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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Gas analyzers – Expression of performance – Part 3: Paramagnetic oxygen analyzers

Analyseurs de gaz – Expression des performances – Partie 3: Analyseurs d'oxygène paramagnétiques

IEC 61207-3:2019-06(en-fr)

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FOREWORD

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International Standard IEC 61207-3 has been prepared by sub-committee 65B: Measurement and control devices, of IEC technical committee 65: Industrial-process measurement, control and automation.

This third edition cancels and replaces the second edition published in 2002. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) all references (normative and informative) have been updated, deleted or added to as appropriate;

b) all the terms, descriptions and definitions relating to the document have been updated where appropriate;

c) all references to “errors” have been replaced by “uncertainties” and appropriate updated definitions applied.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
65B/1155/FDIS	65B/1157/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

This International Standard is to be used in conjunction with IEC 61207-1:2010.

A list of all parts in the IEC 61207 series, published under the general title *Gas analyzers – Expression of performance*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

Paramagnetic oxygen analyzers respond to the partial pressure of oxygen in the measured gas, and the volumetric concentration is then determined by knowledge of the total pressure, as in many other gas analyzers. Due to this fact, many paramagnetic oxygen analyzers use pressure compensation (see 4.4.4 and 4.4.5). They are used in a wide range of industrial, laboratory, medical, and other applications where the rated measuring range of the analyzer is between 0 % to 1 % and 0 % to 100 %, at reference pressure (usually near atmospheric).

Only a few gases display significant paramagnetism (for example, oxygen, nitric oxide and nitrogen dioxide), and oxygen has the strongest paramagnetic susceptibility (see Annex A) among gases. By employing this particular property of oxygen, analyzers have been designed that can be highly specific to the measurement in most industrial and medical applications, where, for example, high background levels of hydrocarbons or moisture may be present.

There are several different techniques described for measuring oxygen by its paramagnetic property, but three main methods have evolved over many years of commercial application.

The three methods are:

– automatic null balance;
– thermomagnetic or magnetic wind;
– differential pressure or Quincke.

These methods all require the sample gas to be clean and non-condensing, though some versions work at elevated temperatures so that samples that are likely to condense at a lower temperature can be analyzed. Because of this requirement, analyzers often require a sample system to condition the sample prior to measurement.

GAS ANALYZERS – EXPRESSION OF PERFORMANCE –

Part 3: Paramagnetic oxygen analyzers

1 Scope

This part of IEC 61207 applies to the three main methods for measuring oxygen by its paramagnetic property, which are outlined in the introduction. It considers essential ancillary units and applies to analyzers installed indoors and outdoors.

Safety-critical applications can require additional requirements from system and analyzer specifications not covered in this document.

This document is intended

– to specify terminology and definitions related to the functional performance of paramagnetic gas analyzers for the measurement of oxygen in a source gas;
– to unify methods used in making and verifying statements on the functional performance of such analyzers;
– to specify what tests are performed to determine the functional performance and how such tests are carried out;
– to provide basic documents to support the application of internationally recognized quality management standards.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61207-1, *Expression of performance of gas analyzers – Part 1: General*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

NOTE Although cgs (centimetre-gram-second) units have been used in this document, SI (Système International) units (such as defined in IUPAC [1] [1]) can also be used.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

[1] Numbers in square brackets refer to the bibliography

3.1
magnetic susceptibility
measure (X) of the variation of the intensity of a magnetic field H, existing in a vacuum, when the vacuum is substituted (filled) by the test substance, expressed as:

$$X = \frac{H^1 - H}{H}$$

where

H is the magnetic field intensity in vacuum

H^1 is the magnetic field intensity in the test substance

Note 1 to entry: $H^1 - H$ is also known as the magnetisation MV (magnetic dipole per unit volume) and therefore this is also the volume magnetic susceptibility.

3.2
paramagnetism
property of substances causing an increase of the magnetic field intensity ($X > 0$)

3.3
diamagnetism
property of substances causing a diminution of the magnetic field intensity ($X < 0$ because $H^1 < H$)

3.4
specific magnetic susceptibility
ratio of magnetic susceptibility to the density derived as follows:

$$X_s = \frac{X}{D}$$

where

D is the density of the considered substance, expressed in g·cm^{-3} at 273,15 K, 101,3 kPa

Note 1 to entry: The measuring unit of X_s is therefore cm^3·g^{-1}. This is also known as the mass magnetic susceptibility.

3.5
molar magnetic susceptibility
X_m
specific magnetic susceptibility multiplied by the molecular mass (M) of the substance considered:

$$X_m = X_s \cdot M$$

where

M is expressed in g per mole (g·mol^{-1}) (for oxygen M = 31,998 8)

Note 1 to entry: The measuring unit of X_m is therefore cm^3·mol^{-1}.

Note 2 to entry: Electrons determine the magnetic properties of matter in two ways:

– an electron can be considered as a small sphere of negative charge spinning on its axis. This spinning charge produces a magnetic moment;

– an electron travelling in an orbit around a nucleus will also produce a magnetic moment.

It is the combination of the spin moment and the orbital moment that governs the resulting magnetic properties of an individual atom or ion.

In paramagnetic materials, the main contribution to the magnetic moment comes from unpaired electrons. It is the configuration of the orbital electrons and their spin orientations that establish the paramagnetism of the oxygen molecule and distinguish it from most other gases.

Note 3 to entry: When paramagnetic gases are placed within an external magnetic field, the flux within the gas is higher than it would be in a vacuum, thus paramagnetic gases are attracted to the part of the magnetic field with the strongest magnetic flux. On the contrary, diamagnetic substances contain magnetic dipoles which cancel out some lines of force from the external field; thus diamagnetic gases are subject to repulsion by the magnetic flux.

Note 4 to entry: The molar magnetic susceptibility of oxygen is inversely proportional to the absolute temperature. According to Van Vleck [2] the molar susceptibility of oxygen can be approximated by Equation (4).

For oxygen,

$$X_{\mathrm{m}} = \frac{8L \cdot \mu_{\mathrm{B}}^{2}}{3kT} \tag{4}$$

where

X_{m} is the molar susceptibility of oxygen, expressed in $\mathrm{cm^3 \cdot mol^{-1}}$;

L is the Avogadro constant = 6,022 7 × 10^{23} $\mathrm{mol^{-1}}$;

μ_{B} is the Bohr magneton = 9,274 × 10^{-24} $\mathrm{A \cdot m^2}$;

k is the Boltzmann constant = 1,38 × 10^{-23} $\mathrm{J \cdot K^{-1}}$;

T is the temperature, expressed in K (kelvin).

Equation (4) can be written as follows:

$$X_{\mathrm{m}} = \frac{1010557}{T} \times 10^{-6}\ \mathrm{cm^3 \cdot mol^{-1}} \text{ (only for oxygen).}$$

Note 5 to entry: A full understanding of paramagnetism and diamagnetism can be obtained from physics and inorganic chemistry textbooks. The explanation in this document is to give the user of paramagnetic oxygen analyzers a simple understanding of the physical property utilized.

3.6
automatic null balance analyzer
analyzer that uses, as a general principle of operation, the displacement of a body containing a vacuum or a diamagnetic gas, from a region of high magnetic field by paramagnetic oxygen molecules

Note 1 to entry: See Figure 1.

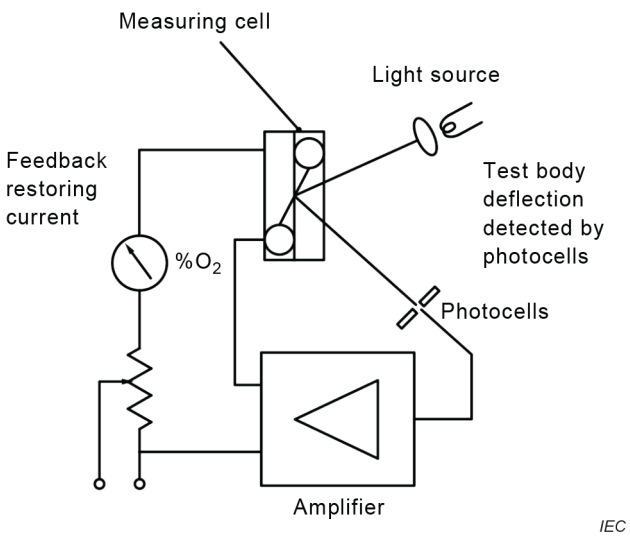

Figure 1 – Magnetic auto-balance system with current feedback

Note 2 to entry: The measuring cell typically employs a glass dumb-bell, with the spheres containing nitrogen, suspended on a torsion strip between magnetic pole pieces or magnets that produce a very strong magnetic field gradient around the dumb-bell. The dumb-bell is then deflected when oxygen molecules enter the measuring cell, a force being exerted on the dumb-bell by the oxygen molecules which are attracted to the strongest part of the

magnetic field. By use of an optical lever, a magnetic actuation coil, and suitable electronics to generate a feedback signal that nulls the magnetic susceptibility force, an output that is directly proportional to the partial pressure of oxygen can be achieved. The transducer can be maintained at a constant temperature to prevent the variations in magnetic susceptibility to temperature from introducing uncertainties. Alternatively, built-in temperature sensors may be used to provide temperature compensation of the oxygen reading. Additionally, the elevated temperature helps in applications where the sample is not particularly dry. Some analyzers are designed so that the transducer operates at a temperature in excess of 373,15 K (100 °C) to further facilitate applications where condensates would form at a lower temperature. Paramagnetic sensor orientation may also affect the oxygen measurement uncertainty and this may be corrected by using a compensation algorithm using, for example, a three-dimensional accelerometer to determine the sensor orientation relative to its orientation during calibration. Due to the mechanical nature of this type of device, there is some inherent susceptibility to vibrational and gyroscopic motion, potentially resulting in increased measurement uncertainty.

3.7
thermomagnetic analyzer

3.7.1
magnetic wind analyzer
analyzer that uses the temperature dependence of the magnetic susceptibility to generate a magnetically induced gas flow which can then be measured by a flow sensor

Note 1 to entry: The sample gas passes into a chamber designed in such a way that the inlet splits the flow.

Note 2 to entry: See Figure 2.

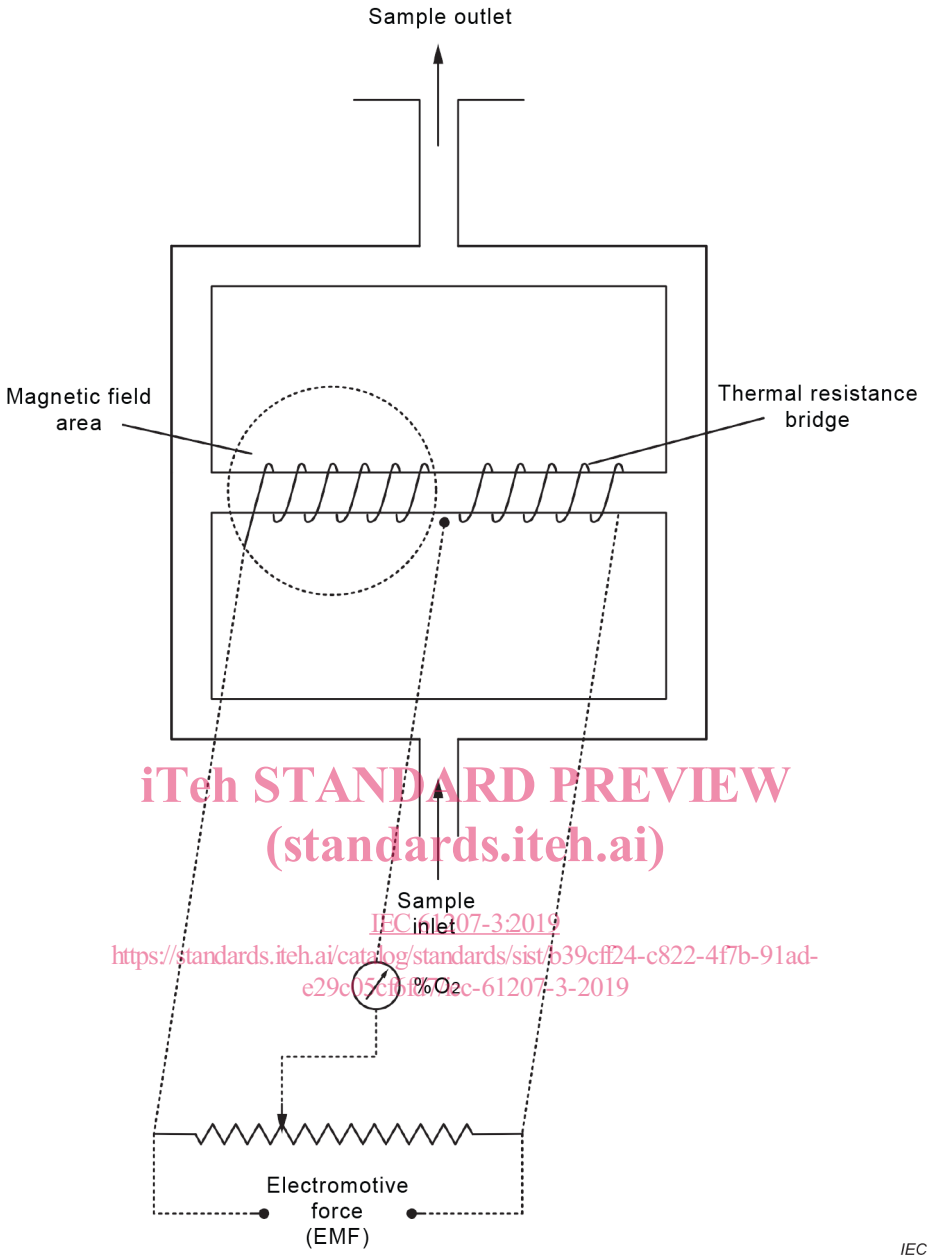

Figure 2 – Thermomagnetic oxygen sensor

Note 3 to entry: The two flows recombine at the outlet. A connecting tube is placed centrally with the flow sensor wound on it. Half of the connecting tube is placed between the poles of a strong magnet. The flow sensor is effectively two coils of wire heated to about 353,15 K (80 °C) by passage of a current. The cold oxygen molecules are diverted by the magnetic field into the central tube, and, as they heat up, their magnetic susceptibility is reduced and more cold oxygen molecules enter the connecting tube. A flow of oxygen is generated in this way through the transversal connecting tube, with the effect of cooling the first coil (which is placed in the magnetic field area), while the temperature of the second coil is not essentially influenced by this transversal flow. Since the two coils are wound with thermosensitive wire (for example, platinum wire) and connected together to build a Wheatstone bridge, the resulting unbalance current is a nearly proportional function of the oxygen partial pressure in the test gas.

More recent analyzers use more refined measuring cells, toroidal shaped resistors instead of the two-coil flow sensor, and employ temperature control to minimize ambient temperature changes.

As this method relies on heat transfer, the thermal conductivity of background gases will affect the oxygen reading and the composition of the background has to be known. Some analyzers can give a first-order correction for this by utilizing further compensation devices.

Thermomagnetic analyzers do not produce a strictly linear output and additional signal processing is required to linearize the output.

3.8
Quincke analyzer

3.8.1
differential pressure analyzer
analyzer that uses a pneumatic balance system established by using a flowing reference gas (such as nitrogen or air)

Note 1 to entry: The measuring cell is designed so that at the reference gas inlet the flow is divided into two paths. These flows recombine at the reference gas outlet, where the sample is also introduced. A differential pressure sensor (or microflow sensor) is positioned across the two reference gas flows so that any imbalance is detected. A magnet is situated in the vicinity of the reference gas outlet in one arm of the measuring cell so that oxygen in the sample is attracted into the arm, thereby causing a small back pressure which is detected by the pressure sensor (see Figure 3).

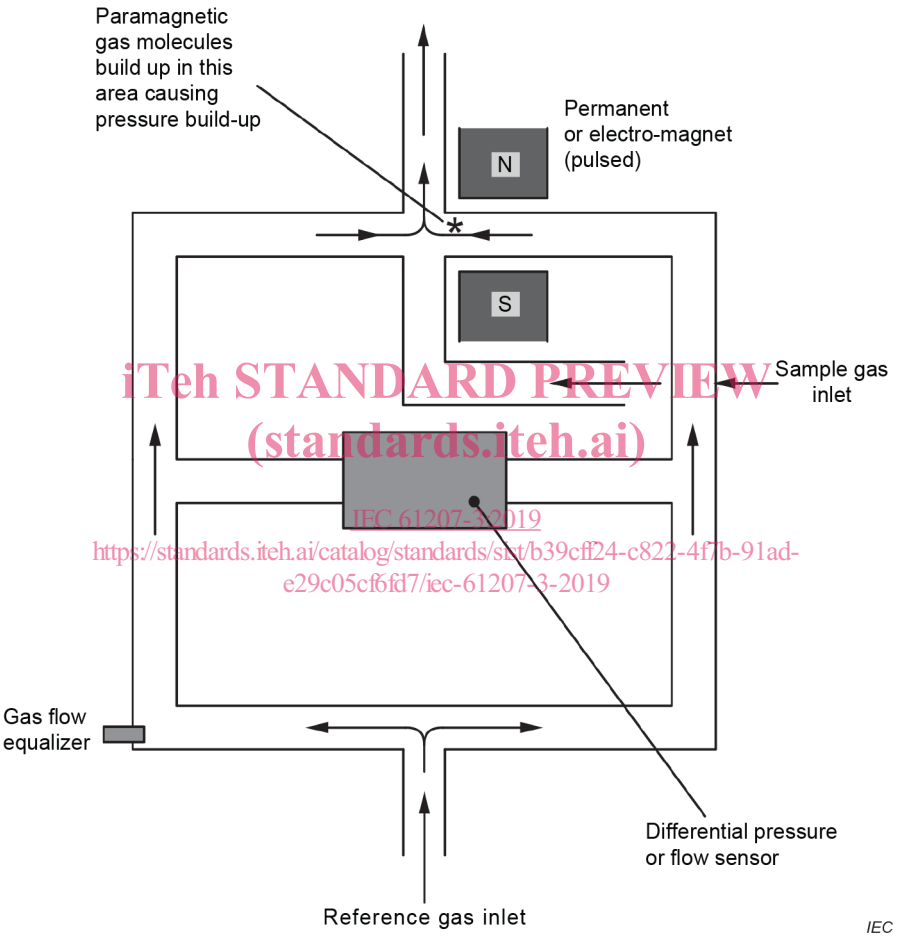

Figure 3 – Differential pressure oxygen sensor

Note 2 to entry: Differential pressure analyzers are independent of thermal conductivity of background gases, and as only the reference gas comes in contact with the sensor, corrosion problems are minimal. Some instruments use pulsed magnetic fields to improve tilt sensitivity, and certain designs compensate for vibration effects.

3.9
hazardous area
area in which an explosive gas atmosphere is present, or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of devices

3.10
essential ancillary unit
unit without which the analyzer will not operate within specifications

EXAMPLE: Calibration systems, reference gas systems, sample systems.

3.11
sample systems
system of component parts assembled on a panel or in an analyzer house with the purpose of transporting the sample gas from the sampling point to the analyzer and presenting the sample in such a manner that reliable measurements can be obtained

Note 1 to entry: The components used can include

- pressure regulators;
- flow meters;
- flow controllers;
- filtration units;
- pumps;
- valves (manual and/or electrically operated);
- catch or knockout pots;
- coolers;
- heaters;
- drying units;
- scrubbing units.

Note 2 to entry: See Figure 4 and Figure 5 for examples of typical sampling systems. For full details of sample system requirements, see IEC 61115 [3]. These components will usually be designed as a sample system by the user or, more often, by a manufacturer, so that the analyzer requirements defined in the specification are within the rated operating range. The required system design is therefore very dependent on the sample conditions of the process. Variations in sample pressure, temperature, dust loading, and pressure of other gases and vapours will affect the final sample system design.

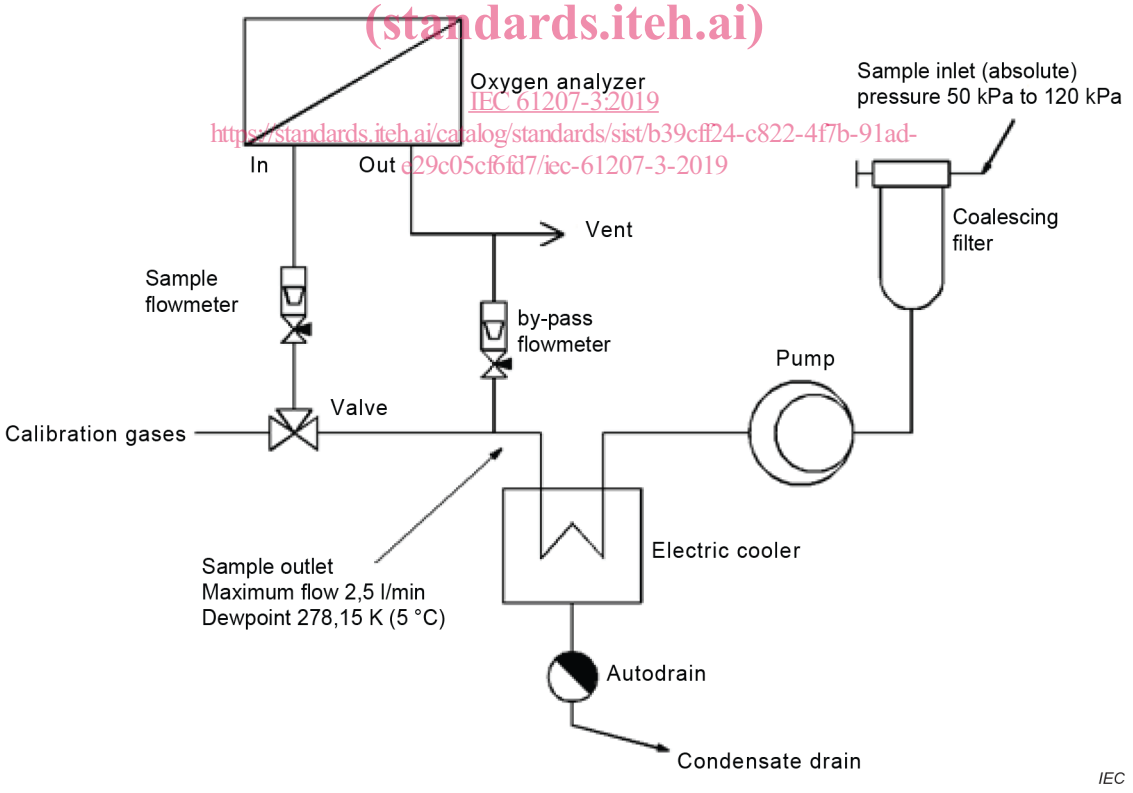

Figure 4 – Typical sampling systems –
Filtered and dried system with pump for wet samples