 0.003\,661\,t)\,]$$

The refractivity of water vapour is less than that of air, so if the air is moist, its refractive index will be smaller than the value calculated for dry air. In the visible region (405-644 nm) the relationship is

$$n_{tpf} - n_{tp} = -f \times R\,(3.7345 - 0.0401\,\sigma^2) \times 10^{-12}$$

where n_{tpf} is the refractive index of air containing water vapour at relative humidity R % and where f is the saturated (i.e. 100% RH) water vapour pressure in Pascal.

The saturated water vapour pressure f Pa, in air at temperature of T Kelvin, is given by the equation from Wagner and Pruss (1993).

$$\ln(f / f_c) = (a_1\tau + a_2\tau^{1.5} + a_3\tau^3 + a_4\tau^{3.5} + a_5\tau^4 + a_6\tau^{7.5})\,T_c / T$$

where	$\tau = 1 - T / T_c$	$a_1 = -7.859\,517\,83$	$a_4 = 22.680\,7411$
	$T_c = 647.096$	$a_2 = 1.844\,082\,59$	$a_5 = -15.961\,8719$
	$f_c = 22\,064\,000$ Pa	$a_3 = -11.786\,6497$	$a_6 = 1.801\,225\,02$

For example at 34 °C the saturated water vapour pressure is 5325 Pa.

For reference, the vacuum wavelength (λ_{vac}) and the wavelength in normal air (λ_{ntp}) at 101,325 Pa, 20°C, 50% RH, 450 ppm CO_2 (calculated as above) of the various Renishaw laser interferometer sources are as shown below.

Note: The vacuum wavelengths should be taken as *exact* values, the NTP values are *rounded* to nine significant figures.

Table G.1 – Vacuum wavelengths

Laser source	λ_{vac} (nm)	λ_{ntp} (nm)
RLE arm 1	632. 990 000	632. 818 270
RLE arm 2	632. 991 450	632. 819 719
XL-80, HS20	632. 990 577	632. 818 846

The derived (interpolated) system resolutions are also shown for reference in Table G.2. The numbers are again *rounded* to nine significant figures. The numbers in bold font are the reference values from which all the other values have been derived by using the Edlen equations above (to go from left to right in the table), or by dividing by successive powers of two (to go down the table).

Table G.2 – Derived system resolution

RLE ARM 1		RLE ARM 2		XL-80 and HS20	
Vacuum resolutions (nm)	NTP resolutions (nm)	Vacuum resolutions (nm)	NTP resolutions (nm)	Vacuum resolutions (nm)	NTP resolutions (nm)
632.990000	632.818270	**632.991450**	632.819719	**632.990577**	632.818846
316.495000	316.409135	316.495725	316.409860	316.495289	316.409423
158.247500	158.204567	158.247863	158.204930	158.247644	158.204712
79.1237500	79.1022837	79.1239313	79.1024649	79.1238221	79.1023558
39.5618750	39.5511418	39.5619656	39.5512324	39.5619111	39.5511779
19.7809375	19.7755709	19.7809828	19.7756162	19.7809555	19.7755890
9.89046875	9.88778546	9.89049141	9.88780811	9.89047777	9.88779448

G.3 Worked example – laser compensation

Figure G.3 below shows a laser interferometer encoder system fitted to the vertical (Y) axis of a horizontal arm milling machine. Positive (forward) movement of the Y axis occurs as the machine spindle moves up the column. The laser and interferometer are positioned at the top of the column and hence are located at the positive end of the axis. The retro-reflector is positioned close to the spindle centre-line. The figure shows the Y axis at the axis reference position. For simplicity of installation, workpiece thermal expansion compensation is also enabled at this position.

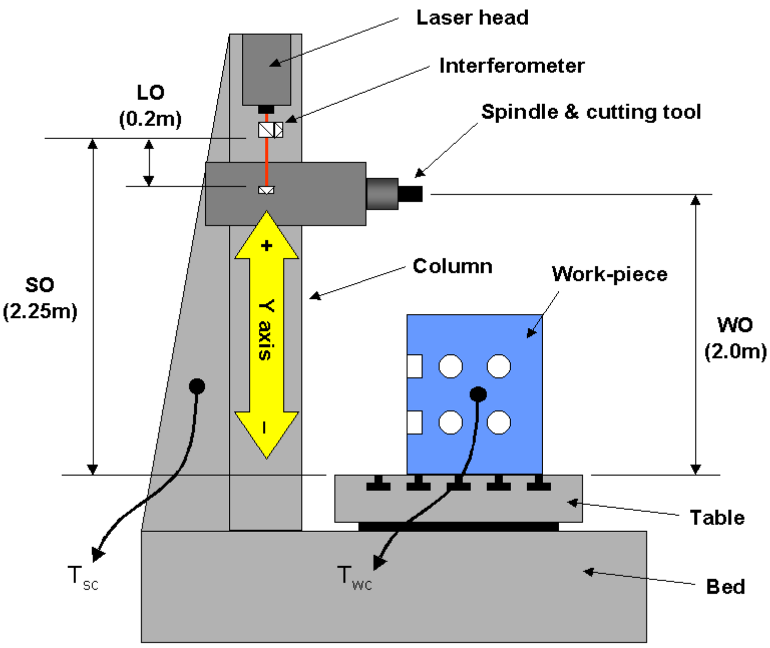

Figure G.3 – Worked example

The text describes how the laser dead path (LO), workpiece expansion offset (WO) and structure compensation (S) parameters are derived.

G.3.1 Direction sense setting

The RCU10 input quadrature direction sense is set so that input quadrature count (IQC) value becomes more positive as the Y axis moves in a positive (forward) direction (spindle assembly moves up the column). The RCU10 output quadrature direction sense is set so that the machine controller also shows positive (forward) movement as the spindle moves up the column.

G.3.2 Laser dead path (LO)

When the machine is at the axis reference position there is a small separation of 200 mm between the interferometer and moving reflector. The laser air dead path is therefore set to -0.2 m. A negative value is entered because the interferometer is located at the positive end of the axis, hence the separation between the optics increases as the axis is moved in a negative (reverse) direction.

G.3.3 Workpiece thermal expansion compensation (α_w, T_{wc}, WO)

The aluminium workpiece is mounted on the cast iron table of the machine. The linear coefficient of thermal expansion of the workpiece (α_w) is entered as 22 ppm/°C into the RCS software. A temperature sensor is fitted to the workpiece to measure the workpiece temperature (T_{wc}).

As the workpiece warms up, it will expand upwards, so the workpiece expansion origin is taken as the machine table surface. However, workpiece expansion compensation is enabled when the machine is at the axis reference (at which time the distance between the tool tip and the table surface is 2 m). It is therefore necessary to include workpiece thermal expansion origin offset compensation by setting WO to -2 m. The value is negative because the axis would have to travel in a *negative* (reverse) direction, in order to move the tool tip, from the point at which workpiece compensation is enabled, to the workpiece expansion origin.

G.3.4 Machine structure thermal expansion compensation (T_{sc}, S)

The interferometer is mounted at the top of the machine column. If the temperature of the column increases, then the column will expand and the interferometer will move upwards. The interferometer is the reference point from which the laser position feedback is derived. Therefore as the interferometer moves upwards, the machine spindle will also move upwards as the machine feedback loop maintains a constant laser based Y axis position.

Machine structure compensation can be used to eliminate this spindle movement. A temperature sensor is attached to the column (away from any localised heat sources) to measure the average column temperature (T_{sc}). The amount of structure compensation (S) required is calculated as follows:

The machine column is made from cast iron with an expansion coefficient of ~11 ppm/°C. The interferometer is fixed to the column at a height of 2.25 m above the machine table. It is therefore expected that the interferometer will move away from the machine table surface at a rate of:

$$2.25 \text{ m} \times 11 \text{ ppm/°C} = 24.75 \text{ µm/°C}$$

The machine structure compensation value (S) required is therefore -24.75 µm/°C. The value is negative because the axis (and hence the spindle) moves in the negative (reverse) Y direction as the temperature of the column rises.

Because the machine thermal behaviour may be quite complex, the value entered for S may be improved by performing a practical test. For example, a clock gauge can be used to measure how much the spindle moves, relative to the table surface, as the column temperature varies.

Note: This test must be performed with the machine in closed loop mode, holding a constant position readout under NC control, with laser wavelength and laser dead path compensations active, but with workpiece thermal expansion and machine structure thermal compensation inactive.

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Appendix H

Test records

Contained in this appendix

H.1 Installation and configuration checklist

Process	**Section in manual**	**Completed (✓)**
Hardware installation	4.1.1	
RCU10 address set-up	4.1.2	
Electrical installation	4.1.3	
RCU CS settings	4.1.4	
Configure system tab	4.2.1	
Configure sensor tab	4.2.2	
Configure compensation tab (including all sub-tabs for each axis)	4.2.3	
Configured parameter tab (all parameter tables validated)	4.2.4	
Transmit configuration	4.2.5	
Switch to compensation mode	4.2.5	
Validate configuration	4.3	

H.2 Installation details

<table>
<tr><td>Customer</td><td colspan="12"></td></tr>
<tr><td>Machine</td><td colspan="12"></td></tr>
<tr><td>RCU10</td><td colspan="2">Axis name</td><td colspan="2">Encoder type</td><td colspan="2">Encoder serial no</td><td colspan="2">RCU model</td><td colspan="2">RCU serial no</td><td colspan="2">Axis length</td></tr>
<tr><td>(example)</td><td colspan="2">X1</td><td colspan="2">RLE Ax1</td><td colspan="2">H11092</td><td colspan="2">RCU10-P</td><td colspan="2">H11802</td><td colspan="2">1000 mm</td></tr>
<tr><td>Axis 1</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Axis 2</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Axis 3</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Axis 4</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Axis 5</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>Axis 6</td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td>No. of parameter tables</td><td colspan="3">1</td><td colspan="3">2</td><td colspan="3">3</td><td colspan="3">4</td></tr>
<tr><td>Error indication</td><td colspan="6">Error</td><td colspan="6">Error, Suspend and Warning</td></tr>
<tr><td>Notes</td><td colspan="12"></td></tr>
<tr><td>Installation engineers</td><td colspan="12"></td></tr>
<tr><td>Date</td><td colspan="12"></td></tr>
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H.3 Sensor record/test sheet

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Sensor type	Serial number	Location/function	Connected to RCU axis number	☑
Example Air temperature	V12345	X axis laser	1	
Air pressure		----------		

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H.4 Parameter table record sheets

Table <1>: ______________________________________

1	Axis	Axis	Axis	Axis	Axis	Axis	Units (select)
Air dead path <1>							mm / m / inch
Workpiece temperature sensor <1>							Serial #
Workpiece expansion coefficient <1>							ppm/°C ppm/°F
Workpiece origin offset							mm / m / inch
Actuation method							-
Structure thermal compensation temperature sensor <1>							Serial #
Expansion coefficient <1>							ppm/°C ppm/°F
Expansion point offset <1>							mm / m / inch

Table <2>: ______________________________________

2	Axis	Axis	Axis	Axis	Axis	Axis	Units (select)
Air dead path <2>							mm / m / inch
Workpiece temperature sensor <2>							Serial #
Workpiece expansion coefficient <2>							ppm/°C ppm/°F
Workpiece origin offset							mm / m / inch
Actuation method							-
Structure thermal compensation temperature sensor <2>							Serial #
Expansion coefficient <2>							ppm/°C ppm/°F
Expansion point offset <2>							mm / m / inch

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Table <3>: ____

3	Axis	Axis	Axis	Axis	Axis	Axis	Units (select)
Air dead path <3>							mm / m / inch
Workpiece temperature sensor <3>							Serial #
Workpiece expansion coefficient <3>							ppm/°C ppm/°F
Workpiece origin offset							mm / m / inch
Actuation method							-
Structure thermal compensation temperature sensor <3>							Serial #
Expansion coefficient <3>							ppm/°C ppm/°F
Expansion point offset <3>							mm / m / inch

Table <4>: ____

4	Axis	Axis	Axis	Axis	Axis	Axis	Units (select)
Air dead path <4>							mm / m / inch
Workpiece temperature sensor <4>							Serial #
Workpiece expansion coefficient <4>							ppm/°C ppm/°F
Workpiece origin offset							mm / m / inch
Actuation method							-
Structure thermal compensation temperature sensor <4>							Serial #
Expansion coefficient <4>							ppm/°C ppm/°F
Expansion point offset <4>							mm / m / inch

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Index of figures and tables

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Part no.: M-9904-1122-09-C
Issued: 05.2023