User guide
F-9908-0294-01-B

RENISHAW
apply innovation™

XC-80

Environmental compensator

Legal information

Safety

Before using the laser system, please consult the laser safety information booklet.

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Renishaw plc declares that the XC compensator unit complies with the applicable directives, standards and regulations. A copy of the full EC declaration of conformity is available at the following address: www.renishaw.com/XLCE.

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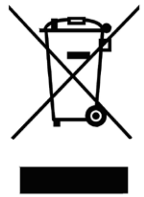

Correct disposal of this product will help to save valuable resources and prevent potential negative effects on the environment. For more information, please contact your local waste disposal service or Renishaw distributor.

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Contents

Introduction

The XC compensator is key to your laser system's measurement accuracy. By very accurately and precisely measuring environmental conditions, it compensates the wavelength of the laser beam for variations in air temperature, air pressure and relative humidity; virtually eliminating any measurement errors resulting from these variations.

Wavelength compensation

The sensor readings from the XC compensator are used to compensate the laser readings in linear measurement only. If compensation is not performed then variations in the refractive index of air can lead to significant measurement errors. Although it is possible to manually enter the environmental conditions (using handheld instruments etc), the benefit of using the XC compensator is that compensation is performed accurately and automatically updated every seven seconds.

Material thermal expansion compensation

The XC compensator can also accept inputs from up to three material sensors, which measure the temperature of the machine or material under test. Provided the appropriate material thermal expansion coefficient has been entered into CARTO software, this will allow measurements to be normalised to a machine (material) temperature of 20 °C.

Environmental compensation can be performed in three ways:

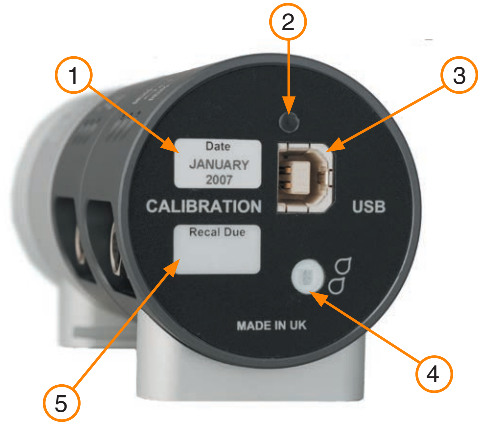
- Automatically updated environmental compensation with XC compensator.
- Manually updated environmental compensation with XC compensator.
- Compensation using manually entered data with no XC compensator.

A full XC compensator specification is given in the specifications section.

The XC compensator is supplied as part of a kit which includes a USB cable, one air temperature sensor and one material temperature sensor.

End panel

The end panel of the XC compensator includes the features shown below:



1	Calibration date
2	Status LED
3	USB socket
4	Relative humidity sensor
5	Recalibration due date

XC compensator connection and configuration

On the end panel of the XC compensator is a USB socket, which is used to connect the XC compensator to a PC via a USB cable (supplied with the XC compensator kit). This enables communication between the XC compensator and the PC and also provides power to the XC compensator and sensors.

Note: Install CARTO software before connecting the XC compensator to the PC. Software installation will ensure that the PC is correctly configured.

Environmental sensors

The air pressure and relative humidity sensors are contained within the body of the XC compensator. In order for the XC compensator to be accurate to within the quoted specification, it should be used with the long axis in a horizontal orientation as shown. Failure to do so may produce a small error in the air pressure readings, reducing the accuracy of compensated measurement readings.

Note: Do not obstruct the relative humidity sensor on the back cover.

Note: Relative humidity is only displayed in the software when the air temperature sensor is connected to the XC compensator.

The air temperature and material temperature sensors shown are separate items and are supplied together with communication cables. Each cable has a female threaded connector to join it to the sensor and a male threaded connector to join it to the corresponding socket on the side of the XC compensator.

Renishaw supplies one material temperature sensor and one air temperature sensor as standard with each XC compensator. For machines with long axes, up to three material temperature sensors may be connected to the XC compensator. Additional material temperature sensor kits may be obtained by contacting your local Renishaw distributor.

The air and material temperature sensors are supplied with 5 m (16.5 ft) cables. These may be combined as required up to a maximum cable length of 60 m – this allows the sensors to be positioned at specific locations on the machine being measured. Additional and replacement sensors and cables may be obtained by contacting your local Renishaw distributor.

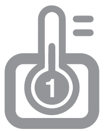
To enable the user to easily identify which cable is connected to which sensor, the cables are supplied with removable naming tags. The cables should be stored attached to their sensors; provision is made for this in the system case.

The temperature sensors contain magnets for attachment to steel or cast iron surfaces, with a ‘through’ hole for a ‘screw-down’ attachment if required.

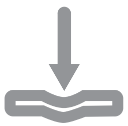
The air and material temperature sensors will only operate if connected to the correct sockets on the XC compensator. Symbols which correspond to the different types of sensor are marked on the side of the XC compensator. The air temperature sensor must be connected to the socket marked with the air temperature symbol shown below. Material temperature sensors can be connected to any socket marked with a material temperature symbol.

Sensor symbols

Air temperature



Material temperature 1



Air pressure

Material temperature 2

Relative humidity

Material temperature 3

The air and material temperature sensor symbols are also marked on the side of the sensors themselves.

Note: There are no sockets for air pressure and relative humidity, as these sensors are built into the XC compensator body.

LEDs

Sensor LEDs

Located on the side of the XC compensator beneath the sensor symbols are six sensor LEDs, corresponding to the air pressure, relative humidity, air temperature and three material temperature sensors. The colour of the LED denotes when a reading is being taken from the sensor, and subsequently the validity of this reading.

The XC compensator interrogates each sensor in turn for seven seconds, on a continuous cycle. As each sensor is interrogated, the corresponding LED turns amber. On receipt of a valid reading from the sensor the LED turns green. If the sensor is not connected or it has a fault, the LED turns red. The values used for wavelength compensation are updated after each sensor reading (every seven seconds).

Status LEDs

On the end panel of the XC compensator is a status LED. This LED turns red when the power is applied to the unit (i.e. when it is connected to the computer via a USB cable) and then turns green when it is ready to start measuring.

XC compensator calibration

To maintain the Renishaw calibration system within its specified accuracy, we advise that the XC compensator and its sensors are calibrated annually. More frequent calibration is advised for units used in extreme environmental conditions, or where damage is suspected. The requirements of your quality assurance programme or national/local regulations may also dictate more frequent recalibration. On the end panel of the XC compensator is a space in which to indicate the recalibration due date. During storage, transportation and use, the XC compensator and sensors should not be subjected to excessive shock, vibration or extremes of temperature, pressure or moisture (see specifications), since any of these factors could invalidate their calibration.

The uncertainty of calibration calculations have been carried out according to the European co-operation for Accreditation document EA-4/02.

All calibrations are included within the scope of Renishaw's EN ISO 9001:2000 quality assurance system. The system is audited and certified by a UKAS accredited agency. UKAS accreditation is recognised in many countries world-wide by the relevant national body in that country.

For details of the calibration procedure refer to the calibration certificates supplied with your system, or visit www.renishaw.com/certificates

The errors and uncertainties associated with normalisation of readings to a material temperature of 20 °C are not included in the system accuracy. These errors and uncertainties will depend not only on the material temperature sensor being within specification (as evidenced by a recent Renishaw calibration certificate), but also on the accuracy of value of expansion coefficient entered into the calibration software, the temperature differential from 20 °C, and the correct placement of the sensors.

Renishaw offers a full recalibration and repair service for XC environmental compensation units and their sensors at its UK factory. Comparative XL laser system recalibrations are available in Renishaw's USA, Germany and China subsidiaries. For more information, refer to your local Renishaw distributor or the Renishaw.com website.

Wavelength compensation

The accuracy of linear positional measurements depends on the accuracy to which the wavelength of the laser beam is known. This is determined not only by the quality of the laser stabilisation, but also by ambient environmental parameters. In particular, the values of air temperature, air pressure and relative humidity will affect the wavelength (in air) of the laser beam.

If the variation in wavelength is not compensated for, then linear laser measurement errors can reach 50 ppm. Even in a temperature-controlled room the variation in day-to-day atmospheric pressure can cause wavelength changes of over 20 ppm. As a guide, an error of approximately 1 ppm will be incurred for each of the following changes in the environmental conditions:

Air temperature	1 °C
Air pressure	3.3 mbar (0.098 in Hg)
Relative humidity (at 20 °C)	50%
Relative humidity (at 40 °C)	30%

Note: These values are worst case, and they are not entirely independent of the values of the other parameters.

These errors can be reduced by using an XC compensator environmental compensation unit.

The XC compensator measures the air temperature, pressure and humidity, then calculates the air's refractive index (and hence the laser wavelength) using the Edlen equation. The laser read-out is then automatically adjusted to compensate for any variations in the laser's wavelength. The advantage of an automatic system is that no user intervention is required and that compensation is updated frequently.

Wavelength compensation only applies to linear measurements. For other measurements (angle, flatness, straightness etc), environmental influences are far less significant, as environmental changes affect both the measurement and the reference beams to a similar degree.

Positioning of air sensors

Positioning of air temperature sensor

CAUTION

To ensure thermal stabilisation, the air temperature sensor should be in the measurement environment for up to 15 minutes before starting measurement.

The air temperature sensor should be placed as close as possible to the laser beam's measurement path and about halfway along the axis of travel. Avoid placing the sensors close to localised heat sources, for example motors, or in cold draughts.

When measuring long axes, check for the presence of air temperature gradients. If the air temperature changes by more than 1 °C along the axis, use a fan to circulate the air. (This is particularly relevant on long vertical axes where air temperature gradients are more likely.) Avoid routing sensor signal leads close to sources of major electrical interference such as high power or linear motors.

For ease of mounting, the air temperature sensors have a 'through hole' to enable them to be bolted to a surface.

Air pressure and relative humidity sensors

The pressure and humidity sensors are mounted within the XC compensator environmental compensation unit. In general, it is not necessary to measure air pressure or relative humidity in the immediate vicinity of the beam path. This is because large variations in pressure and humidity are required to give a significant error in measurement and there should be no significant variation in either, across the work area. However, the relative humidity sensor should be positioned away from sources of heat or draught.

It is important to ensure the humidity sensor is not obstructed when mounting.

When calibrating vertical axes over 10 metres long, it is also recommended to place the pressure sensor halfway up the axis of travel.

Material thermal expansion compensation

The international reference temperature used by the calibration community is 20 °C and CMMs and machine tools are normally calibrated with reference to this temperature. In a normal factory environment where precise temperature control is often not available, the machine will not be at this temperature. Because most machines expand or contract with temperature, this could cause an error in the calibration.

To avoid this calibration error, the linear measurement software incorporates a mathematical correction called thermal expansion compensation or 'normalisation' which is applied to the linear laser readings. The software normalises measurements using the coefficient of expansion, which must be entered manually, and a mean machine temperature measured using the XC compensator. The objective of this correction is to estimate the laser calibration results that would have been obtained if the machine calibration had been performed at 20 °C.

Material thermal expansion coefficients

The amount that most materials expand or contract with changing temperature is very small. For this reason, the thermal expansion coefficient is specified in parts per million per degree C (ppm/°C). These coefficients specify the amount that the material will expand or contract for every degree rise or fall in material temperature. For example, suppose the coefficient of thermal expansion is +11 ppm/°C. This means that for every 1 °C rise in material temperature, there will be a material expansion of 11 ppm, which is equivalent to 11 micrometres per metre of material or 11 microinches (.000011 in) per inch of material.

Incorrect compensation for material thermal expansion is one of the primary sources of error in laser linear distance measurements in non-temperature controlled environments. This is because the expansion coefficients of common engineering materials are relatively large compared to the coefficients associated with wavelength compensation errors and laser beam alignment errors.

The normalised measurement will have an error relating to the measurement accuracy of the material temperature sensor. The size of this error depends on the thermal expansion coefficient of the machine under test. The material temperature sensor has an accuracy of ±0.1 °C and therefore if the machine under test has a thermal expansion coefficient of 10 ppm/°C, then the error in the normalisation of the measurement would be ±1 ppm. This is in addition to the system measurement accuracy (±0.5 ppm) when using the XC compensator environmental compensation unit.

However, since the two errors are uncorrelated, their combined effect is the square root of the sum of their squares and not their arithmetic sum. Thus, for the above example, the normalised measurement accuracy will be ±1.2 ppm for the laser and XC compensator systems.

Additional measurement errors will occur if an incorrect thermal expansion coefficient is entered into the software. Since the values of the thermal expansion coefficients of different machines can vary by 10 ppm/°C or more, care should be taken to ensure that the correct values are entered. If necessary, seek the advice of the machine's manufacturer.

The expansion coefficient of the machine's feedback system is normally entered into the software, unless you are estimating the accuracy of machined parts when returned to 20 °C. The table below gives typical expansion coefficients for different materials used in construction of machines and their position feedback systems.

Note: Since material expansion coefficients can vary with material composition and treatment, these values are for guidance only and should only be used in the absence of manufacturer's data.

Material	Application	Expansion coefficient ppm/°C
Iron/steel	Machine structural elements, rack and pinion drives, ballscrews	11.7
Aluminium alloy	Lightweight CMM machine structures	22
Glass	Glass scale linear encoders	8
Granite	Machine structures and tables	8
Concrete	Machine foundations	11
Invar	Low expansion encoders/structures	<2
Thermally stable glass	Zero expansion encoders/structures	<0.2

When trying to identify the expansion coefficient, be particularly careful where there are two materials with different coefficients fixed together. For example, in the case of a rack and pinion feedback system, the expansion coefficient may be closer to the cast-iron rail to which the rack is fixed. In the case of large gantry machines with floor mounted rails, the expansion coefficient of the rail may be reduced by the restraining action of the concrete foundations. Also, many modern scales are composed of a number of different materials, e.g. a glass scale may be bonded to an aluminium spar which is mounted, in turn, on a cast-iron machine member. In such cases, selection of the appropriate coefficient can be difficult. You should seek the advice of the manufacturer of the scale and/or the machine on which it is used.

Positioning of material sensor

CAUTION

To ensure thermal stabilisation, the material temperature sensor should be fixed to the material for 25 minutes before starting measurement.

When positioning the material temperature sensors, the first step is to decide on your primary objective for performing material expansion compensation. This is usually one of four possible objectives.

1. To estimate the linear positioning accuracy that would be obtained if the machine was operated in an ambient environment of 20 °C. This is often the objective during machine build, sign off, commissioning or recalibration, and in most cases is the same as defined in a National or International Machine Acceptance Standard.
2. To perform a calibration in accordance with a National or International Machine Acceptance Standard.
3. To estimate the linear accuracy that the machine feedback system could achieve if the feedback system was at a temperature of 20 °C. This is useful for diagnosing faults in the feedback system.
4. To estimate the accuracy of parts that the machine will produce when those parts are returned to 20 °C for inspection. This objective is particularly important in the production of accurate non-ferrous parts in non-temperature controlled shops, where machine feedback and workpiece expansion coefficients differ significantly.

The differences between these objectives are often significant, particularly if the machine position feedback system gets hot during machine operation (for example a ballscrew), or if the workpiece expansion coefficient is significantly different from that of the position feedback system, for example, an aluminium workpiece with glass scale linear encoders.

The material temperature sensor supplied with the XC compensator has a strong magnetic base for ‘clamping’ to the machine under test. Ensure there is good thermal contact between the material temperature sensor and the material being measured.

Estimate accuracy of the machine if it was operated in 20 °C environment

To estimate the accuracy of the machine if it was operated in an environment of 20 °C, the material temperature sensor(s) should be placed on the table of the machine or on some other massive part of the machine structure that is NOT close to any sources of heat such as motors, gearboxes, bearing housings, exhausts etc. The material expansion coefficient should be set to that of the feedback system.

Calibration in accordance with National and International Standards

To calibrate the accuracy of the machine in accordance with a National or International Standard, the procedure defined in the standard should be followed. This should cover where to place the material sensor, what expansion coefficient to use, and what machine warm up cycle to perform. If a thermal drift test is also defined in the standard, this must also be included.

If the air and machine temperatures are significantly different, then it is also likely that there are significant temperature differences between material surface and core temperatures. Under these circumstances, care should be taken to locate the material temperature sensors where they will measure the core temperature. The temperature can be measured at a number of points using up to three material sensors and the compensation factor applied will be based on an average value.

It is a common misconception that material sensors should always be placed on the ballscrew, or feedback system. This is not always the case, as the following example illustrates.

Example:

Suppose a machine is being calibrated in a shop at 25 °C, and because of heat generated by machine operation, the ballscrew is 5 °C warmer, at 30 °C. If the material sensors are placed on (or very close to) the ballscrew, the laser readings will be compensated to estimate the readings that would have been obtained if the ballscrew was operating at 20 °C. However, if the machine were being operated in an environment at 20 °C, the ballscrew would NOT be at 20 °C.

The heat generated by operation of the screw and the motor would still be there, so the ballscrew temperature would still be about 5 °C warmer than ambient (25 °C). Putting the material sensor(s) on the ballscrew will therefore result in overcompensation. It is better to place the sensor(s) on a massive part of the machine to give a temperature reading related to the average ambient temperature around the machine over the last few hours.

Estimate accuracy of machine feedback system if it was at 20 °C

This procedure is often used for diagnostic purposes. Perhaps the machine has failed calibration against Objective 1 or 2, and the accuracy of the feedback system at 20 °C now needs verifying. To meet this objective, the laser beam should be aligned as close to the axis of the feedback system as possible (to minimise Abbé offset error).

The material temperature sensor(s) should be placed on (or very near to) the feedback system and the expansion coefficient should be set to that of the feedback system. The temperature can be measured at a number of points using up to three material sensors.

Manufacture of parts which must be accurate at 20 °C

If a machine tool is always used to machine workpiece materials with a significantly different expansion coefficient to those of the feedback system, for example, aluminum alloys, carbon composites, ceramics, etc., it may be beneficial to use the expansion coefficient of the workpiece and not the one of the machine feedback system. Although this will not give a calibration that represents the performance of the machine at 20 °C, it can improve the accuracy of the workpieces when they are returned to 20 °C for measurement.

The material temperature sensor(s) should be located to measure a temperature similar to that expected of the workpiece. This is often on the table of the machine, but other factors like the type of coolant system employed and the metal removal rates may need to be considered. Care should also be taken to perform this type of calibration under typical conditions, and it can only be truly effective if the temperature and expansion coefficients of the various workpieces are relatively consistent.

Automatic compensation

Automatic environmental compensation uses the XC compensator environmental compensation unit to perform laser wavelength compensation and material thermal expansion compensation. If calibration is being performed in an environment where the atmospheric conditions are likely to vary during the test, then automatic compensation is strongly recommended.

To perform automatic compensation first connect the air and material temperature sensors to the appropriate sockets in the side of the XC compensator. Refer to environmental sensors for more information. Next connect the XC compensator to the PC using the USB cable provided.

In Capture, the XC device monitor panel will indicate that the XC compensator is available. Environmental compensation is now performed automatically.

XC compensator readings are taken every seven seconds, and are used to compensate the laser readings accordingly. Refer to XC compensator update cycle for more information.

To define the default environmental units which are used select 'more', 'settings', then 'environmental units'.

CAUTION

Before starting any calibration run:

Make sure that the machine to be calibrated has been exercised sufficiently to warm up the drive and scale of the axis to be calibrated.

Make sure that the correct value has been entered for the coefficient of thermal expansion by adjusting the material expansion compensation parameter.

XC compensator update cycle

Every seven seconds, a reading is taken from one of the six environmental sensors and passes to the PC. With this reading, the environmental compensation factor is updated. The order in which the environmental sensor readings are taken is as follows: air temperature, relative humidity, air pressure and the three material temperature sensors.

Fixed material compensation

Certain machine applications may require the user to enter a fixed material temperature value for compensation. An example of this is a machine with a built in material sensor or sensors and cooling system to maintain the bed at a controlled temperature.

To use a fixed material temperature, go to 'Machine' in the 'Define' tab in Capture and select 'Fixed material temperature'. The user can input the fixed temperature value here.

Specifications

Introduction

This section, together with the weights and dimensions section, summarises the physical and operational specifications of the various components of the system.

Renishaw reserves the right as part of their policy of continued product improvement to change the appearance or specification of the product without notice.

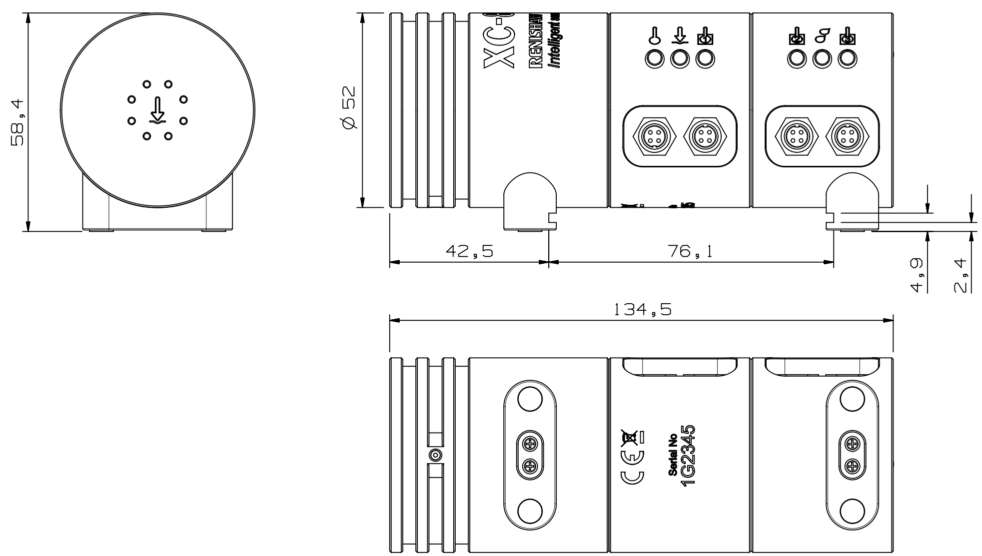
System storage	
Storage temperature range	-25 °C – 70 °C
Storage humidity range	0% – 95% non-condensing
Storage pressure range	10 mbar – 1200 mbar

XC environmental compensation unit and sensors	
Air temperature sensor measurement range	0 °C – 40 °C
Air temperature sensor measurement accuracy	±0.2 °C
Air pressure sensor measurement range	650 mbar – 1150 mbar
Air pressure sensor measurement accuracy	±1.0 mbar#
Relative humidity sensor measurement range	0% – 95% (non-condensing)
Relative sensor measurement humidity accuracy	±6%
Wavelength compensation accuracy	±0.5 ppm †*
Material temperature sensor measurement range	0 °C – 55 °C
Material temperature sensor measurement accuracy	±0.1 °C
Automatic compensation update interval	7 seconds
Individual sensor update interval	42 seconds
Recommended recalibration period	12 months
Outputs	USB 2 compliant
Power supply	Powered via USB Maximum current usage = 100 mA
# XC compensator in a horizontal orientation	
† Note: The accuracy values do not include the errors associated with the normalisation of the readings to a material temperature of 20 °C. * k=2 (95% confidence) EA-4/02, ISO	

Weights and dimensions

XC environmental compensation unit (dimensions in mm)

Description	Weight
XC-80 compensator	490 g
Air temperature sensor	48 g
Material temperature sensor	45 g



Part numbers

Part number	Includes	Part number
A-9908-0510 XC-80 compensator kit	XC-80 compensator	N/A
	Material temperature sensor and cable	A-9908-0879
	Air temperature sensor and cable	A-9908-0879
	XC mounting plate	A-9908-0892
	USB cable	A-9908-0286

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