Gas-tight Oxygen Probe
SIRO$_2$ DS Probe

Revision 1.1, April 2019

Contents

1   Revision History

Initial release – First draft 8 March 2017.

Update Section 11 Theory of operation – 14 March 2017:

- Use with standard equipment having an input impedance of 1 MΩ, the lowest operating temperature based upon the Arrhenius impedance temperature relationship will be approximately 600 °C.

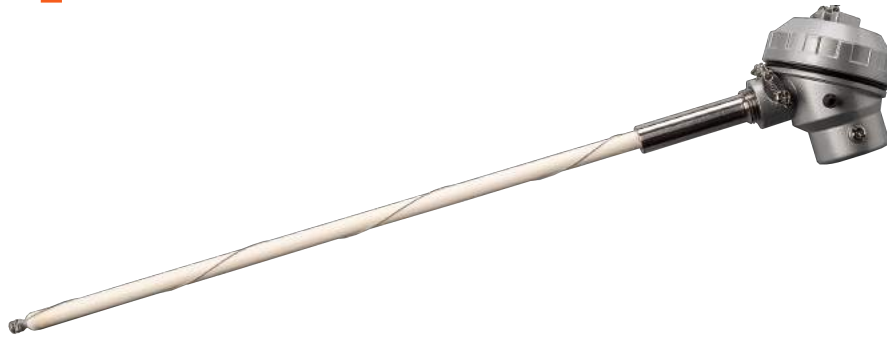- Update Section 6: Equipment setup.

Update Section 3 Specification – April 2017:

- Introduction of temperature limit on the control head.

Update Section 9 Thermocouple Ranges – April 2019

- Correction to K or N type thermocouple ranges

SIRO$_2$ DS Probe

2   Description

The DS gas-tight probe incorporates a SIRO$_2$ all ceramic oxygen sensor. The DS probe comes with an optional ceramic sheath for extended life and additional protection. The probe design is specifically intended for small apertures into furnaces. It is used for measurement and control of oxygen sensitive environments at high temperatures. The sensor operates in situ, and measures oxygen concentration in real time, without the need for expensive gas sampling, or gas extraction equipment. The probe comes with a K- or R-type thermocouple.

Features

- Specific for O$_2$
- High O$_2$ sensitivity and selectivity
- High dynamic range of detection
- High temperature of operation
- Rapid responses
- In situ measurement
- Solid state electronic component – rugged sensor
- No power consumed for operation under all conditions
- No bias required to operate
- Available up to 1350 mm

Applications

- Fuel combustion efficiency control
- Furnace gas analysis
- Temperature and oxygen control of kilns
- Potters' kilns
- Large and small electric kilns
- O$_2$ levels at high temperatures
- CO$_2$ harsh environments
- Technical ceramic kiln systems
- Industrial applications
- Molten systems (single use only)
- Copper reverberator

3   Specifications

Thermal				
Parameter	Minimum	Typical	Maximum	Unit
Operating temperature†	600	1200	1650	$^{\circ}$C
Operating temperature	1112	2192	3002	$^{\circ}$K
Control head operating temperature	—	60	80	$^{\circ}$C
Ramp rate	—	—	400	$^{\circ}$C/hour
Storage	5	20	50	$^{\circ}$C

Electrical				
Parameter	Minimum	Typical	Maximum	Unit
Output voltage range	2.0	1130	1400††	mV @ $T \geq 700\ ^{\circ}$C
Output impedance	1.00	2.00	10.00	kΩ @ $T \geq 700\ ^{\circ}$C
Response time	10	20	10000	ms @ $T \geq 700\ ^{\circ}$C
Offset Error @ 700°C **	1	± 2	–	mV @ $pO_2 = pO_2'$

Measurement Range				
Parameter	Minimum	Typical	Maximum	Unit
O_2 Atmosphere	10^{-24}	–	1	pO_2 @ $700\ ^{\circ}$C
O_2 Atmosphere	10^{-12}	–	1	pO_2 @ $1300\ ^{\circ}$C
Gas tight - pressure tested	–	–	–	kpa (psi)
Reference air	1	10	20	mL/min

Probe Mechanical				
Parameter	Minimum	Typical	Maximum	Unit
Sensor outer Diameter	7.86	8.00	8.15	mm
Length	300	–	1350	mm ± 3 mm
Weight	0.5	–	1.5	kg

Sheath Mechanical Ceramic				
Parameter	Minimum	Typical	Maximum	Unit
Outer Diameter	14.9	15.0	15.5	mm
Probe length	300	–	1350	mm ± 3 mm
Weight	1	–	3	kg

Electrical Connections			
Description	Pin No	Type	Wiring (internal)
Thermocouple positive leg	1	Output	Black (thermocouple $+$)
Thermocouple negative leg	2	Output	Red (thermocouple $-$)
Sensor internal (reference) connection	3	Output	Blue (O_2, sense-reference)
Sensor external (sense) connection	4	Output	Grey (O_2, sense-chamber)

Connector		
Mating connector	Manufacturer	Part Number
4 Pin male XLR Cannon	Switchcraft	QG4M

† Continuous use of sensor above 1300 $^{\circ}$C reduces the lifetime of the sensor.

†† Under some conditions, an output voltage of 1650 mV may be observed. Readings above 1400 mV or greater than 1600 degrees may result in erroneous readings. Absolute maximum output voltage without damage to the sensor for the given atmosphere of 10^{-24} oxygen concentration. The sensor will provide an output response above 1130 mV, however lifetime cannot be guaranteed under these operating conditions.

** Offset error should be subtracted from the voltage reading during measurements for high accuracy applications. Also, note that this off-set value is temperature dependent.

The sensor within a probe can be installed anywhere in the kiln or furnace if used at temperatures below 1100°C. For operating temperatures above 1100°C, the probe should hang vertically, to avoid sag and loss of internal electrical contact. When hanging vertically, the installer must provide appropriate insulation around the probe entry point, to ensure probe head does not overheat.
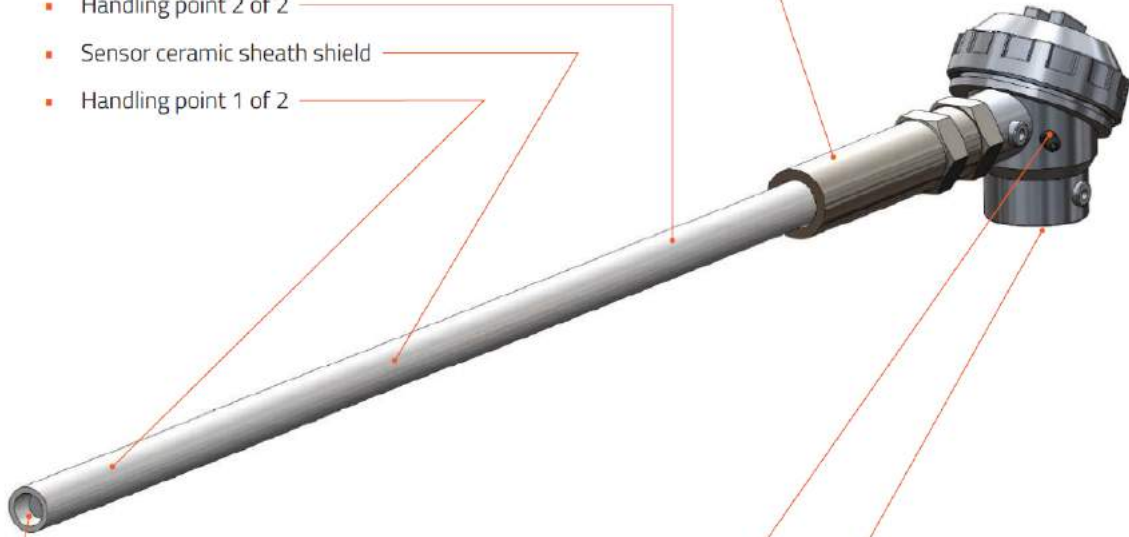
4   Features DS Probe

- Probe head
- Reference air
- Stainless steel sheath support
- Electrical connections

5   Features DS Probe Sheathed

- Stainless steel sheath support
- Handling point 2 of 2
- Sensor ceramic sheath shield
- Handling point 1 of 2

- Oxygen sensor tip
- Reference air
- Electrical connections

6   Installation

The standard DS probe must not be handled by the probe head.

The ceramic sheathed DS probe must be handled by the ceramic sheath with no weight or force applied to the head assembly. Two hands should be applied at the quarter mid-points of the ceramic sheath. Carefully insert the probe into the furnace aperture. Once the probe has been inserted the instrument interface cable and reference air may then be connected. The DS-1200-K-FLS is shown below installed into a furnace having a wall thickness of 750 mm.

7   General Measurement Setup

Key to accurate measurements of the oxygen concentration of the gaseous environments is the measurement setup, namely:

1. Probe location;

2. Electrical interface;

3. Measurement instrumentation;

4. Reference air and air flow rate.

7.1   General Setup

Ideal electrical interface to the probe will have the following characteristics, and include a diaphragm air pump to supply the clean reference air.

Oxygen Sensor Measurement Instrument		
Parameter	Typical	Unit
Ideal input impedance	1	TΩ
Input voltage range	$\pm$ 2000	mV
Filter	50 – 60	Hz
Thermocouple Measurement Instrument		
Parameter	Typical	Unit
Ideal input impedance	10	MΩ
Input voltage range	$\pm$ 100	mV
Filter	50 – 60	Hz

- Probe location

In all systems monitoring oxygen concentrations of gases in high temperature environments, the probe sensor needs to be positioned where the gas reaction requiring measurement occurs. This means that the probe length needs to accommodate the distance from the outside flue or kiln wall, through the thermal insulation, and then to the point of measurement. The measurement should be as close as possible to where the bulk of the gas measurement occur.

- Electrical interface

Electrical interface between the probe measuring the oxygen concentration and the temperature is a potential source of measurement error. This measurement error manifests as noise in the thermocouple and oxygen monitoring cables. The DS Probe uses a K-Type thermocouple, and so a K-Type thermocouple compensation cable should be used to to connect the probe to the measurement instrument. To reduce the potential of noise corrupting the oxygen sensing cables, a twisted paired should be used, and it is preferable to use a shielded twisted pair cable if available, grounding at the measurement instrument.

- Measurement instrumentation

Measurement instruments are intended to monitor and record, without influencing the signal. In a perfect measurement world, the measurement instruments would have an infinite input impedance.

The reality of test and measurement equipment is quite different. The actuality of measurement equipment is that they do have an input impedance, and this input impedance directly alters the signal being measured.

Similarly for the frequency response. A measurement instrument with a lower frequency response than that exhibited by the signal being measured will mean information about the signal monitored will be lost.This directly equates to signal changes not being fully observed or even missed.

Generally speaking, to achieve low measurement errors, the measurement instrument will need to have several orders of magnitude higher input impedance to accurately measure the signals presented at its input.

- Reference air and flow rate

Clean reference air is essential. A key metric of the reference air cleanliness is that it is breathable. If the air is not good for people or somehow contaminated, then it cannot be used as the reference air. The reference air flow rate should be within the range stipulated in Specification section.

8 Thermocouple interface

Connecting the thermocouple to instrumentation must be done with consideration to optimize accuracy and, ensure unwanted noise does not appear in the measurement process. The resultant temperature measurement is only as accurate as the sensor and its interface.

The thermocouple produces a small thermo-electric electromotive force (emf), typically 40 V/°C and it is necessary to minimize spurious thermal emf signals and ohmic effects which would otherwise result in incorrect readings.

The length of cable used between the sensor and the instrument is an important consideration because the line resistance has to be taken into account (although the instrument input is effectively high impedance, typically 1 MΩ - 10 MΩ). Most instruments specify a maximum of 100 Ω loop cable resistance without accuracy being compromised.

With long cable runs, the cable may need to be screened and earthed at one end (at the instrument) to minimize noise pick-up (interference) on the measuring circuit.

An extension cable uses true thermocouple wire and is designated X (e.g. KX for type K); compensation cable has a C designation (e.g. KC for VX, type K) and consists of VX and U types. An extension cable should be selected for its temperature and electromotive force relationship to an appropriate standard over the complete temperature range, for the thermocouple used. This cable can then be used for joining thermocouples to their measuring instruments.

Compensating cable, which uses lower cost alloys, has a different composition to an extension cable but still having a similar temperature versus electromotive force relationship, but only over a limited environmental temperature range. Therefore, compensating cables should only be used for short distances to connect thermocouples to their measuring instruments. Due to these differences in electromotive force generated for temperatures in contrast to thermocouple voltages, these cables cannot be used at temperatures above ambient. This means that care must be taken to ensure the entire electrical connection from the probe to the measurement device is at ambient. For example, the temperature at the probe head connector can be higher than ambient, and so this will cause a voltage to be generated in the compensating cable that can influence the overall voltage measured by the instrumentation, and so result in an error in actual temperature reading.

Direct connection is made using an appropriate type of cable; this is indicated by colour coding according to IEC 584-3 on the insulation. Correct polarity and a mechanically sound connection is vital.

Compensation and extension cables should be used for all measurements with thermocouples. The reference air and compensation or extension cables are available on request, and are quoted for separately. Standard shielded signal cable can be used for interfacing the oxygen sensor to the measurement instruments. For best performance, the measurement made should be using differential inputs to the instrument to remove unwanted common mode noise.

Australian Oxytrol Systems supplies interface cable that supports the following connections:

(i) R or K type compensation cable

(ii) Electrical interface for O_2 sensor

(iii) Reference air

9 Thermocouple ranges

	Temperature Range		Tolerances-Reference			
			Standard Tolerances		Special Tolerances	
Type[†]	°C	°F	°C	°F	°C	°F
T	-200 to 0	-328 to 32	± 1.0 or ± 1.5 %		††	
T	0 to 370	32 to 700	± 1.0 or ± 0.75 %	Note 1	± 0.5 or 0.4 %	Note 1
J	0 to 760	32 to 1400	± 2.2 or ± 0.75 %		± 1.1 or 0.4 %	
E	-200 to 0	-328 to 32	± 1.7 or ± 1 %		††	
E	0 to 870	32 to 1600	± 1.7 or ± 0.5 %		± 1.0 or 0.4 %	
K	-200 to 0	-328 to 32	± 2.2 or ± 2 %		††	
K or N	0 to 1260	32 to 2300	± 2.2 or ± 0.75 %		± 1.1 or 0.4 %	
R or S	0 to 1480	32 to 2700	± 1.5 or ± 0.25 %		± 0.6 or ± 0.1 %	
B	870 to 1700	1600 to 3100	± 0.5 %		± 0.25 %	
C	0 to 2315	32 to 4200	± 4.4 or ± 1 %			

† K and R type thermocouples are standard options for probes.

†† Special tolerances for temperatures below 0°C are difficult to justify, values for Type E and T thermocouples are suggested as a guide.

Type E (-200 to 0) °C ± 1 °C or ± 0.5 %, whichever is greater

Type T (-200 to 0) °C ± 0.5°C or ± 0.8 %, whichever is greater

Note 1: The Fahrenheit tolerance is 1.8 times larger than the °C tolerance at the equivalent °C temperature. Note particularly that percentage tolerance applies only to temperatures expressed in °C.

10 Sensor Interface

The instrument interfacing to the sensor should support positive and negative voltage polarities, with the measurement instrument having a high input impedance, typically TΩ. For best performance, the measurement made should be using differential inputs to the instrument to remove unwanted common mode noise.

11   Theory of operation

The zirconia-based pellet in the sensor is an oxygen ion conducting solid electrolyte. When the sensor is exposed to different partial pressures of oxygen, across the internal and external faces, an electromotive force is produced. The generated electromotive force follows the Nernst equation:
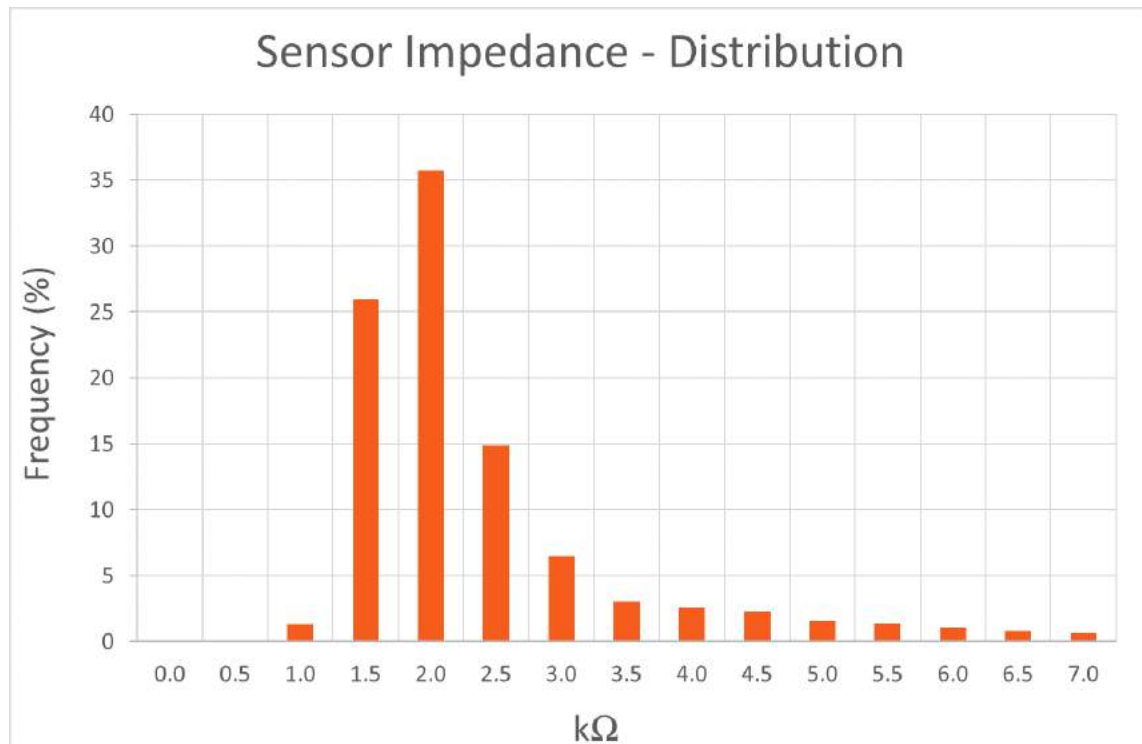
$$E = \frac{RT}{4F} ln \left(\frac{pO_2}{pO_2'} \right)$$

- E is the electromotive force as a voltage (V);

- T is the temperature in degrees Kelvin;

- pO_2' partial pressure of oxygen in reference air (inside sensor);

- pO_2 partial pressure of oxygen in test gas (outside sensor);

- F Faraday's constant 96485 C mol^{-1};

- R Gas constant 8.3145 $JK^{-1}mol^{-1}$.

The reference partial pressure of gas is 20.9 %, making pO'_2=0.209. Note, COF's convention is for reducing atmospheres ($pO_2 < 0.209$) to result in a negative E value. Rearranging for the partial pressure of oxygen external to the reference partial pressure of oxygen:

$$pO_2 = pO_2' e^{\frac{4FE}{RT}}$$

The source impedance of the sensor is subject to the temperature of operation, and varies subject to gas conditions, temperature and reference air. The sensor impedance varies, presenting as an open circuit when cold; MΩ at low temperatures; kΩ at operating temperatures of 700 °C and above. The operating impedance has a range subject to manufacturing tolerances, and can been seen as a distribution below (700 °C).

12 Example calculations and error propagation

12.1 Calculating voltage (for calibrated gases)

Using the Nernst equation to calculate sensor output voltage with respect to known oxygen concentration.

$$E = \frac{RT}{4F} ln \left(\frac{pO_2}{pO_2'} \right)$$

- E is the electromotive force as a voltage (V);
- T is the temperature in degrees Kelvin;
- pO_2 partial pressure of oxygen outside;
- pO_2' partial pressure of oxygen inside;
- F Faraday's constant 96485 C mol^{-1};
- R Gas constant 8.3145 $JK^{-1}mol^{-1}$.

Using the following values:

1. Kiln temperature measured by the probe is 700 °C;
2. Partial pressure of O_2 in reference air of 0.2095 (or 20.95%)[†];
3. Measurement air to have 1 % oxygen concentration (partial pressure of 0.01);
4. E is the unknown component.

† Since the partial pressure of reference air (oxygen inside) and measurement air (oxygen outside) concentrations are taken as a ratio, this ratio becomes dimensionless.

$$E = \frac{RT}{4F} ln \left(\frac{pO_2}{pO_2'} \right)$$

The above can now be written as follows:

$$E = \frac{8.3145 JK^{-1}mol^{-1} \left(700°C + 273.15 \right)}{4.96485 C mol^{-1}} ln \left(\frac{0.01}{0.2095} \right)$$

$E = -0.063768V$ or $E = -63.768mV$

12.2 Calculating oxygen concentration (for measured EMF readings

Rearranging the Nernst equation to calculate oxygen concentration from the sensor output, as a measured millivolt reading.

$$pO_2 = pO_2' \cdot e^{\frac{E \cdot 4F}{RT}}$$

Using the following known values:

1. Kiln temperature measured by the probe is 700 °C;
2. Partial pressure of O_2 in reference air of 0.2095 (or 20.95%)[†];
3. E is the known component, E=-0.063768 V (as measured);
4. pO_2 is the unknown component.

$$= 0.2095 \cdot e^{\frac{-0.063768 \cdot 4 \cdot 96485 C mol^{-1}}{8.3145 JK^{-1}mol^{-1} \cdot (700°C + 273.15)}}$$

pO_2=0.01 or 1% concentration

12.3   Error propagation rules

The following error propagation rules may be applied to the calculations to obtain uncertainties.

$$f = A \cdot B \quad \sigma_f^2 \approx f^2 \cdot \left[\left(\frac{\sigma_A^2}{A} \right)^2 + \left(\frac{\sigma_B^2}{B} \right)^2 + 2\frac{\sigma_{AB}}{AB} \right]$$

$$f = \frac{A}{B} \quad \sigma_f^2 \approx f^2 \cdot \left[\left(\frac{\sigma_A^2}{A} \right)^2 + \left(\frac{\sigma_B^2}{B} \right)^2 - 2\frac{\sigma_{AB}}{AB} \right]$$

$$f = aA^b \quad \sigma_f^2 \approx \left(\frac{fb\sigma_A}{A} \right)^2$$

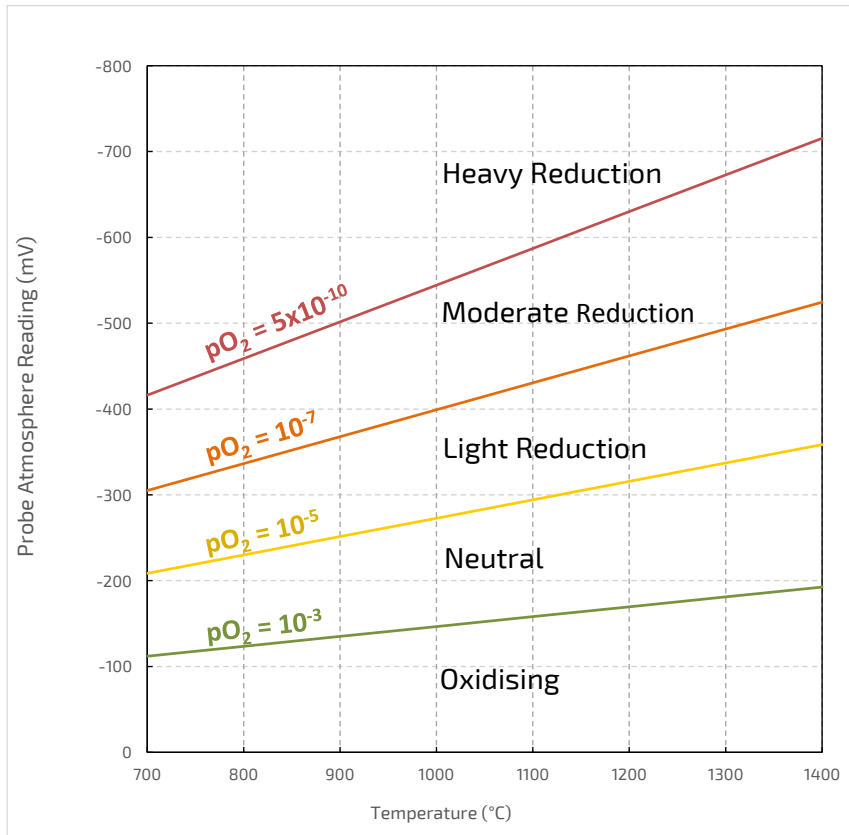$$f = a\ln(bA) \quad \sigma_f^2 \approx \left(a\frac{\sigma_A}{A} \right)^2$$

12.4   A table of typical emf readings for various inert gases

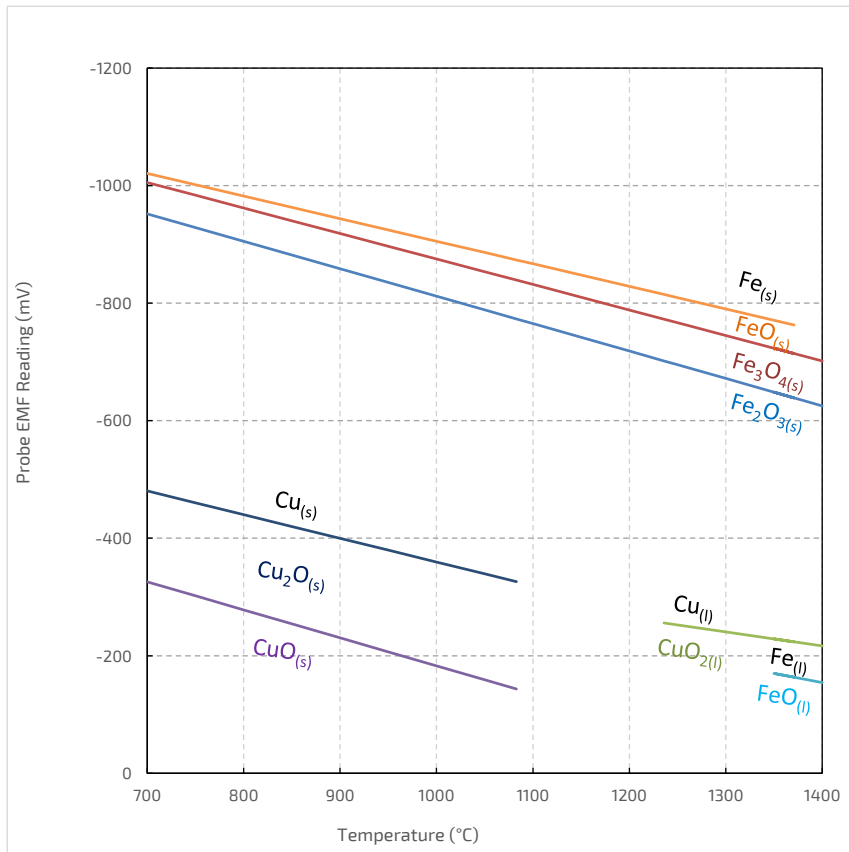| Molar/Volume % O_2 in Inert Gas (eg Nitrogen). EMF values are negative mV									
Temperature		1% O_2 in N_2		5% O_2 in N_2		Industrial N_2		HP N_2		UHP N_2
°C / (F)		1% ± 0.02%		5% ± 0.08%		10ppm ± 1ppm		2ppm ± 0.1ppm		0.1ppm ± 0.05ppm
600	/(1112)	56.80 – 57.56		26.60 – 27.21		185.31 – 189.09		216.46 – 218.35		266.10 – 286.77
650	/(1202)	60.06 – 60.85		28.13 – 28.76		195.93 – 199.92		228.86 – 230.85		281.34 – 303.19
700	/(1292)	63.31 – 64.15		29.65 – 30.32		206.54 – 210.75		241.25 – 243.35		296.58 – 319.61
750	/(1382)	66.56 – 67.44		31.18 – 31.88		217.15 – 221.57		253.65 – 255.86		311.82 – 336.03
800	/(1472)	69.81 – 70.74		32.70 – 33.44		227.76 – 232.40		266.04 – 268.36		327.05 – 352.45
850	/(1562)	73.07 – 74.04		34.22 – 35.00		238.37 – 243.23		278.44 – 280.86		342.29 – 368.87
900	/(1652)	76.32 – 73.33		35.75 – 36.55		248.99 – 254.06		290.84 – 293.37		357.53 – 385.29
950	/(1740)	79.57 – 80.63		37.27 – 38.11		259.60 – 264.89		303.23 – 305.87		372.77 – 401.72
1000	/(1832)	82.83 – 83.92		38.79 – 39.67		270.21 – 275.71		315.63 – 318.37		388.01 – 418.14
1050	/(1922)	86.08 – 87.22		40.32 – 41.23		280.82 – 286.54		328.02 – 330.88		403.24 – 434.56
1100	/(2012)	89.33 – 90.52		41.84 – 42.79		291.43 – 297.37		340.42 – 343.38		418.48 – 450.98
1150	/(2102)	92.58 – 93.81		43.36 – 44.34		302.05 – 308.20		352.81 – 355.88		433.72 – 467.40
1200	/(2192)	95.84 – 97.11		44.89 – 45.90		312.66 – 319.03		365.21 – 368.38		448.96 – 483.82
1250	/(2282)	99.09 – 100.40		46.41 – 47.46		323.27 – 329.85		377.60 – 380.89		464.20 – 500.24
1300	/(2372)	102.34 – 103.70		47.93 – 49.02		333.88 – 340.68		390.00 – 393.39		479.43 – 516.67
1350	/(2462)	105.60 – 106.99		49.46 – 50.58		344.49 – 351.51		402.40 – 405.89		494.67 – 533.09
1400	/(2552)	108.85 – 110.29		50.98 – 52.13		355.10 – 362.34		414.79 – 418.40		509.91 – 549.51
1450	/(2642	112.10 – 113.59		52.50 – 53.69		365.72 – 373.17		427.19 – 430.90		525.15 – 565.93
1500	/(2732)	115.35 – 116.88		54.03 – 55.25		376.33 – 383.99		439.58 – 443.40		540.39 – 582.35
1550	/(2822)	118.61 – 120.18		55.55 – 56.81		386.94 – 394.82		451.98 – 455.91		555.63 – 598.77
1600	/(2912)	121.87 – 123.47		57.07 – 58.37		397.55 – 405.65		464.37 – 468.41		570.86 – 615.19

Notes

- Please note that other impurities such as CO, CO_2, H_2, H_2O, CH_4, etc. may also have an effect on the emf
- Values given are a guide only and dependent on gas suppliers, please refer to your own certificate of analysis for O_2 impurity content and uncertainties
- HP is High Purity
- UHP is Ultra-High Purity

12.5 Kiln Atmosphere

12.6 Metal Reduction/Oxidation Graph

12.7 Consideration of sensor impedance

Sensor conductance has an Arrhenius relationship with temperature. Impedance as a function of temperature is an important consideration from the following perspectives:

1. Measurement equipment input impedance;

2. Response time of sensor to gas changes;

3. Electrical noise as observed by the measurement system.

Sensor impedance is an important consideration when interfacing to measurement equipment. The lower the temperature the more influence the measuring equipment input impedance has on the measured signal. Namely, if the input impedance of the measurement equipment is not sufficiently high, errors in signal measurement may fall into unacceptable bounds with respect to measurement uncertainties. In short, the input impedance of the measurement equipment should not load the measured signal.
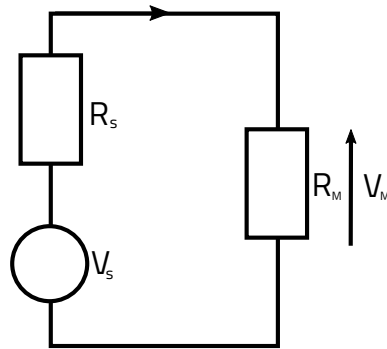
12.8 Example of measurement error

Using the following values:

- Kiln temperature measured by the probe is 350 °C;

- Partial pressure of reference air 0.2095;

- Reference gas that has a 1 % oxygen concentration (pO_2 = 0.01);

- E is the unknown component.

Using the Nernst equation, we calculate a sensor output voltage of E=-40.830 mV. The impedance derived from both the plot above and the interpolation, yields a signal source impedance of 1.2 MΩ. Using an instrument with an input impedance of 1 MΩ, the actual measured voltage is calculated as follows, using the known components:

- Kiln temperature measured by the probe is 350 °C;

- Sensor voltage output should be, V=-40.830 mV;

- Impedance of sensor at 350 °C is R_S=1.2MΩ;

- Instrument input impedance R_M=1.0MΩ; V_M is the voltage measured.

Calculating the system current to be defined as $i = \frac{V_s}{(R_s + R_M)}$, the voltage seen by the measurement equipment will then be $V_M = i \cdot R_M$. In this instance the measurement voltage will be -19.3 mV, approximately half the sensor unloaded voltage.

The oxygen concentration based upon the erroneous voltage reading will be 5.257%, and not the 1% as was the case in the earlier calculation.

To ensure that voltage measurements are within 1% of the actual voltage to be measured, the instrument input impedance required can be calculated as follows:

- Sensor voltage output should be V=-40.380 mV;

- 1% error on voltage to be measured, $V_\varepsilon = -0.4038$ mV;

- Impedance of sensor at 350°C is R_S=1.2MΩ;

- Unknown required instrument impedance;

The voltage drop across the sense resistor for a 1% error in value will be $V_\varepsilon = -0.42468$ mV, therefore the current in the circuit will be:

$$i_T = \frac{V_\varepsilon}{R_s}$$

To support a measurement voltage less the error at the input to the instrument, the input impedance will be defined as:

$$R_M = \frac{V_S - V_\varepsilon}{i_T}$$

This translates to the measurement instrument needing an input impedance of $R_M = 120.0 M\Omega$, which is substantially higher than that of most standard instruments.

The oxygen concentration calculated as a result of the increased input impedance, namely the measured signal, within 1% of the actual generated sensor voltage now yields an oxygen concentration of $O_2 = 1.03\%$. For use with standard equipment having an input impedance of 1 MΩ, the lowest operating temperature based upon the Arrhenius equation will be approximately 600°C.

12.9   Response time with respect to gas changes

Response times to changes in O_2 concentration levels vary according to temperature and gas flow. And importantly the magnitude of change, namely the ΔpO_2 . Typically, we note that response times are $0.1 \leq t \leq 0.5$ to within 90% of final stabilised voltage reading for temperatures above 700 °C.

12.10   Reducing measurement noise

Reject DC Common-Mode voltage

Making highly accurate measurements often starts with differential readings. An ideal differential measurement device reads only the potential difference between the positive and negative terminals of its instrumentation amplifier(s). Practical devices, however, are limited in their ability to reject common-mode voltages. Common-mode voltage is the voltage common to both the positive and negative terminals of an instrumentation amplifier.

Reject AC Common-Mode voltage

Rarely do common-mode voltages consist of only a DC level. Most sources of common-mode voltage contain an AC component in addition to a DC offset. Noise is inevitably coupled onto a measured signal from the surrounding electromagnetic environment. This is particularly troublesome for low-level analogue signals passing through the instrumentation amplifier on a DAQ device.

Sources of AC noise may be broadly classified by their coupling mechanisms – capacitive, inductive, or radiative. Capacitive coupling results from time-varying electric fields, such as those created by nearby relays or other measurement signals. Inductive or magnetically coupled noise results from time-varying magnetic fields, such as those created by nearby machinery or motors. If the electromagnetic field source is far from the measurement circuit, such as with fluorescent lighting, the electric and magnetic field coupling is considered combined electromagnetic or radiative coupling. In all cases, a time-varying common-mode voltage is coupled onto the signal of interest, most often in the range of 50-60 Hz (power-line frequency).
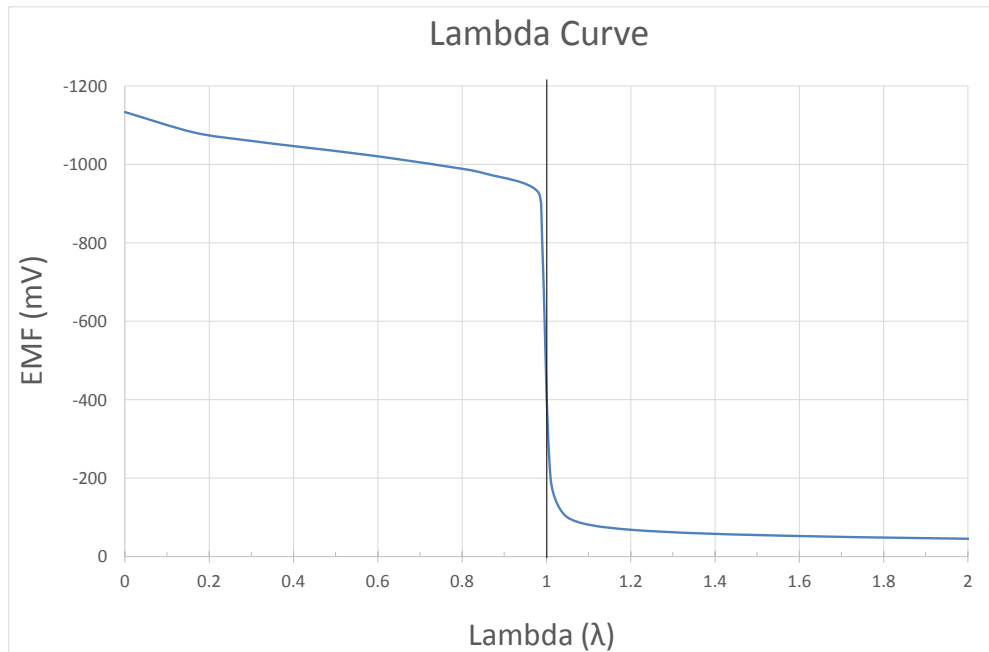
An ideal measurement circuit has a perfectly balanced path to both the positive and negative terminals of an instrumentation amplifier. Such a system would completely reject any AC-coupled noise.

Break Ground Loops

Ground loops are arguably the most common source of noise in data acquisition systems. Proper grounding is essential for accurate measurements, yet it is a frequently misunderstood concept. A ground loop forms when two connected terminals in a circuit are at different ground potentials. This difference causes a current to flow in the interconnection, which can produce offset errors. Further complicating matters, the voltage potential between signal source ground and DAQ device ground is generally not a DC level. This results in a signal that reveals power-line frequency components in the readings.
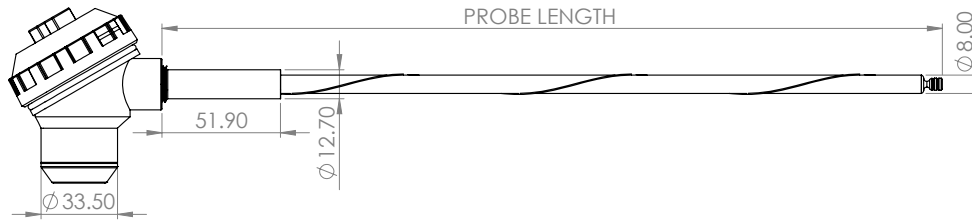
12.11   Lambda Point for control

The Oxygen Sensor is most sensitive to changes in air/fuel mixture ratios around the lambda point of a given fuel as depicted in the generic sensor response curve given below.

Lambda Curve

It is important to note that for non-equilibrium reacting systems the sensor coating will partially or fully complete the reaction locally. There are many variables that can influence the extent of this reaction including temperature, mixture ratios, flow rate past the sensor tip, and other reactor design factors. The oxygen sensor is not only well suited to carburising industries and carbon-based equilibrium systems but also responds to changes in O_2 partial pressure for all gas mixtures. The sensor is accurate over a wide range of O_2 partial pressures as given in the Specifications section at the front of this document.

13   Ordering information

This probe can be ordered in a range of different sizes in steps of 100 mm, and with two different thermocouples.

The probe part number has the following format.

DS - 0300 - K - FLS

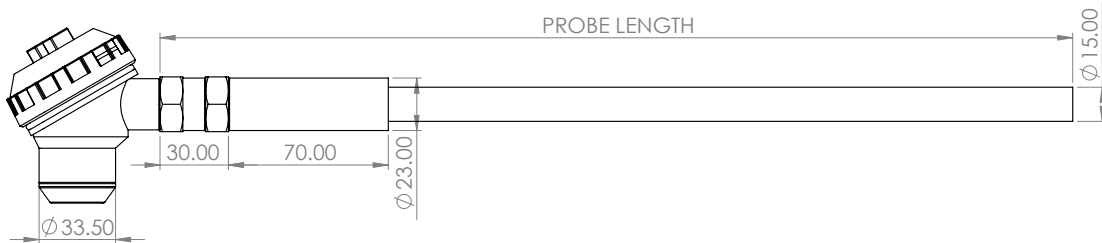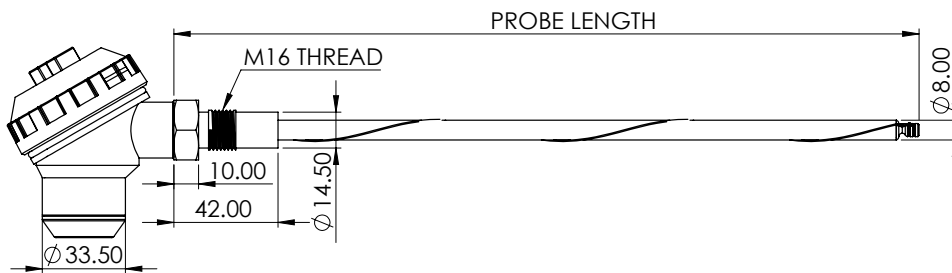|	
Ceramic sheath	FLS for Full-length Ceramic Sheath
	M16 for No Sheath with an M16 thread
	NSH for No Sheath
Thermocouple	R for R-type thermocouple
	K for K-type thermocouple
	X for no thermocouple
Probe length	0300 for 300 mm
	0400 for 400 mm
	...
	1350 for 1350 mm

13.1 Fitting and sheath options

NSH – Has no ceramic sheath. Appropriate for small furnace openings.

FLS – Comes with a full-length ceramic sheath running the entire length of the probe. The ceramic sheath provides a measure of protection to the sensor tip from direct exposure to corrosive and high velocity gases, reducing overall wear. A 1" BSPT or NPT compression fitting is available for this sheath option.

M16 – Has no ceramic sheath and comes with an M16 thread. Providing that the furnace has an M16 aperture thread, the probe can be mounted directly to the furnance, without any additional fittings.

14 Contact information

Australian Oxytrol Systems Pty Ltd
85 Wood Street
California Gully VIC 3556
Australia

P   + 61 3 5446 1530
F   + 61 3 5446 1215
W   www.australianoxytrolsystems.com
E   info@australianoxytrolsystems.com

15   Australian Oxytrol Systems Pty Ltd one (1) year limited warranty

15.1   Introduction

This is a limited warranty from Australian Oxytrol Systems Pty Ltd (as warrantor) that gives you specific legal rights.

You may also have other rights under specific consumer protection laws and regulations – if any (referred to in this warranty as "law") of the country, state or province in which the Product was purchased ("your jurisdiction"). This warranty is governed by and subject to law and is not intended to and does not exclude, limit or suspend any rights you have under law. Some or all of the limitations or exclusions described below may not apply to you.

For the purposes of this warranty –

AOS means Australian Oxytrol Systems Pty Ltd (Australian Business Number 59 007 371 824).

Product means any AOS – branded hardware product manufactured by or for AOS and identified by the AOS trademark, trade name, or logo affixed to it.

You means the original end-user and retail purchaser of a AOS Product.

AOS reserves the right to make changes at any time to:

1. Product hardware and software components and specifications; and
2. Terms and conditions governing Product use, service and repair; and
3. AOS services.

Such changes are entirely at AOS's discretion and may involve modification, upgrade, enhancement, replacement, deletion or abandonment.

15.2   Specific Warranty obligations

AOS warrants that its Product is free from defects in materials and workmanship under normal use for a period of one (1) year from the date of your purchase (the *"Warranty Period"*). Subject to law and the conditions set out below, if a Product is defective, AOS will decide whether to:

1. Repair the Product at no charge, using new parts or parts that are equivalent to the new in performance or reliability; or
2. Exchange the Product with either a new product or one that is equivalent to new in performance, reliability and functionality; or
3. Refund the purchase price of the product,

provided that your claim is made in accordance with this warranty and is received by AOS within the warranty period.

A replacement product or part assumes the remaining warranty of the original Product or ninety (90) days from the date of replacement or repair, whichever provides you with the longer coverage.

When a Product or part of a Product is exchanged, any replacement items become your property and the replaced item becomes AOS's property. Parts provided by AOS in fulfillment of its warranty obligation must only be used in the Product for which warranty service is claimed.

If AOS agrees to refund the purchase price of a Product, the refund can only be paid after you have returned that Product to AOS. All returned Products become AOS's property.

AOS does not make any representation that it will be able to repair or exchange any Product without loss of or corruption to programs and data.

15.3   Warranty exclusions and limitations

This limited warranty applied only to AOS Products and does not apply to any non–AOS hardware product or any software, even if packaged and sold with a AOS product. Manufacturers, suppliers, or publishers, other than AOS, may provide their own warranties to you, but AOS, in so far as permitted by law, provides itself "as is".

AOS Limited Warranty

Software (including system software) and hardware distributed by AOS with or without the AOS brand name is not covered under this warranty. Refer to the licensing agreement accompanying such software for details of your rights and obligations concerning its use.

AOS is not responsible for damage arising from failure to properly follow instructions relating to the Product's use.

This warranty does not apply to:

1. consumable parts, such as batteries, unless damage has occurred due to a defect in materials or workmanship; or
2. cosmetic damage, including but not limited to scratches, dents, and worn material on ports; or
3. damage caused by use with non-AOS products; or
4. damage caused by accident, abuse, misuse, or external causes (such as earthquake, fire or flood); or
5. damage caused by operating the product outside the permitted or intended uses described by AOS; or
6. damage caused by service (including upgrades and expansions) performed by anyone who is not a representative of AOS or a AOS authorised service provider; or
7. modifications by someone else other than AOS to alter Product functionality or capability without AOS's written approval; or
8. any AOS Product where its serial number has been removed or defaced.

15.4 Important!

Opening a hardware Product may cause damage; such damage is not covered by this warranty. Only AOS or an authorised service provider should open and perform Product service.

To the extent permitted by law:
(1) this warranty and your rights under it are exclusive and are in lieu of any other oral, written, statutory, express or implied warranties, remedies and conditions; and
(2) AOS disclaims all other warranties, including but not limited to warranties of merchantability and fitness for a particular purpose and warranties against hidden or latent defects.

If AOS cannot lawfully disclaim statutory or implied warranties then, to the extent permitted by law, all such warranties will be limited in the duration of the express warranty and to the repair or replacement service or refund as determined by AOS in its absolute discretion.

No AOS reseller, agent, or employee is authorised to make any amendment, extension, or addition to this warranty.

If any term or condition of this warranty is held to be illegal or unenforceable, the legality of the enforceability of the remaining terms and conditions will not be affected or impaired.

Except as provided in this warranty and to the maximum extent permitted by law, AOS is not responsible for direct, special, incidental or consequential damages resulting from any breach of the warranty or condition, or under any clause, category of head of claim, including but not limited to loss of use; loss of revenue; loss of actual or anticipated profits (including loss of profits on contracts); goodwill; loss of reputation; loss of damage to or corruption of data; any or indirect or consequential loss or damage howsoever caused including the replacement of equipment and property, and costs of recovering, programming or reproducing any program or data stored in or used with the AOS Product and any failure to maintain the confidentiality of data stored on the AOS product.

AOS does not authorise use of and reliance on any AOS Product in safety critical situations, where the failure of AOS Product or its compromised performance or interrupted operation could cause or contribute to personal injury or death ("potentially life threatening situations" or "PLTS"). For the avoidance of doubt out of the arising use or misuse and operation of any of its Products in such circumstances.

AOS may be prepared to assist you to undertake a risk management assessment and prepare a protocol for your use of AOS Products in the context of the PLTS, but always on the basis that all such use (including misuse) remains entirely at your risk.

It is your responsibility to identify and comply with the law governing your use of the Product applicable in each jurisdiction in which the Product is to be used.

15.5 Obtaining Warranty Service

Before seeking warranty service, please first refer to AOS's online help resources identified in the Product documentation.

If the product is still not functioning properly, you should contact the AOS representatives or, if applicable, a AOS retail store, distributor or authorised service provider.

AOS will determine whether the Product requires service, and if so, AOS will advise you how, where and by whom the service will be performed.

It is important that you assist AOS to diagnose issues with your Product and that you follow AOS's warranty processes.

Service options, parts availability and response times vary according to the place in which service is requested. Please note that service options are subject to review and change by AOS at any time and AOS may restrict service to be performed in the place at which the Product was originally sold.

Upon receipt of the replacement Product or part, the original Product or part becomes the property of AOS and you agree to properly follow instructions, including if required, arranging the return of the original Product or part to AOS in a timely manner.

When providing service requiring the return of the original Product or part, AOS may require a credit card authorisation as security for the retail price of the replacement Product or part and applicable shipping costs. If you follow AOS's instructions, AOS will cancel the credit card authorisation, and you will not be charged for the Product or part and shipping costs. If you fail to return the replaced Product or part as instructed, AOS will charge your credit card for the authorised amount.

If you seek service in a country that is not the country of original purchase, you must comply with the relevant export requirements and be responsible for the payment of all duties, taxes, levies, fees and other charges including shipping and handling costs.

Where international service is available, AOS may repair or exchange defective Products and parts with comparable Products or parts that comply with local law.

AOS may require you provide proof of purchase details and or comply with registration or other requirements before providing warranty service,

AOS will collect, maintain and use your information in accordance with AOS's privacy policy.