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# 1. Overview

Oxygen concentration is widely measured for the sake of conserving energy, preventing air pollution, controlling quality, and so forth.

There are many types of oxygen analyzers which use various principles of measurement. Zirconia oxygen analyzers, which can measure the oxygen concentration in high-temperature gases directly, are optimal for combustion management and control, etc. in combustion equipment and are used in many industries such as iron- and steelmaking, electric power, oil and petrochemicals, chemicals, ceramic, paper and pulp, and textiles.

The ZR22G/ZR402G Separate Type Zirconia Oxygen Analyzers have the following features:

- A general-purpose detector can directly measure gas of up to 700°C. Moreover, when combined with the high-temperature probe adapter, it can measure gas of up to 1400°C.
- For the Zirconia cell, which is a key component of zirconia oxygen analyzers, a zirconia element and platinum electrodes are molecularly bonded by a method developed by Yokogawa. Therefore, the zirconia sensor can deliver consistent measurements for a long period without the electrode being peeled off.
- The heater assembly used to heat up the zirconia cell is constructed so that it can be replaced in the field. Even if a wire in the heater breaks, the heater can be easily replaced in the field.
- The converter features a large liquid-crystal display that is easy to see and read.
- A high-resolution graphic display is available, and trend graph display of up to 150 min is possible.
- A touch panel is used for operations, allowing information to be easily read out and set up.
- Operations are performed interactively with the operation display, so the Instruction Manual is not needed in daily operations.
- During calibration, the sensor (cell) response time, internal resistance value, zero calibration factor, span collection factor, etc. are checked and the data are evaluated comprehensively. This allows the remaining life of the cell to be predicted.
- Two current outputs (4 – 20 mA) and four SPDT relay contact outputs are available. Measurement data, alarms, errors, etc. can be output.

This technical information document (TI 11M12A01-03E) is intended to help users understand and make the best use of these features of the ZR22G/ZR402G Separate Type Zirconia Oxygen Analyzers.

For descriptions of typical applications, see the following application edition of this technical information document:

ZR22G, ZR402G Separate Type Zirconia Oxygen Analyzers (Application Edition) (TI 11M12A01-01E)

## 2. Measurement Principle of Zirconia Oxygen Analyzers

A solid electrolyte such as zirconia can conduct oxygen ions at high temperature.

As shown in Figure 2.1, when a zirconia element with platinum electrodes bonded to both sides of it is heated up in contact with gases having different partial-oxygen pressures on either side, the element acts as a concentration cell. In other words, the electrode in contact with the gas with a higher partial-oxygen pressure acts as a negative electrode. As the gas comes in contact with the zirconia element in this negative electrode, oxygen molecules in the gas acquire electrons and become oxygen ions. Moving in the zirconia element, they eventually arrive at the positive electrode on the opposite side. There, the electrons are released and the ions return to oxygen molecules by the following process:



By this reaction, an electromotive force is generated between the two electrodes governed by Nernst's equation:

$$E = -\frac{RT}{nF} \ln \frac{P_X}{P_A} \quad \dots\dots\dots (1)$$

where, R: Gas constant

n: 4

F: Faraday's constant

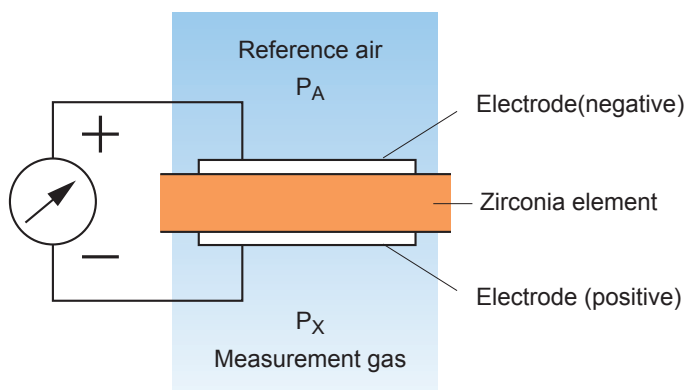
T: Absolute temperature

P<sub>X</sub>: Oxygen concentration in a gas (measurement gas) in contact with the positive electrode (%)

P<sub>A</sub>: Oxygen concentration in a gas (reference air) in contact with the negative electrode (%)

Because the sensor (zirconia element) of the ZR22G Detector is heated up to 750°C, equation (1) becomes:

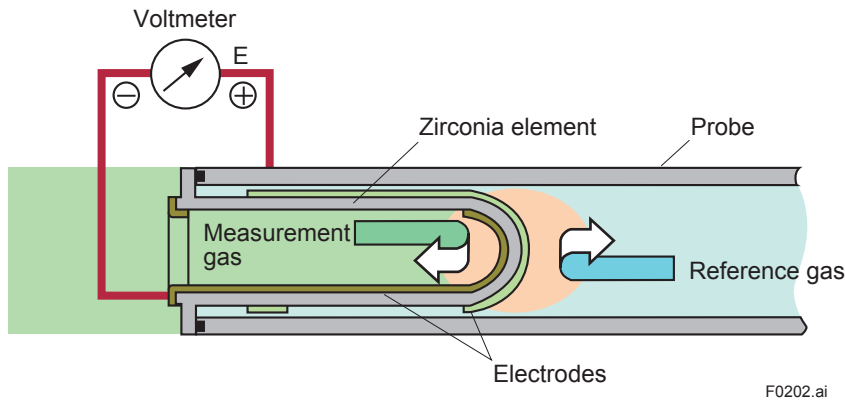
$$E = -50.74 \log \frac{P_X}{P_A} \quad \dots\dots\dots (2)$$



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**Figure 2.1 Schematic diagram of measurement principle**

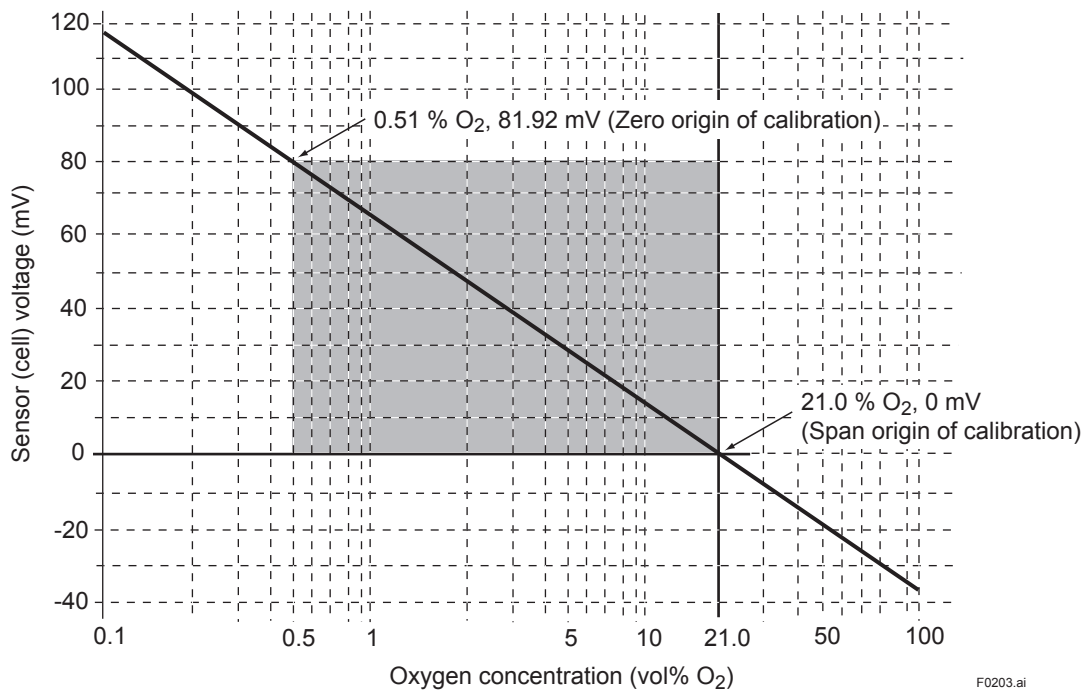
Figure 2.2 shows the principle construction of the ZR22G Detector.



**Figure 2.2 Principle construction of the ZR22G Detector**

When air is used as a reference gas on the negative electrode side, the relationship between the oxygen concentration of the measurement gas and the electromotive force of the sensor (= cell) is as shown in Figure 2.3.

The relationship between the oxygen concentration and the electromotive force of the cell in Figure 2.3 is only theoretical. Usually, in practice, a sensor shows a slight deviation from the theoretical value; this deviation is corrected by conducting calibration using calibration gas. For details of calibration, see chapter 6, "Calibration."



**Figure 2.3 Oxygen concentration in measurement gas vs. sensor (cell) voltage (on the basis of 21.0% O<sub>2</sub>)**

## 3. System Configuration

The system configuration of zirconia oxygen analyzers is divided into two main types, those using either a general-purpose detector (measurement gas temperature of 700°C and below) or those using a high-temperature detector (measurement gas temperature of 1400°C and below).

Moreover, each of these types is further divided into three subtypes, giving six types in total.

**Table 3.1** Types of System Configuration

System Type No.	Detector	Calibration Method	Remarks
L1	General-purpose type	Simple type	The standard gas unit is used.
L2		General type (manual)	Instrumentation air and zero gas cylinder are used.
L3		General type (automatic)	
H1	High-temperature type	Simple type	The standard gas unit is used.
H2		General type (manual)	Instrumentation air and zero gas cylinder are used.
H3		General type (automatic)	

There are two methods of feeding in reference air: one is to feed in air near the detector by natural convection and the other is to use instrument air. The method of using air near the instrument is simple but there is a problem as described below, so instrument air should be used if it is available.

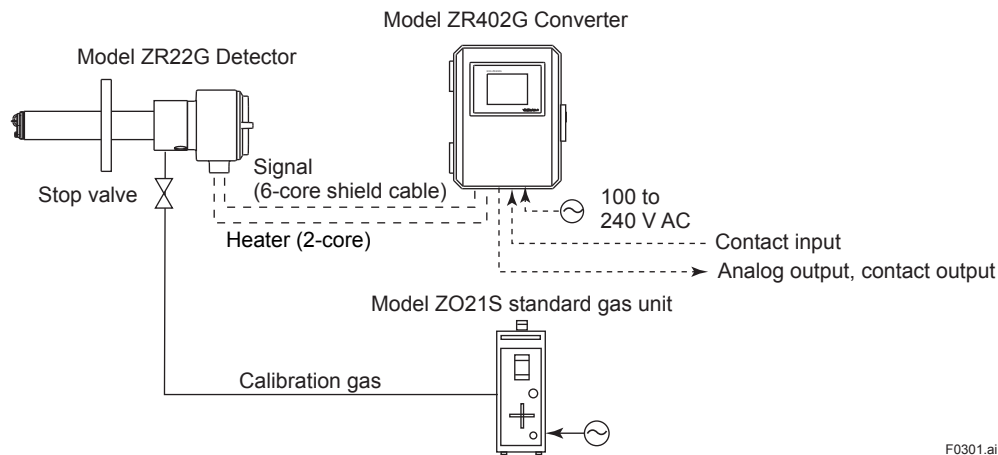
In case of using natural convection: Measurement may be affected by the humidity in the air that is fed in. A large variation in humidity causes a measurement error, so care is required.

In case of using instrument air: Air that has been dehumidified at a dew point temperature of -20°C or less and from which oil mist and dust have been removed should be used.

### 3.1 System Configuration Using a General-purpose Detector

#### (1) Type: L1 (simple measurement type)

This is the simplest system consisting of a detector and a converter. This system can be implemented for monitoring oxygen concentration in the combustion gases of a package boiler. No piping is required for the reference gas (air) which is fed in at the installation site. The handy ZO21S standard gas unit is used for calibration.



**Figure 3.1** System configuration diagram for type L1

## (2) Type: L2 (without automatic calibration)

This system is for monitoring and controlling oxygen concentration in the combustion gases of a large-size boiler or heating furnace. Clean (dry) air (21% O<sub>2</sub>) is used as the reference gas and the span gas for calibration. Zero gas is fed in from a cylinder during calibration. The gas flow is controlled by the ZA8F flow setting unit (for manual valve operation).

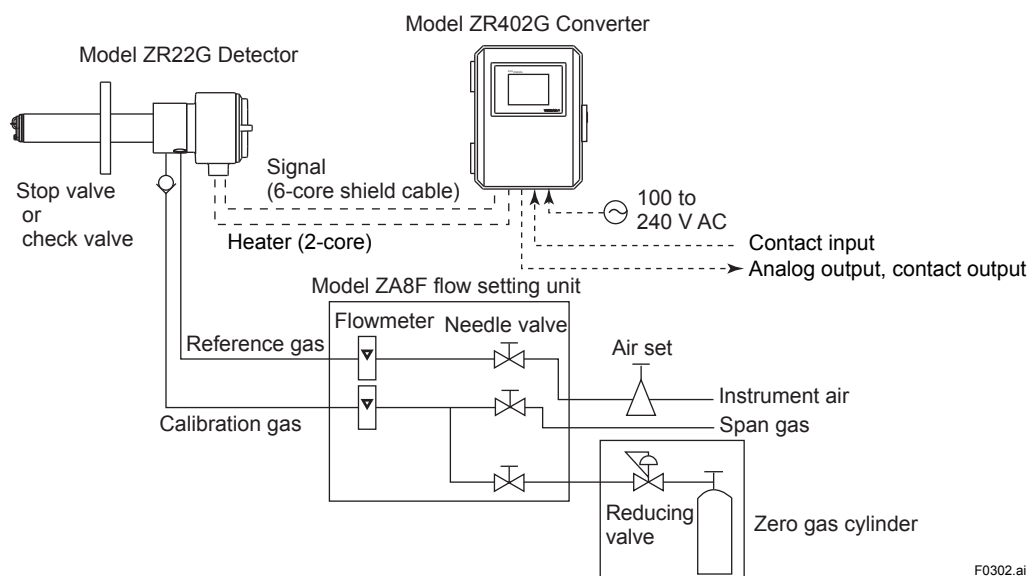


Figure 3.2 System configuration diagram for type L2

## (3) Type: L3 (with automatic calibration)

This system represents typical applications in large boilers and heating furnaces, where there is a need to monitor and control oxygen concentration. The reference gas and calibration-time span gas are (clean, dry) instrument air. Zero gas is supplied from a gas cylinder.

This system uses the ZR40H autocalibration unit, with auto-switching of the calibration gas. A “combustible gas detected” contact input turns off power to the heater. There’s also contact output from the converter that can be used to operate a purge gas valve to supply air to the sensor.

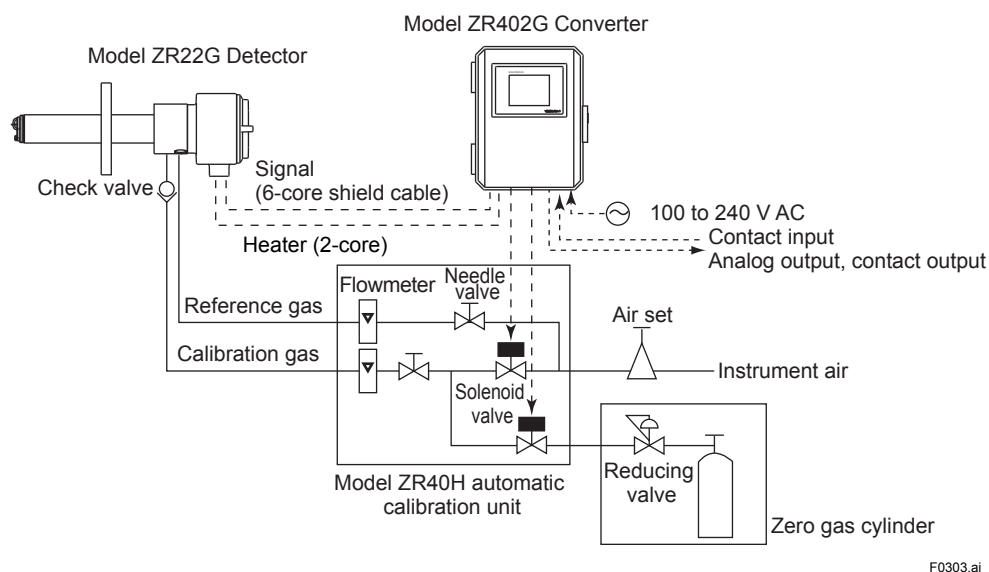


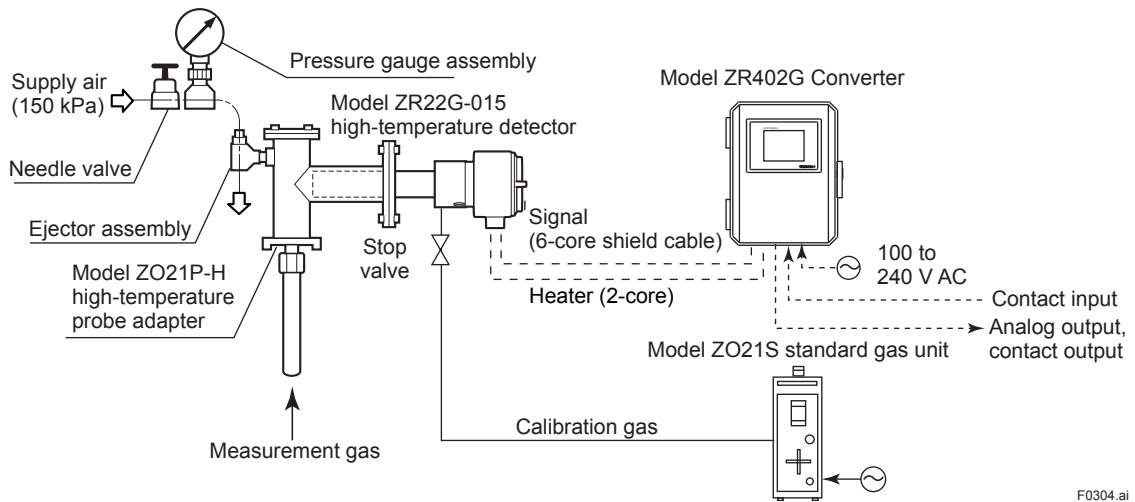
Figure 3.3 System configuration diagram for type L3

## 3.2 System Configuration Using a High-temperature Detector

### (1) Type: H1 (simple measurement type)

This is the simplest system configuration for high-temperature applications and is used for a package boiler, etc.

For the reference air, air near the installation site is fed in. Calibration is done manually and zero gas and span gas (air) are introduced to the detector via the ZO21S standard gas unit.



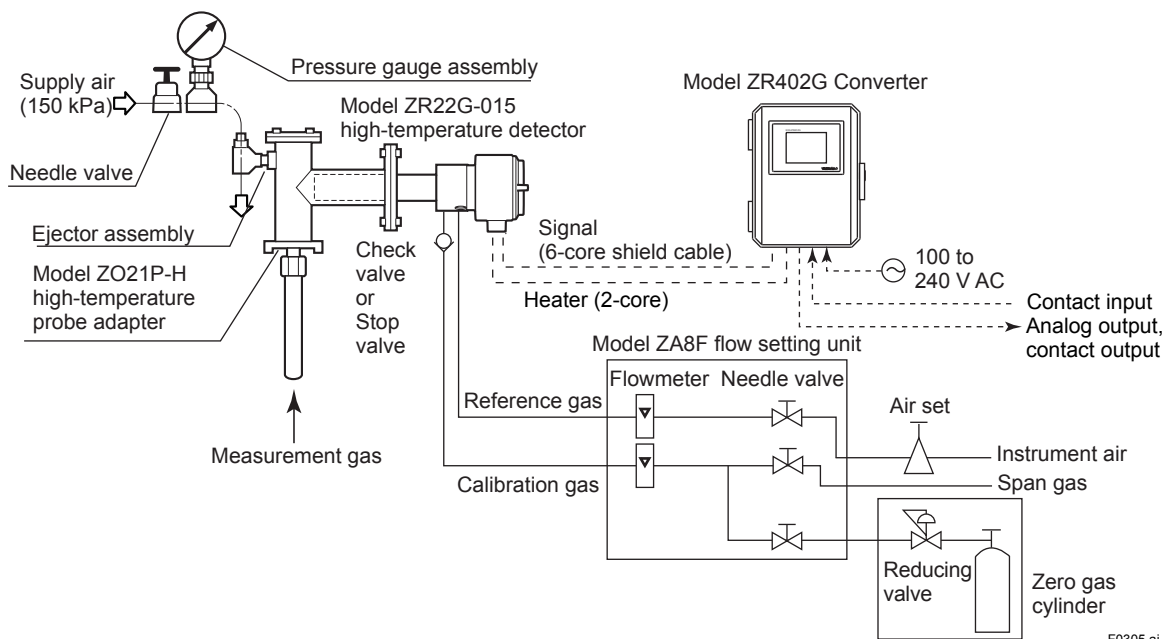
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Figure 3.4 System configuration diagram for type H1

### (2) Type: H2 (without automatic calibration)

This system is for controlling and measuring oxygen concentration with high accuracy in a large boiler or heating furnace.

The reference gas uses instrument air. Calibration is done manually, and zero gas (from a cylinder) and span gas (instrument air) are fed via the ZA8F flow setting unit.



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Figure 3.5 System configuration diagram for type H2

### (3) Type: H3 (with automatic calibration)

This system is for controlling and measuring oxygen concentration with high accuracy in a large boiler or heating furnace.

The reference gas uses instrument air. Calibration is performed by operating the automatic calibration unit based on commands from the converter.

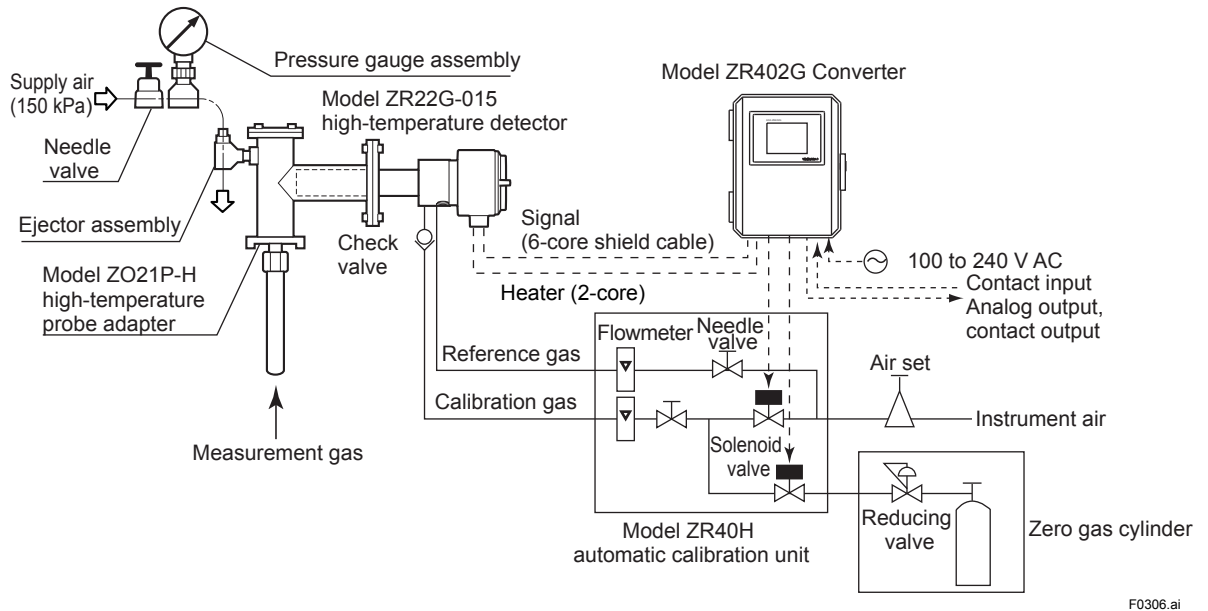


Figure 3.6 System configuration diagram for type H3

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## 4. ZR22G Detector Construction and Features

The ZR22G Zirconia Oxygen Analyzer Detector can measure gas of up to 700°C directly.

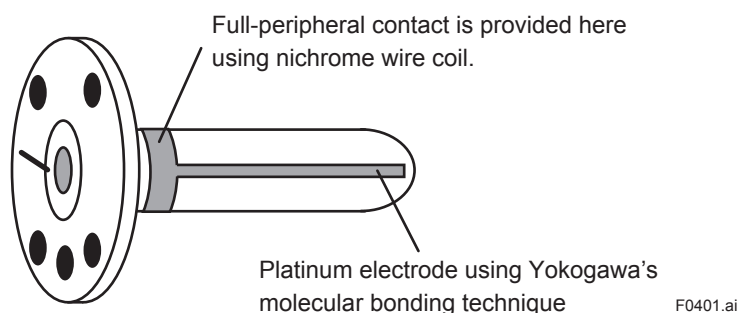
If gas with temperatures higher than 700°C needs to be measured, the high-temperature probe adapter can be used to measure gas of up to 1400°C.

The ZR22G Detector has the following features:

- The zirconia element and platinum electrodes are molecularly bonded by a method developed by Yokogawa, which eliminates the risk of peeling.

Thanks to a special coating, the platinum electrodes are also protected from deterioration caused by the measurement gas and are not affected by SO<sub>2</sub> or NO<sub>x</sub> contained in the measurement gas. This allows the detector to perform consistently for a long period.

- Because the zirconia cell uses a leadless electrode construction thanks to full-peripheral contact using nichrome wire coil, there is no risk of wire breakage and the cell can be easily replaced.
- The heater assembly used to heat up the zirconia element is constructed so that it can be replaced in the field. Even if a wire in the heater breaks, the heater assembly can be easily replaced.

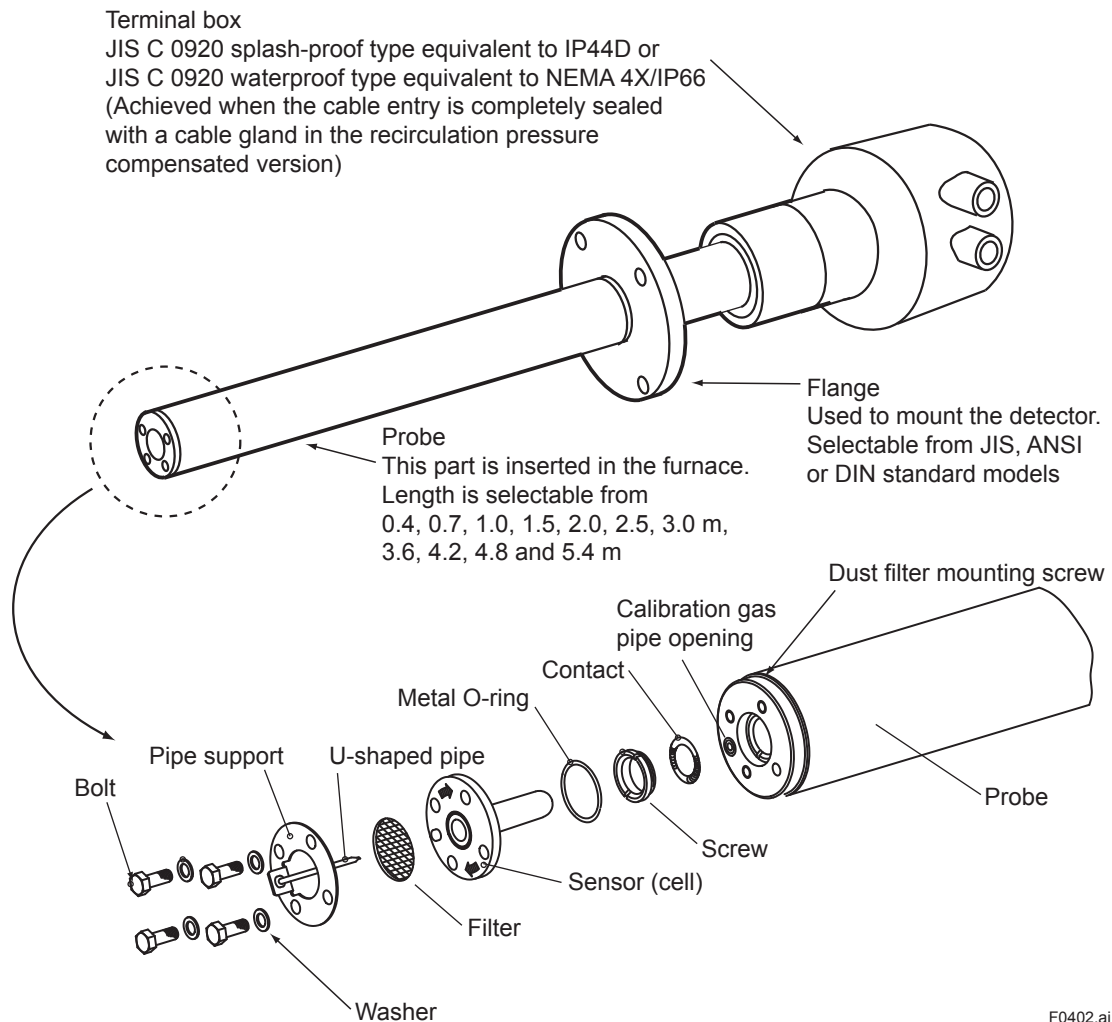


**Figure 4.1 Appearance of the zirconia sensor**

## 4.1 General-purpose Detector Construction

Figure 4.2 shows the part names and functions of the general-purpose detector.

The sensor (zirconia cell) can be easily replaced by simply removing four bolts. The filter attached at the front of the sensor is a large-mesh wire net that prevents large dust particles from entering the sensor.



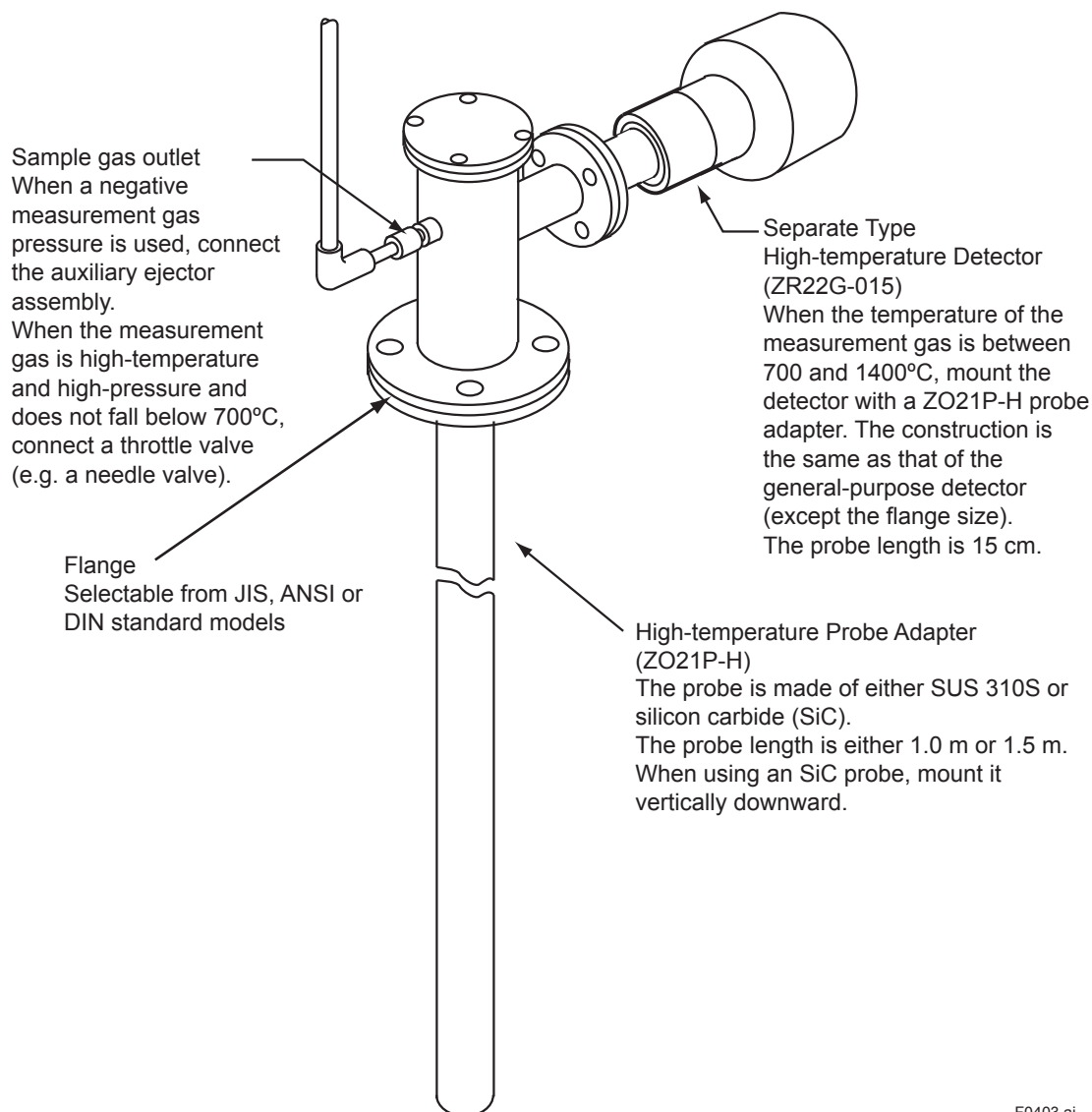
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**Figure 4.2** Part names and functions of general-purpose detector (standard type)

## 4.2 High-temperature Detector Construction

Figure 4.3 shows the part names and functions of the high-temperature detector.

The detector construction is the same as that of the general-purpose detector noted above, but the flange size is different. For the high-temperature probe adapter, two types of probe materials are provided: SUS310S and silicon carbide (SiC). The SUS310S probe adapter is used to measure gases at up to 800°C, while the silicon carbide (SiC) probe adapter is for gases up to 1400°C.



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**Figure 4.3** Part names and functions of the high-temperature detector

## 4.3 Pressure Compensation Method

If the in-furnace pressure is high or there are variations in the in-furnace pressure, the pressure balance between the inside of the furnace and the reference air is lost, making it difficult to measure the oxygen concentration accurately.

In this case, the detector's pressure compensation function can be used to return the reference air to the furnace to maintain the pressure balance between the inside of the furnace and the reference air side. This enables reliable measurements to be made.

This function allows in-furnace pressures of up to 250 kPa to be measured.

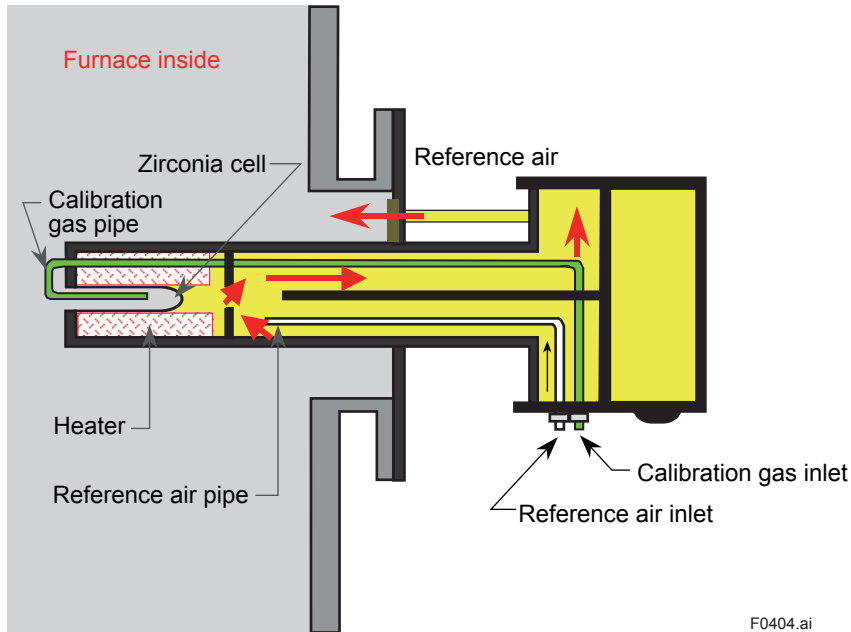


Figure 4.4 Pressure compensation method

# 5. ZR402G Converter Functions and Features

## 5.1 Human Machine Interface (HMI)

- Equipped with a back-lit large display unit that is easy to see and read.
- High-resolution graphic display. Up to 150 minutes of trend graph can be displayed.
- The touch panel allows information to be easily read and set up.
- Interactive operations along with operation display, eliminating the need for an Instruction Manual.

### 5.1.1 Basic Panel and Touch Panel Switch

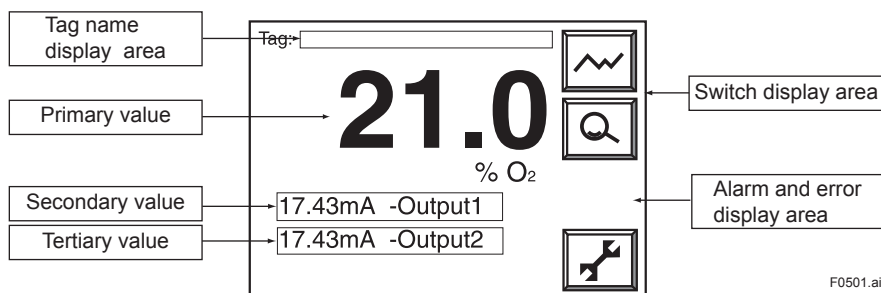


Figure 5.1 Basic panel display

#### ● Basic panel display

Tag name display area:	Displays the set tag name.
Primary to tertiary display items:	Displays the selected item in large letters (see Table 5.1).
Secondary and tertiary display items:	Display the selected items in small letters (see Table 5.1).
Switch display area:	Displays switches and functions selected according to the panel display (see Figure 5.2).
Alarm and error display area:	Displays an error if an alarm or error occurs. If you touch this area, the details of the error or alarm are then displayed.

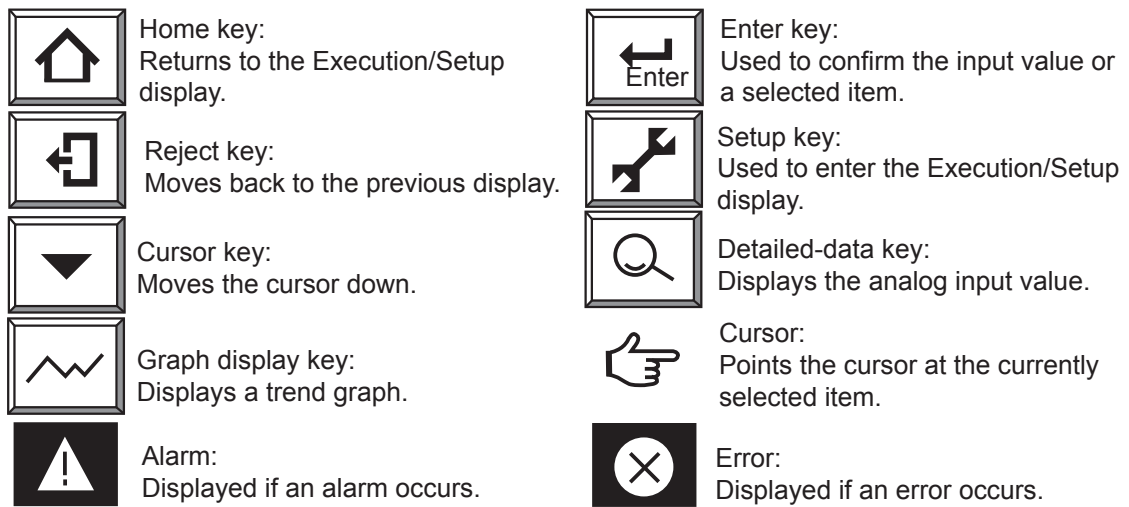
Table 5.1 Display Items

Item	Primary value	Secondary & tertiary values	Display
Oxygen concentration	○	○	Oxygen concentration during measurement
Air ratio		○	Current computed air ratio
Moisture quantity		○	Moisture quantity (%H <sub>2</sub> O) in the exhaust gas
Output 1 item	○	○	Oxygen concentration with the equipment set for oxygen analyzer (See *1 below.)
Output 2 item	○	○	Oxygen concentration with the equipment set for oxygen analyzer (See *1 below.)
Current output 1		○	Current value output from analog output 1
Current output 2		○	Current value output from analog output 2

\*1: If an analog output smoothing constant is set, the oxygen concentration display then includes these settings.

### ● Touch Panel Switch

The ZR402G uses a touch panel that can be operated by just touching the switch display. The switches displayed in this area and their functions vary depending on the panel display, allowing all switch operations. Figure 5.2 shows the types of switches and their functions.

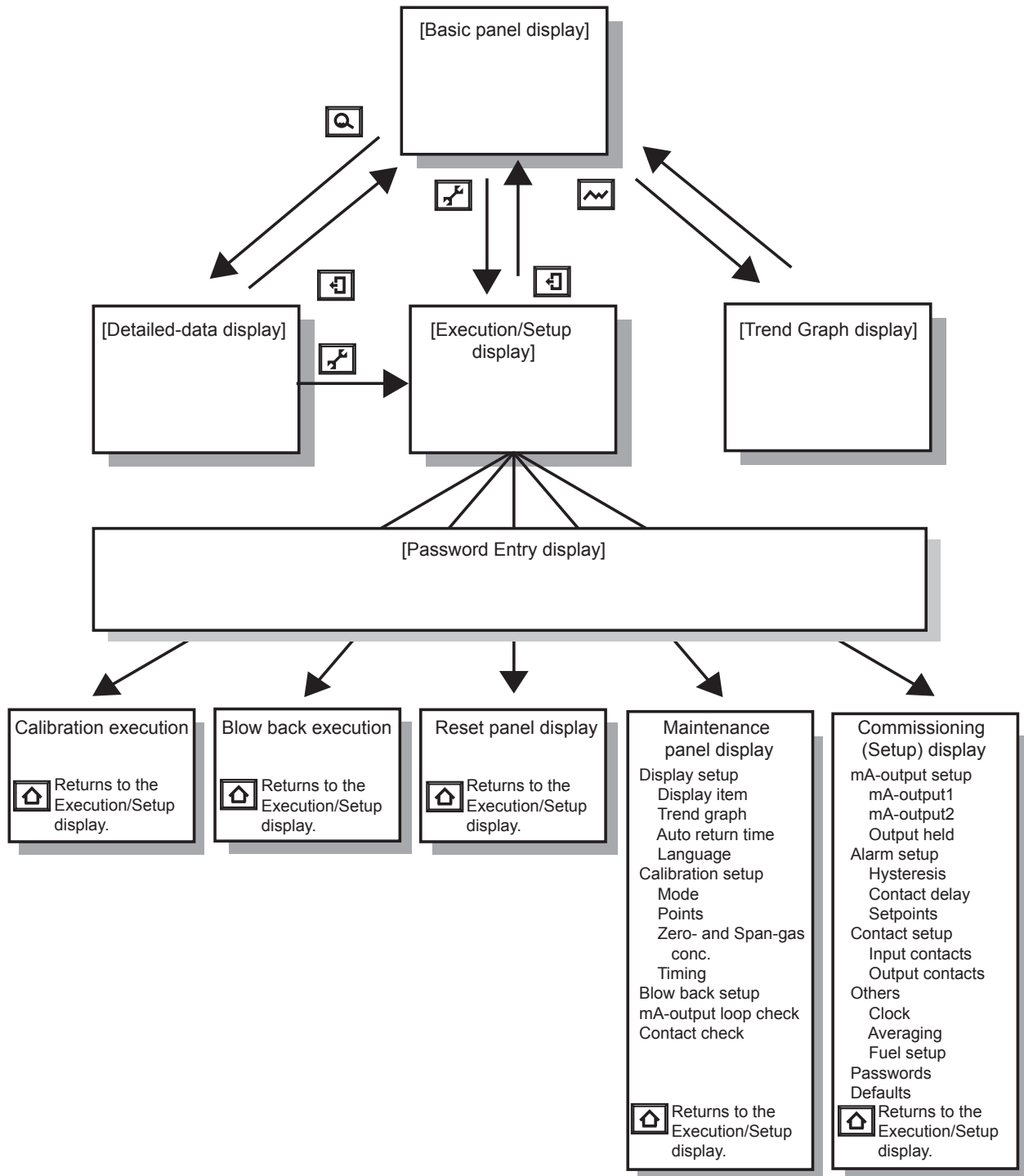


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**Figure 5.2 Switch names and their functions**

### 5.1.2 Display Configuration (for Oxygen Analyzer)


Figure 5.3 shows the display configuration. A password can be used to protect the displays positioned below the Execution/Setup display.



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Figure 5.3 Display configuration

### 5.1.3 Trend Graph Display

When the  key is pressed in the basic panel display, the graph display showing measured values on the time axis appears. This display is useful for viewing the trend of measured values or checking the stability of the reading by observing trend data of the oxygen concentration during automatic calibration.

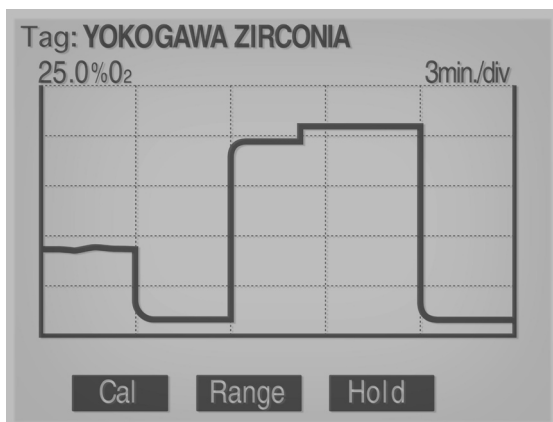


Figure 5.4 Trend Graph display

- **Display of the Trend Graph Display**

Time axis (user selectable, 1 to 150 min)

Measured value axis (user selectable)

Tag number (user settable)

Currently measured value

- **Sampling Period**

This graph allows the plotting of 60 data items on one graduation on the time axis. So, if you set a ten-second sampling period, one graduation corresponds to 600 seconds (Figure 5.5).

The allowable sampling periods range from 1 to 30 seconds. If you set a one-second sampling period, the axis of the abscissas then corresponds to five minutes. If you set it to 30 seconds, the axis of the abscissas then corresponds to 150 minutes.

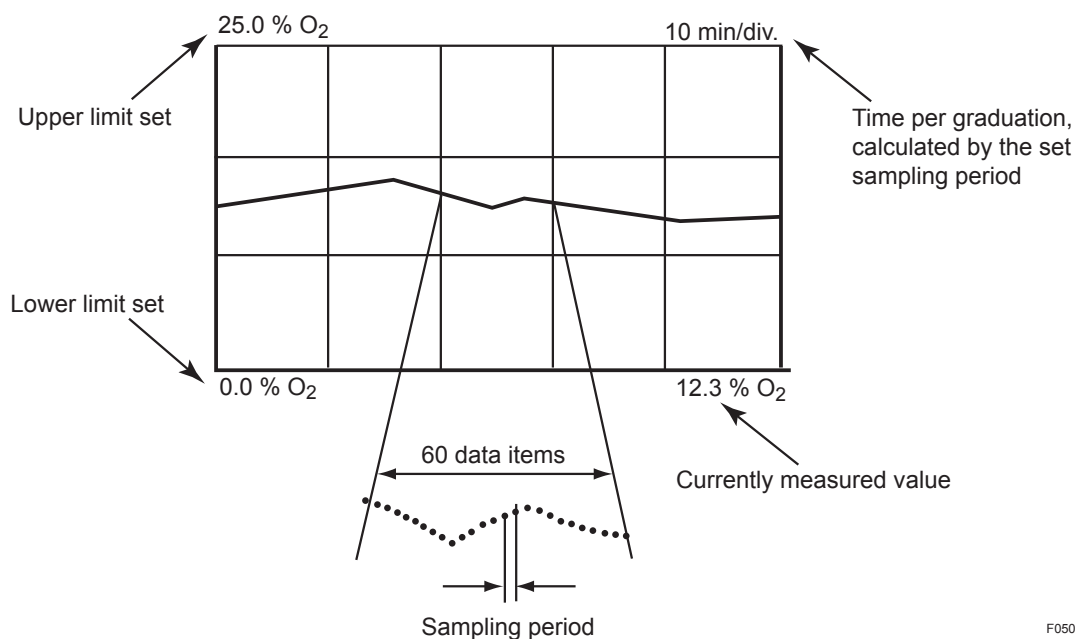


Figure 5.5 Sampling period

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### ● Measured Value Axis

Set the upper and lower limits of measured values on the y-axis of the graph. The allowable settings for both upper-limit and lower-limit values range from 0 to 100% O<sub>2</sub>.

## 5.1.4 Detailed-data Display

The Detailed-data display is used to display the detailed operation data.

There are ten panel displays for viewing detailed data. The following briefly describe the operational data displayed on the detailed-data display.

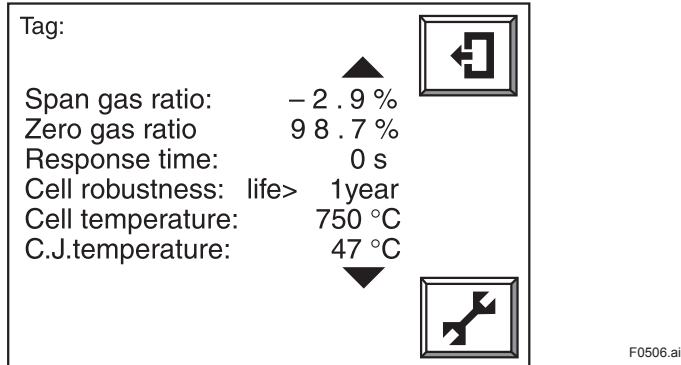


Figure 5.6 Detailed-data display

### (1) Span-gas and Zero-gas Correction Ratios

These are used to check for degradation of the sensor (cell). If the correction ratio is beyond the limits as shown in Figure 5.7, the sensor should no longer be used. These ratios are calculated as shown below.

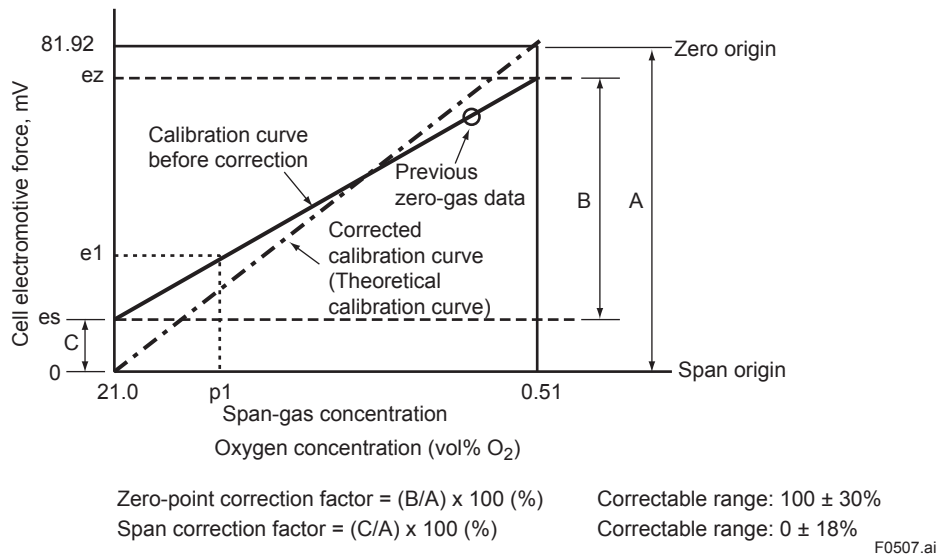


Figure 5.7 Calculation of a two-point calibration curve and correction factors using zero and span gases

## (2) Response Time

The cell's response time is obtained in the procedure shown in Figure 5.8. If only either a zero-point or span calibration has been carried out, the response time will not be measured just as it will not be measured in manual calibration.

The response time is obtained after the corrected calibration curve has been found. The response time is calculated, starting at the point corresponding to 10% of the analog output up to the point at 90% of the analog output span. That is, this response time is a 10 to 90% response.

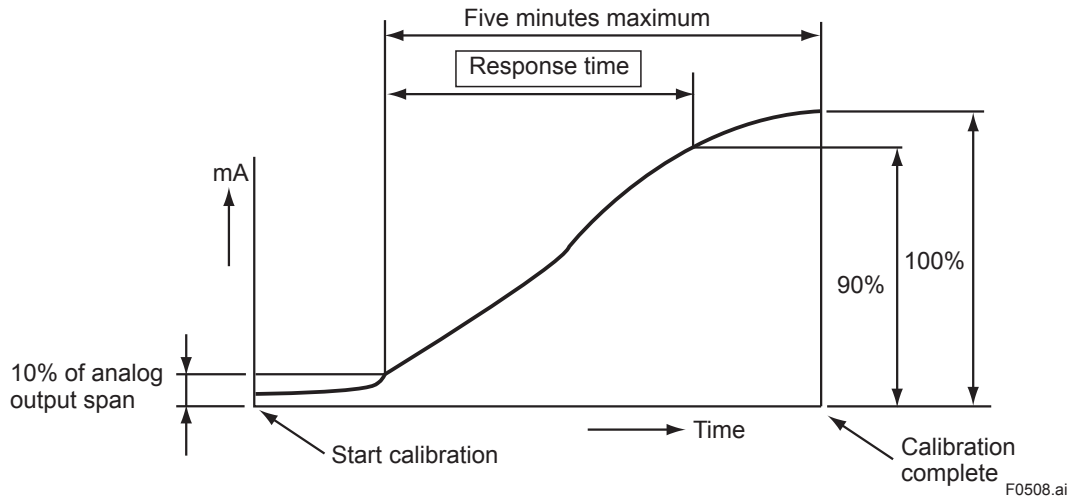


Figure 5.8 Functional drawing of response time

## (3) Robustness of a Cell

The robustness of a cell is an index for predicting the remaining life of a sensor and is expressed as one of four time periods during which the cell may still be used:

- (1) more than one year
- (2) more than six months
- (3) more than three months
- (4) less than one month

The above four time periods are tentative and used only for preventive maintenance, not for warranty of the performance.

This cell's robustness can be found by a comprehensive evaluation of data involving the cell's response time and internal resistance and zero gas and span gas ratios.

## (4) Cell Temperature

This indicates the cell (sensor) temperature, usually 750°C, obtainable from the "thermoelectromotive force" and "cold junction temperature" described below.

## (5) C. J. Temperature

This indicates the detector terminal box temperature, which compensates for the cold junction temperature for a thermocouple measuring the cell temperature. When the ZR22G Detector is used, the maximum C. J. temperature will be 150°C. If the terminal box temperature exceeds this, take measures, for example, so that the terminal box is not exposed to radiation to reduce that temperature.

The maximum C. J. temperature varies depending on the type of detector.

## (6) Cell Voltage

The cell (sensor) voltage will be an index to determine the amount of degradation of the sensor. The cell voltage corresponds to the oxygen concentration currently being measured. If the indicated voltage approximates the ideal value (corresponding to the measured oxygen concentration), the sensor will be assumed to be normal.

The ideal value of the cell voltage (E), when the oxygen concentration measurement temperature is controlled at 750°C., may be expressed mathematically by:

$$E = -50.74 \log (P_x/P_A) \text{ [mV]}$$

where,  $P_x$ : Oxygen concentration in the measured gas

$P_A$ : Oxygen concentration in the reference gas, (21% O<sub>2</sub>)

Table 5.2 shows oxygen concentration versus cell voltage.

**Table 5.2 Oxygen Concentration Vs. Cell Voltage, (cell temperature: 750°C)**

%O <sub>2</sub>	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
mV	117.83	102.56	93.62	87.28	82.36	78.35	74.95	72.01	69.41
%O <sub>2</sub>	1	2	3	4	5	6	7	8	9
mV	67.09	51.82	42.88	36.54	31.62	27.61	24.21	21.27	18.67
%O <sub>2</sub>	10	21.0	30	40	50	60	70	80	90
mV	16.35	0	-7.86	-14.2	-19.2	-23.1	-26.5	-29.5	-32.1
%O <sub>2</sub>	100								
mV	-34.4								

## (7) Thermocouple Voltage

The cell (sensor) temperature is measured with a Type K (chromel-alumel) thermocouple. The thermocouple cold junction is located in the detector terminal box. The cell temperature and the thermocouple voltage (including the voltage corresponding to the cold junction temperature) are displayed.

## (8) Cold Junction Resistance (C. J. Voltage)

The ZR22G Detector measures the cold junction temperature using an RTD (Pt 1000).

## (9) Cell's Internal Resistance

A new cell (sensor) indicates its internal resistance of 200Ω maximum. As the cell degrades, so will the cell's internal resistance increase. The degradation of the cell cannot be found only by changes in cell's internal resistance, however. Those changes in the cell's internal resistance will be a hint to knowing the sensor is degrading. The updated values obtained during the calibration are displayed.

## (10) Software Revision

The revision (number) of the software installed in the ZR402G Converter is displayed.

## (11) Maximum Oxygen Concentration

The maximum oxygen concentration and the time of its occurrence during the period specified in the Averaging display are displayed. If the setup period elapses, the maximum oxygen concentration that has been displayed so far will be cleared and a new maximum oxygen concentration will be displayed. If the setup period of time is changed, the current maximum oxygen concentration will be displayed.

**(12) Minimum Oxygen Concentration**

The minimum oxygen concentration and the time of its occurrence during the period specified in the Averaging display are displayed. If the setup period elapses, the minimum oxygen concentration that has been displayed so far will be cleared and a new minimum oxygen concentration will be displayed. If the setup period of time is changed, the current minimum oxygen concentration will be displayed.

**(13) Average Oxygen Concentration**

The average oxygen concentration during the periods over which average values are calculated that is specified in the Averaging display is displayed. If the setup period elapses, the average oxygen concentration that has been displayed so far will be cleared and a new average oxygen concentration will be displayed. If the setup period of time is changed, the current average oxygen concentration will be displayed.

**(14) Heater On-Time Ratio**

The probe sensor is heated to and maintained at 750°C. When the measured gas temperature is high, the amount of heater ON-time decreases.

**(15) Time**

The current date and time are displayed. These are backed up by the built-in batteries after the power is switched off, so no adjustment is required.

**(16) History of Calibration Time**


The calibration-conducted dates and times, and span-gas and zero-gas ratios for the past ten calibrations are stored in memory.

### 5.1.5 Execution/Setup Display

This display is used to calibrate or maintain the equipment or perform basic setup. There are three execution displays and two data setup displays (five displays in total). Their operations can be protected by a password.

- **Basic Panel Display**

This display shows the general measurement status.

When the  key is pressed, the following display appears.

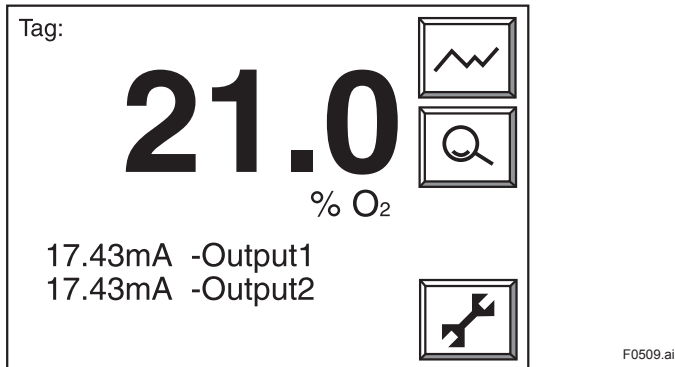


Figure 5.9 Basic panel display

- **Execution/Setup Display**

Select the required item from among the items displayed.

For example, if you wish to make setup, select Setup using the ▼ key and press the [Enter] key.

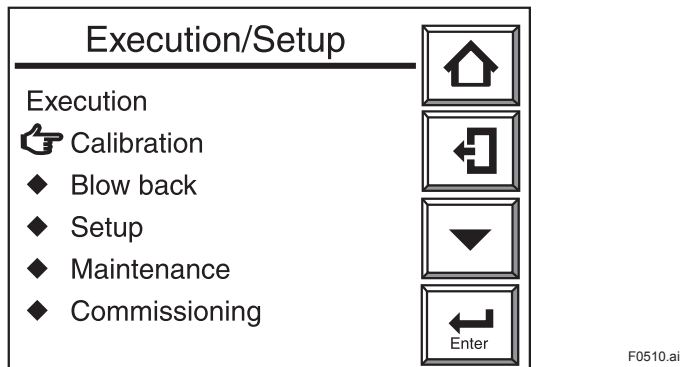
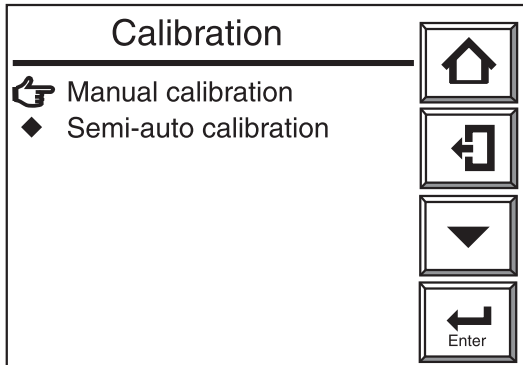


Figure 5.10 Execution/Setup display

## (1) Execution display

### ● Calibration Execution Display

This is the execution display for calibration, and is used to perform manual or semi-automatic calibration.

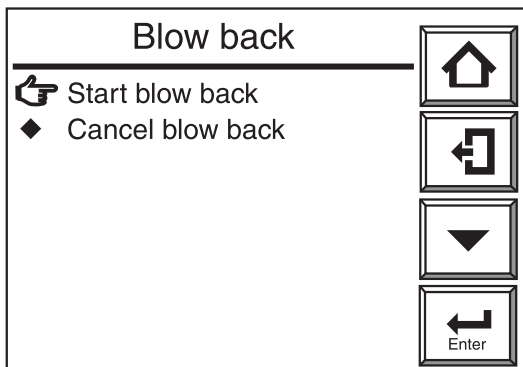


F0511.ai

Figure 5.11 Calibration execution display

### ● Blow back Execution Display

This display is used to execute blow back.



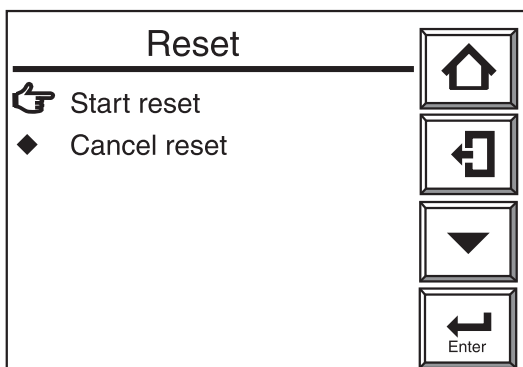
F0512.ai

Figure 5.12 Blow back execution display

### ● Reset display

If an error occurs, you can reset the equipment from this display in the following cases:

- (1) Error 1 – if the cell voltage is incorrect
- (2) Error 2 – if a temperature alarm occurs
- (3) Error 3 – if the A/D converter is defective
- (4) Error 4 – if an EEPROM write error occurs



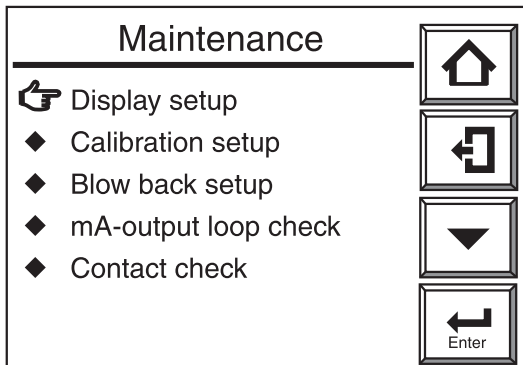
F0513.ai

Figure 5.13 Reset display

## (2) Setup display

### ● Maintenance Display

This display is used to set data for equipment maintenance or make a loop check, etc.

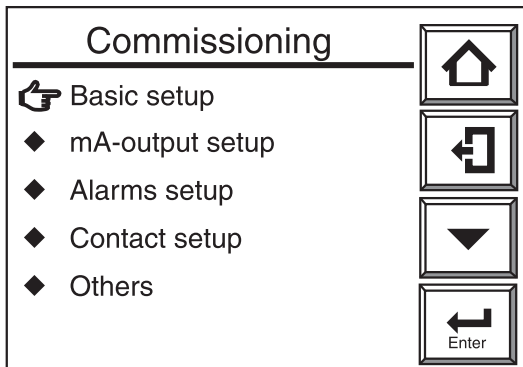


F0514.ai

Figure 5.14 Maintenance display

### ● Commissioning (Setup) Display

This display is used to set up the operation data such as current outputs or alarms.



F0515.ai

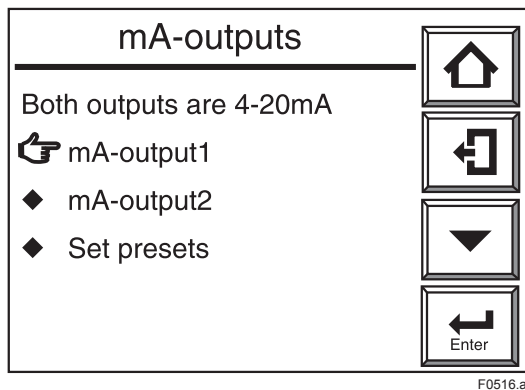
Figure 5.15 Commissioning (Setup) display

## 5.2 Output Functions

### 5.2.1 Current Output

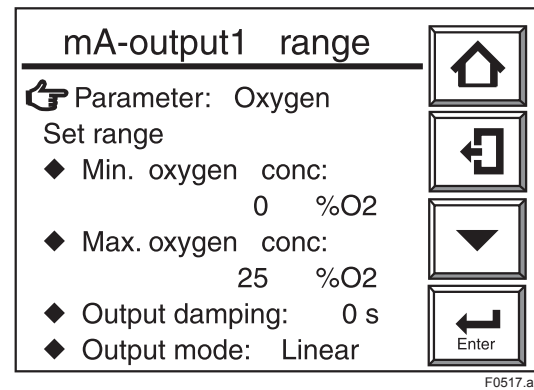
The ZR402G Zirconia Oxygen Analyzer Converter has two 4 – 20 mA DC current outputs. The output range of measured value (oxygen concentration) can be arbitrarily set from 0 to 5 in a range of 0 to 100 vol% O<sub>2</sub>. A partial range can also be set (the ratio between the maximum and minimum values should be 1.3 or more).

Setting is made by selecting “mA-output setup” in the Commissioning (Setup) display shown in Figure 5.15 and then choosing “mA-output 1” or “mA-output 2” in the mA-output setup display.



F0516.ai

Figure 5.16 mA-output setup display



F0517.ai

Figure 5.17 mA-output 1 range display

The following output functions can also be set up.

- **Setting Output Smoothing Constants**

If a measured value which is adversely affected by rapid changes in the oxygen concentration of the measurement gas is used as the basis for control, frequent on-off actions of the output may result. To avoid this, the converter allows output smoothing constants to be set from 0 to 255 seconds, using the mA-output 1 range display shown in Figure 5.17.

- **Output Hold Setting**

The “output hold” functions hold an analog output signal at the measured value just before occurrence or a preset value during the equipment’s warm-up time or calibration or if an error arises. Outputs 1 and 2 cannot be set individually.

Table 5.3 shows the relationship between individual equipment states and the analog outputs that can be retained.

Table 5.3 Individual Equipment States and the Analog Outputs That Can Be Retained

Equipment state Output hold values available	During warm-up	Under maintenance	Under calibration During blow back	On error occurrence
4 mA	○			
20 mA	○			
Without hold feature		○	○	○
Retains output from just before occurrence		○	○	○
Set value (2.4 to 21.6 mA)	○	○	○	○

○: The output hold functions are available.

To set the output hold function, select “Set presets” on the mA-output setup display. This causes the display shown in Figure 5.18 to appear.

From this display, select the desired item. Figure 5.19 shows an example of selecting “Maintenance.” Then the desired output status can be selected.

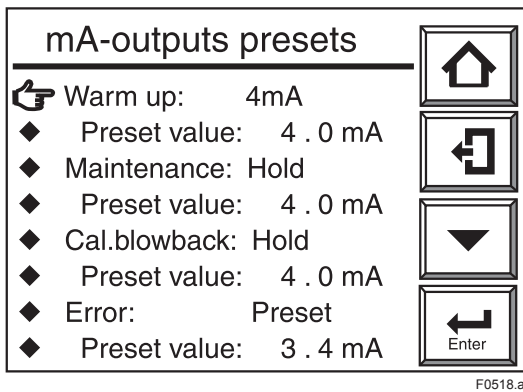


Figure 5.18 mA-output presets display

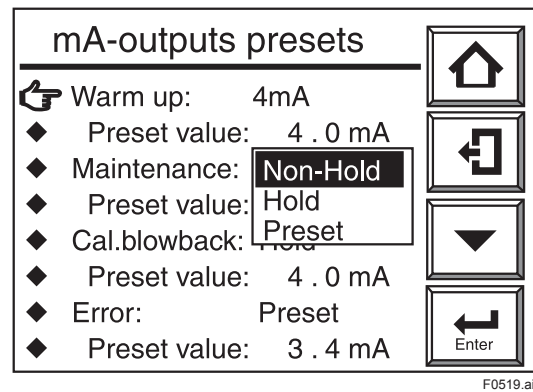


Figure 5.19 Example of mA-output presets

## 5.2.2 Contact Output

There are four contact outputs.

For contact outputs 1 to 3, you can select either normally energized or normally de-energized. Setting items can also be selected. Table 5.4 shows a list of setting items.

Contact output 4 is normally energized and the setting item is also fixed to “Error.”

The setting items and contact actions of contact outputs 1 to 3 are handled as follows: Press the Setup key in the basic panel display to display the Execution/Setup display shown in Figure 5.10 and select “Setup.” Then select “Contact setup” in the Commissioning (Setup) display shown in Figure 5.15. The Contact setup display shown in Figure 5.20 appears. In this display, select “Contact output 1” to “Contact output 3” to set up individual items.

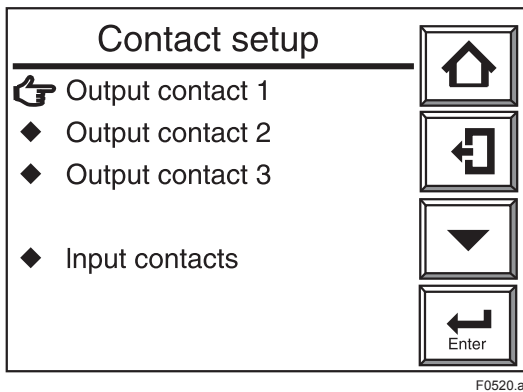


Figure 5.20 Contact setup display

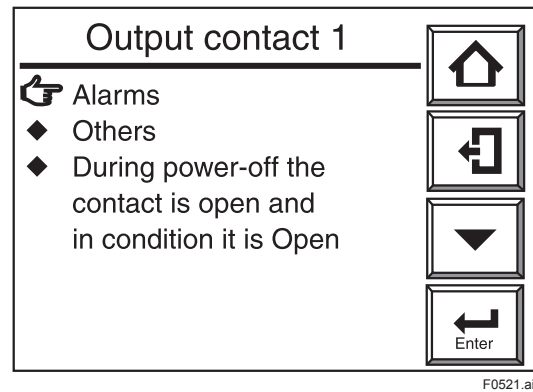


Figure 5.21 Output contact 1 display

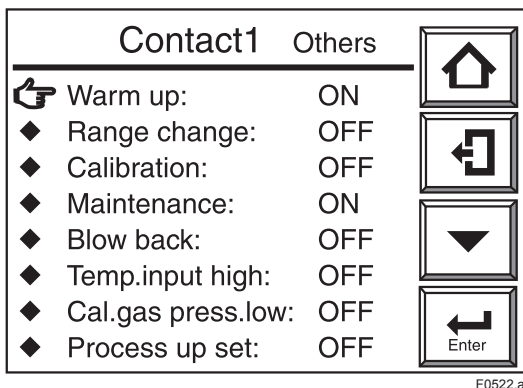


Figure 5.22 Example display of setting Contact 1 Others

Table 5.4 Contact Output Settings

	Item to be selected	Description
Alarm and Error Settings	High-high-limit alarm	If "high-high alarm ON" is selected, contact output occurs when the high-high-limit alarm is issued. To do this, it is required, in alarm setup, that the high-high alarm be set on beforehand.
	High-limit alarm	If "high alarm ON" is selected, contact output occurs when the high-limit alarm is provided. To do this, it is required, in alarm setup, that the high-limit alarm be set on beforehand.
	Low-limit alarm	If "low alarm ON" is selected, contact output occurs when the low-limit alarm is provided. To do this, it is required, in alarm setup, that the low-limit alarm be set on beforehand.
	Low-low-limit alarm	If "low-low alarm ON" is selected, contact output occurs when the low-low-limit alarm is issued. To do this, it is required, in alarm setup, that the low-low alarm be set on beforehand.
	Calibration coefficient alarm	If calibration coefficient alarm is ON (enabled), then when a zero- calibration coefficient alarm (alarm 6) or span calibration coefficient alarm (alarm 7) occurs then calibration coefficient alarm contact output occurs.
	Startup power stabilization timeout alarm	If set ON then contact output occurs when startup power stabilization timeout alarm (alarm 8) occurs.
	Error	If "Error ON" is selected, contact output occurs when an error results.
Other settings	Warm-up	If "Warm-up ON" is selected, contact output occurs during warm-up. For the definition of warm-up.
	Output range change	If "Range Change ON" is selected, contact output occurs ("answer-back signal to a range change signal") while a range change signal is applied to a contact input. To do this, it is required, in input contact setup, that the range change be selected beforehand.
	Calibration	If "Calibration ON" is selected, contact output occurs during calibration. For the definition of "During calibration,".
	Maintenance	If "Maintenance ON" is selected, contact output occurs during maintenance. For the definition of "During maintenance,".
	Blow back	If "Blow back ON" is selected, contact output occurs during blow back. For the definition of "During blow back,".
	High-limit temperature alarm	Not supported by the oxygen analyzer.
	Calibration gas press. low	If "Cal. gas press. low ON" is selected, contact output occurs ("answer-back signal to a calibration-gas low-pressure signal")when a calibration-gas low-pressure signal is applied to the contact input. To do this, it is required, in input contact setup, that "Cal. gas press. Low" be selected beforehand.
	Process upset	If "Process upset" is selected, contact output occurs ("answer-back signal to a process upset signal") when the process upset signal is applied to the contact input. To do this, it is required, in input contact setup, that "process upset" be selected beforehand.

Note: To provide an alarm with an output contact, be sure to make an alarm setting.  
When using contact output as an answer-back signal for an input contact, be sure to make an input contact.

## 5.3 Oxygen Concentration Alarms

The analyzer enables four alarms — high-high, high, low, and low-low alarms — to be set for the oxygen concentration.

The setting range is 0 to 100% O<sub>2</sub> for any alarm.

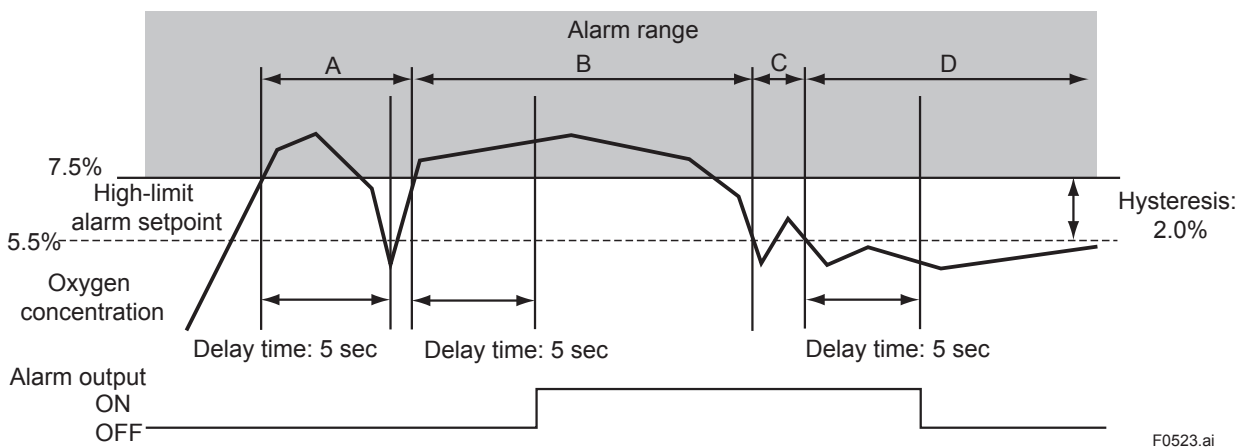
### 5.3.1 Alarm Output Actions

If the measured values of the oxygen concentration fluctuate between normal (steady state) values and the alarm setting, alarm-outputs may be frequently issued and canceled. To avoid this, set an alarm delay and hysteresis for alarm canceling under the alarm output conditions.

When a delay time is set, an alarm will not be issued so quickly even if the measured value differs from the steady-state and enters the alarm setpoint range. If the measured value remains within the alarm setpoint range for a certain period of time (the preset delay time), an alarm will be issued. On the other hand, there will be a similar delay each time the measured value returns to the steady state from the alarm setpoint range (canceling the alarm status).

If hysteresis is set, alarms will be canceled when the measured value is less than or greater than the preset hysteresis values.

If both the delay time and hysteresis are set, an alarm will be issued if the measured value is in the alarm setpoint range and the delay time has elapsed. For the alarm to be reset (canceled), the measured value must be beyond the preset hysteresis value and the preset delay time must have elapsed. These alarm output actions are shown in Figure 5.23.



**Figure 5.23 Alarm output action**

In the example in Figure 5.23, the high-limit alarm point is set to 7.5% O<sub>2</sub>, the delay time is set to five seconds, and hysteresis is set to 2% O<sub>2</sub>. Alarm output actions in each section in the figure above are as follows:

- Section "A": Although the oxygen concentration exceeds the high-limit alarm setpoint, it falls below the high-limit alarm setpoint before the preset delay time of five seconds elapses. So, no alarm is issued.
- Section "B": The oxygen concentration exceeds the high-limit alarm setpoint and the delay time elapses during that measurement. So, an alarm is issued.
- Section "C": Although the oxygen concentration falls below the hysteresis set value, the value rises again and exceeds the hysteresis set value before the preset delay time elapses. So, the alarm is not canceled.
- Section "D": The oxygen concentration falls below the hysteresis set value and the preset delay time elapses, so the alarm is canceled.

### 5.3.2 Setting Alarms

To set alarm setpoints, hysteresis, and delay time, do the following.

Press the Setup key in the basic panel display to show the Execution/Setup display in Figure 5.10 and then select "Setup". Then select "Alarm setup" in the Commissioning (Setup) display in Figure 5.15 to show the Alarm setup display in Figure 5.24.

In this display, select the required item and make the respective settings.

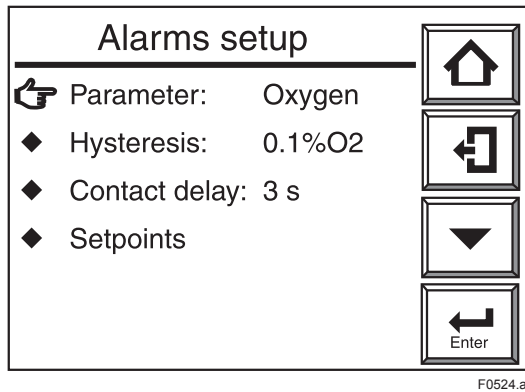


Figure 5.24 Alarm setup display

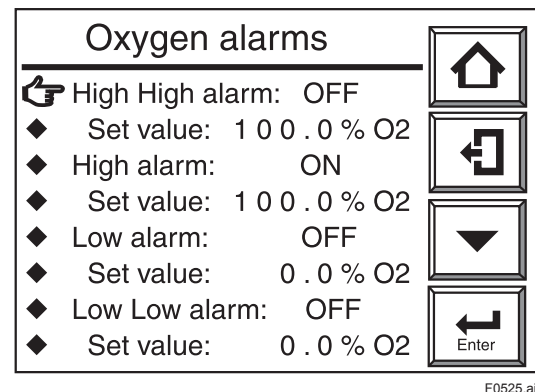


Figure 5.25 Oxygen alarms display

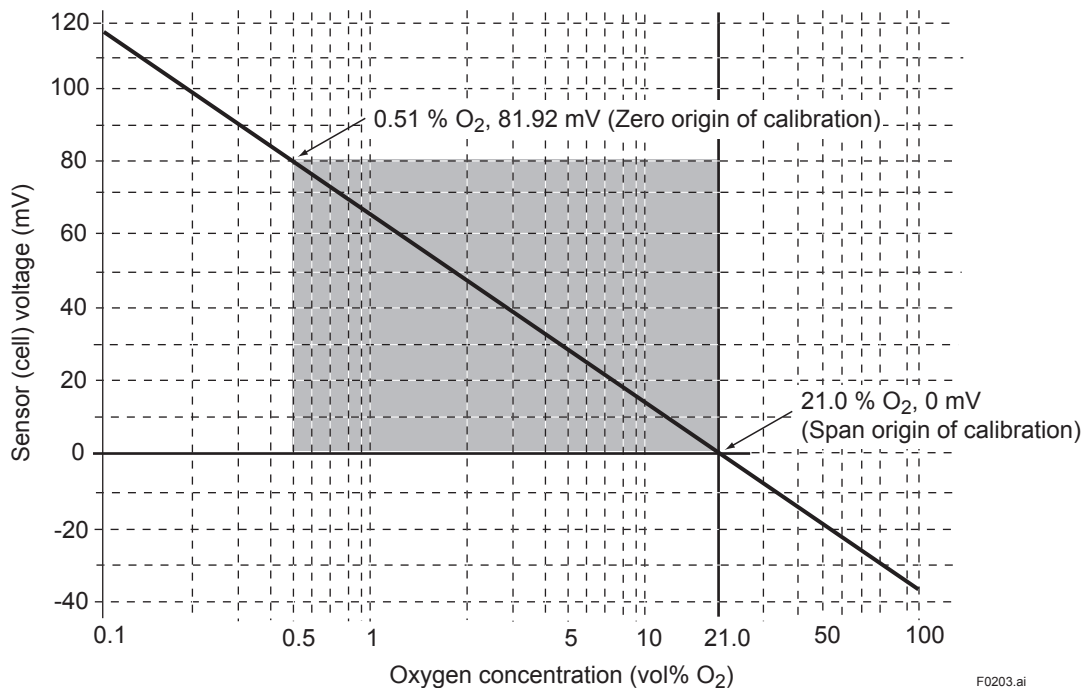
## 6. Calibration

### 6.1 Calibration Overview

The sensor (cell) electromotive force of the zirconia oxygen analyzer is governed by Nernst's equation (see chapter 2, "Measurement Principle of Zirconia Oxygen Analyzers").

When the sensor is heated up to 750°C and air is used as the reference gas, the relationship between the oxygen concentration of the measurement gas and the electromotive force of the sensor (cell) is as shown in Figure 6.1. However, this relationship is only theoretical. In practice, the sensor (cell) usually shows a slight deviation from the theoretical value. Moreover, the sensor deteriorates over time, causing the electromotive force to change.

Therefore, it is necessary to calibrate using calibration gas to correct the deviation from the theoretical value.



**Figure 6.1** Relationship between oxygen concentration in measurement gas and cell's electromotive force (on the basis of 21.0% O<sub>2</sub>)

### 6.2 Calibration Gas

A gas with a known oxygen concentration is used for calibration. Normal calibration is performed using two different gases: a "zero gas" of low oxygen concentration and a span gas of high oxygen concentration (two-point calibration).

In some cases, only one of the gases needs to be used for calibration. However, even if only one of the gases is normally used, calibration using both gases should be done at least once.

The following gases are normally used for zero gas and span gas.

- Zero gas: Oxygen concentration of 0.95 to 1.0 vol% O<sub>2</sub> with a balance of nitrogen gas (N<sub>2</sub>)
- Span gas: Clean air (at a dew-point temperature below -20°C and free of oily mist or dust as in instrument air)

Note: Nitrogen gas (N<sub>2</sub>) with an oxygen concentration of 0% cannot be used as zero gas.

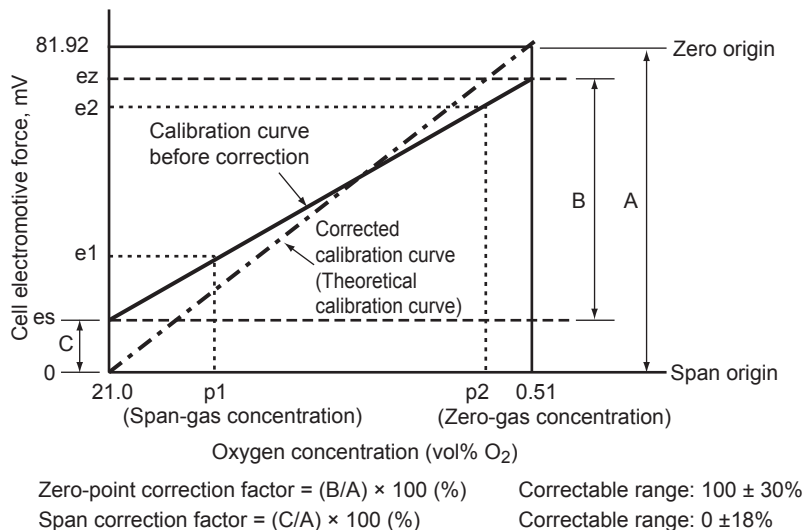
This is because, as described in the chapter on the measurement principle, the zirconia oxygen analyzer detects, as electromotive force (E), changes in the partial oxygen pressure (P<sub>X</sub>) on the measurement side with respect to the partial oxygen pressure (P<sub>A</sub>) on the reference side.

Because this electromotive force (E) is logarithmically proportional to P<sub>X</sub>/P<sub>A</sub>, if P<sub>X</sub> is 0%, the electromotive force becomes infinite, disabling calibration. In general, gas of 1% O<sub>2</sub> is used for calibration with zero gas.

## 6.3 Two-point Calibration

Figure 6.2 shows a two-point calibration using two gases: zero and span gases. Cell electromotive forces for a span gas with an oxygen concentration  $p_1$  and a zero gas with an oxygen concentration  $p_2$  are measured while determining the calibration curve passing between these two points. The oxygen concentration of the measurement gas is determined from this calibration curve.

In addition, the calibration curve corrected by calibration is compared with the theoretical calibration curve for determining the zero-point correction ratio represented by  $B/A \times 100 (\%)$  on the basis of A, B and C shown in Figure 6.2 and a span correction ratio of  $C/A \times 100 (\%)$ . If the zero-point correction ratio exceeds the range of  $100 \pm 30 \%$  or the span correction ratio becomes larger than  $0 \pm 18 \%$ , calibration of the sensor becomes impossible.



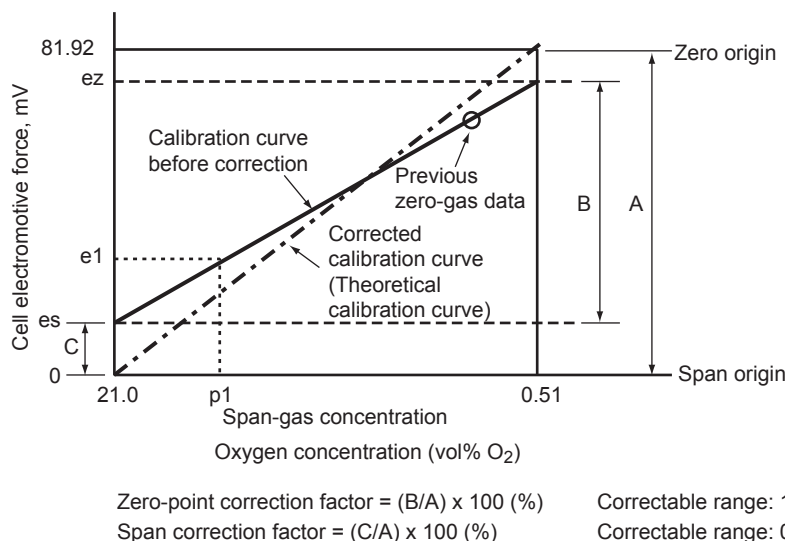
F0602.ai

**Figure 6.2 Calculation of a Two-point Calibration Curve and Correction Factors using Zero and Span Gases**

## 6.4 One-point Calibration

Figure 6.3 shows a one-point calibration using only a span gas. In this case, only the cell electromotive force for a span gas with oxygen concentration  $p_1$  is measured. The cell electromotive force for the zero gas is carried over from a previous measurement to obtain the calibration curve. The principle of calibration using only a span gas also applies to the one-point calibration method using a zero gas only.

The methods of obtaining the span correction ratio and zero-point correction ratio are the same as those of two-point calibration.



F0507.ai

**Figure 6.3 Calculation of a One-point Calibration Curve and Correction Factors using a Span Gas**

## 6.5 Calibration Modes

Zirconia oxygen analyzers employ the following three operation modes for calibration.

- Manual calibration: Allows zero and span calibrations, or either one manually in turn.
- Semi-automatic calibration: Lets calibration start with the touch panel or a contact input, and undergoes a series of calibration operations following preset calibration periods and stabilization time.
- Automatic calibration: Performs calibration automatically following preset calibration periods.

## 6.6 Setting the Calibration Time

### (1) For manual calibration

First set the output stabilization time. This indicates the time required from the end of calibration to entering a measurement again. This time, after calibration, the measurement gas enters the sensor to set the time until the output returns to normal. The output remains held after completing the calibration operation until the output stabilization time elapses. The calibration time set ranges from 00 minutes, 00 seconds to 60 minutes, 59 seconds.

### (2) For semi-automatic calibration

Set the output stabilization time and calibration time. The calibration time is the time required from starting the flow of the calibration gas to reading out the measured value. The set calibration time is zero and span calibrations.

The calibration time set ranges from 00 minutes, 00 seconds to 60 minutes, 59 seconds.

Figure 6.4 shows the relationship between the calibration time and output stabilization time.

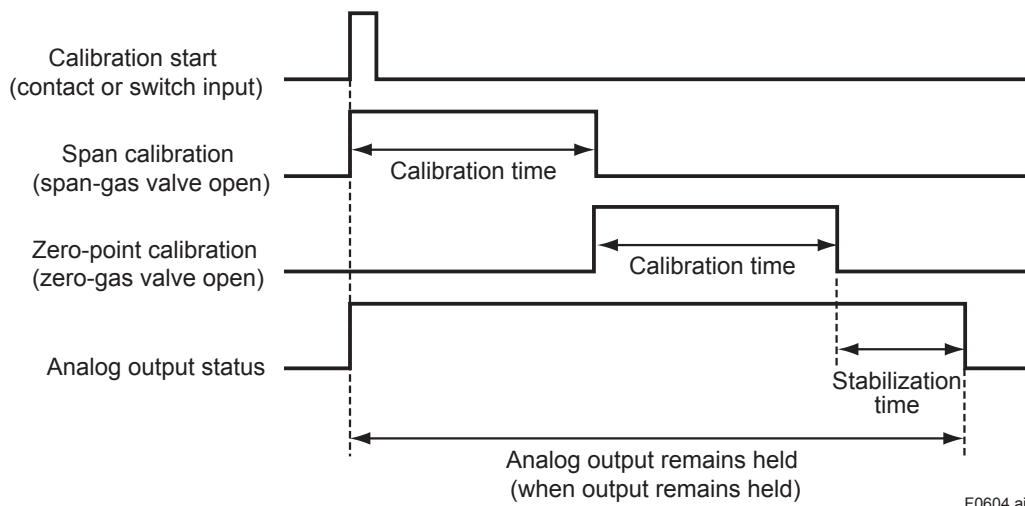


Figure 6.4 Calibration and output stabilization time settings

### (3) For automatic calibration

In addition to the above output stabilization time and calibration time, set the interval, start date, and start time. Interval means the calibration interval, ranging from 000 days, 00 hours to 255 days, 23 hours. Set the first calibration day, and the start-calibration time, respectively.

## 7. Blow Back Function

The probe easily becomes clogged if the sample gas contains too much dust such as in a recovery boiler or cement kiln. The blow back function is used to remove such dust with air pressure.

### 7.1 Blow Back Modes

The zirconia oxygen analyzer offers the following two blow back modes:

- **Semi-automatic blow back**

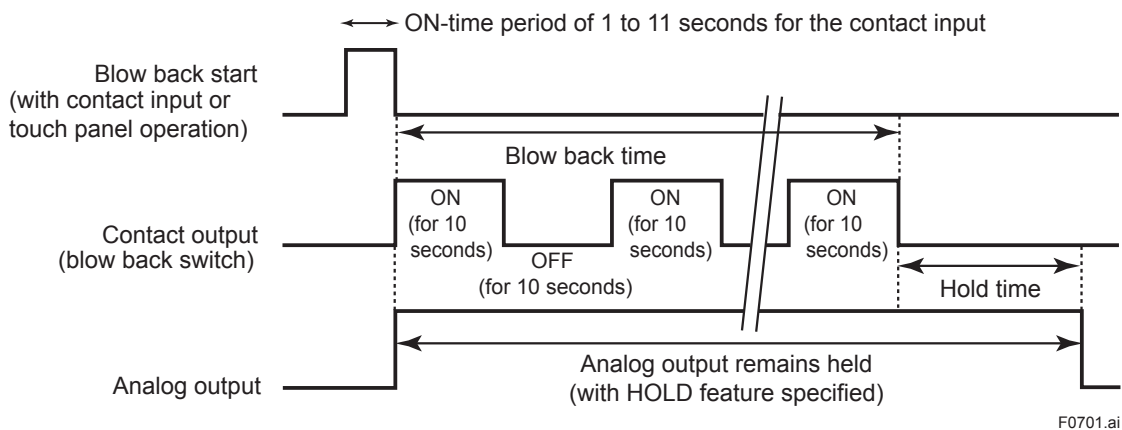
In this mode, touch panel operations or contact input signals will start and perform blow back operations according to a preset blow back time and output stabilization time.

- **Automatic blow back**

Performs blow back operations automatically according to a preset interval, blow back time, and output stabilization time.

### 7.2 Blow Back Operations

Figure 7.1 shows a timing chart for the operation of blow back. To execute blow back with a contact input, use a contact input with an ON-time period of 1 to 11 seconds. Once blow back starts, a contact output opens and closes at 10 second intervals during the preset blow back time. After the blow back time elapses, the analog output remains held at the preset status until the hold time elapses. As the hold (output stabilization) time, set the time until the measured gas is returned to the sensor and the output returns to the normal operating conditions, after completing blow back operations.



F0701.ai

**Figure 7.1 Operation of blow back**

- Blow back time: Can be set from 00 min, 00 sec to 60 min, 59 sec.
- Hold time (output stabilization time): Can be set from 00 min, 00 sec to 60 min, 59 sec.

## 8. Directions for Use

To achieve accurate measurements with a zirconia oxygen analyzer, the following must be considered.

### 8.1 Effect of Coexisting Combustible Gases

The sensor (zirconia element) is heated to 750°C during measurements. If the process gas contains combustible gases such as carbon monoxide, hydrogen, and methane, these gases burn in the detector and consume oxygen, causing the oxygen concentration measured by the oxygen analyzer to be smaller than the actual value. Therefore, zirconia oxygen analyzers should be used only when the effect of coexisting combustible gases can be ignored or when their effect on oxygen concentration can be corrected.

Generally, exhaust gases after combustion that are emitted from combustion equipment such as boilers and industrial furnaces have been completely burned; the volume of combustible gases such as carbon monoxide is very small in comparison with oxygen, and so their influence can be ignored. However, if the excess air ratio is extremely small or if combustion is non-uniform, causing carbon monoxide to be produced, care is required.

### 8.2 Effect of Humidity in Reference Gas (Air)

Zirconia oxygen analyzers use a gas whose oxygen concentration is known and always consistent, as the reference gas.

In general, air is used as the reference gas. The oxygen concentration of dry air is constant at 20.95%; however, air generally contains water vapor, in which case the oxygen concentration varies with temperature and humidity.

In zirconia oxygen analyzers, a measurement error is caused if the temperature or humidity of the reference gas (air) varies significantly between calibration and measurement. When instrument air is used as the reference gas, this error can be ignored, but if it cannot be used, care is required.

### 8.3 Precautions When Shutting Down a Furnace or Boiler

When operating an instrument such as boiler or industrial furnace is stopped with the zirconia oxygen analyzer operation, moisture can condensate on the sensor portion and dusts may stick to it.

If operation is restarted in this condition, the sensor which is heated up to 750°C firmly fix the dusts on itself. Consequently, the dusts can make the sensor performance very lower. If a large amount of water is condensed, the sensor can be broken and never reusable.

To prevent the above nonconformity, take the following action when stopping operation.

- (1) If possible, keep on supplying the power to converter and flowing reference air to the sensor. If impossible to do the above, remove the detector.
- (2) If unavoidably impossible to supply the power and removing the detector, keep on following air at 600ml/min into the calibration gas pipe.

## 8.4 Dry Gas Base and Wet Gas Base

Exhaust gas emitted by combustion of fuel contains water vapor generated by the burning of hydrogen in the fuel.

When directly measuring gases in a flue with a zirconia oxygen analyzer, exhaust gas containing moisture is measured. Values measured under these conditions are called “values based on a wet gas.”

In contrast, for oxygen analyzers that sample and measure exhaust gases, the sample gas temperature is lowered to normal temperature in the process of being introduced into the analyzer and moisture that would condense into water is also removed from the sample gas. Values measured after removing the moisture in this way are called “values based on a dry gas.”

While a value based on a dry gas regards the total gas composition available after moisture removal as 100%, a value based on a wet gas assumes that the gas composition including water vapor is 100%. Therefore, the results differ between both measurement types even when the oxygen concentration of the same exhaust gas is measured (see Figure 8.1).

This difference between the measurement types is largest when gas containing much hydrogen is burned (since much water vapor is generated). Special care is required when the output (based on a wet gas) of the zirconia oxygen analyzer is calculated in combination with other analytical values measured based on a dry gas (for example, CO or NO<sub>x</sub> concentration measured using an infrared gas analyzer).

Note: Our model ZR402G Zirconia Oxygen Analyzer Converter incorporates a “dry gas-based” calculation function; it can output dry gas-based values.

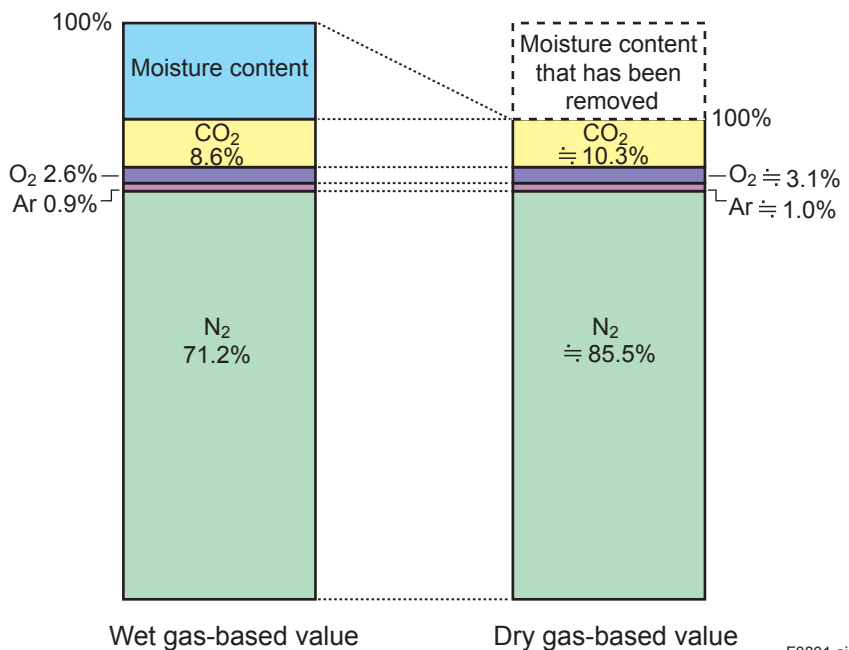


Figure 8.1 Values based on a wet gas or dry gas

## 8.5 In Case Equipment is Turned On and Off Frequently

To avoid temperature changes around the sensor, it is recommended that (rather than turning it on and off) power be continuously supplied to the Oxygen Analyzer if it is used in an application where it is used periodically.

It is also recommended to flow a span gas (instrument air) beforehand.

# Revision History

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