Vacuum xxx (2015) 1–5

Contents lists available at ScienceDirect

Vacuum

journal homepage: www.elsevier.com/locate/vacuum

Temperature calibration of quartz oscillator for outdoor hydrogen sensing

Atsushi Suzuki [a,*], Hisao Hojo [b], Takichi Kobayashi [c]

[a] *National Institute of Advanced Industrial Science and Technology, AIST, Japan*
[b] *Vacuum Products Co, Japan*
[c] *Vacuum Products Instruments Co, Japan*

ARTICLE INFO

Article history:
Received 27 October 2014
Received in revised form
26 February 2015
Accepted 20 March 2015
Available online xxx

Keywords:
Hydrogen sensing
Quartz oscillator
Influences of temperature and humidity
Outside use
Temperature calibration
Fuel cell vehicle
Hydrogen energy

ABSTRACT

For outdoor hydrogen sensing using a quartz friction pressure gauge (Q-gauge), we investigated the influence of ambient temperature on the output from a Q-gauge, because the change in the baseline of the Q-gauge output might be comparable in degree to the changes resulting from hydrogen leakage, which results in an error for hydrogen sensing. At constant relative humidity, the output from the Q-gauge changed with the change in temperature within the range 15–50 °C. The largest differences in the output with respect to temperature corresponded to those seen in hydrogen leakage with about 6 vol% hydrogen concentration, judging from the correlation between the change in the Q-gauge and hydrogen concentration. 6 vol% hydrogen concentration is clearly higher than the necessary minimum for detection of hydrogen concentration because one-fourth of the low explosive level hydrogen concentration is 1 vol%; therefore, temperature calibration is necessary for outdoor use of this hydrogen sensing method. We tried to suppress the influence of temperature on the Q-gauge output using the temperature dependence of the experimental output. We found that the influence of temperature could be reduced to change the output by less than 1 vol% hydrogen concentration.

1. Introduction

The principle of hydrogen sensing using a quartz oscillator is based on the oscillator's electric impedance, which depends on the viscosity and molecular weight of the gas measured [1–17]. Because hydrogen leakage into air results in a decrease in the viscosity and molecular weight of the hydrogen-leaked air compared to the pure air, hydrogen sensing can be accomplished by measuring the viscosity and molecular weight of air using a device containing a quartz oscillator, such as a quartz friction pressure gauge (Q-gauge) [4,6,18]. The Q-gauge is a pressure gauge that can work for a wide range of absolute pressures, from 1 to 10^5 Pa [4]. The Q-gauge output depends on the viscosity and molecular weight of the gas measured and is expressed in units of pressure.

Hydrogen sensing with a quartz oscillator has various advantages compared to other hydrogen sensing methods, such as safety, measurement without any external energy at room temperature, applicability to a wide range of hydrogen concentrations, fast response, and small size (the quartz oscillator is less than 1 mm × 4 mm) [1,8,19–30]. Because of the advantages mentioned above, Q-gauge hydrogen sensing can be applied for various purposes in a so-called hydrogen society, such as production, storage, and distribution of hydrogen and in fuel cell vehicles.

Some of these applications may possibly be performed outdoors. However, of course, outdoor temperature and humidity fluctuate. This affects the Q-gauge hydrogen sensing because temperature affects the resonant frequency of the quartz oscillator, and therefore may affect the electrical impedance, which is the source for the Q-gauge output [31]. As the relative humidity increases, the viscosity and molecular weight of the air decrease because water has lower viscosity and molecular weight than pure air does.

In this study, the influence of temperature on the baseline of the Q-gauge hydrogen sensing was investigated for a range of ambient temperatures at various relative humidities (RHs). In addition, temperature calibration was tested for reduction of the influence of temperature on the Q-gauge hydrogen sensing.

---

* Corresponding author.
E-mail address: a-suzuki@aist.go.jp (A. Suzuki).

http://dx.doi.org/10.1016/j.vacuum.2015.03.020

Please cite this article in press as: Suzuki A, et al., Temperature calibration of quartz oscillator for outdoor hydrogen sensing, Vacuum (2015), http://dx.doi.org/10.1016/j.vacuum.2015.03.020

2. Experimental procedure

The experimental system is presented in Fig. 1. The influence of temperature on the electric impedance of a quartz oscillator was investigated using a Q-gauge, which contains the quartz oscillator. Details of the Q-gauge have been reported in a previous work [4]. The Q-gauge was calibrated with respect to air, meaning that nominal pressure, which depends on the kind of gas measured, is equal to the absolute pressure when measured for pure air.

Two kinds of Q-gauge were investigated in this study. One is a conventional single Q-gauge (SQG), which has one quartz oscillator. The other is a Q-gauge, which has two quartz oscillators (WQG), with an additional quartz oscillator, which is separated with a cover from the outside, being only used for temperature measurement. This measured temperature is used for temperature calibration of the WQG. The quartz oscillators used in the gauge head for gas measurements were used without any covers that would block dust and particles, in order to be more sensitive to temperature and humidity change.

To investigate the influence of temperature, the sensor head of the Q-sensor with a pre-amp and the inlet of the sensor head of a diaphragm gauge (D-gauge) were fixed in the inside of a temperature and humidity chamber, which is an environmental chamber inside of which the temperature and humidity can be controlled. The sensor head of the D-gauge was set outside the chamber to suppress the influence of temperature on the D-gauge measurement. Because the distance between the edge of the inlet and the plate in the sensor head in the D-gauge is about 5 cm, the pressure at the edge of the inlet should be the same as at the plate in the sensor head of the D-gauge. The D-gauge was used to measure absolute pressure inside the temperature and humidity chamber for the purpose of pressure calibration for the Q-gauge output. The sensor head for measuring temperature and humidity (TH sensor) was also installed in the chamber.

All electronic outputs from the Q-gauge, absolute pressure, temperature, humidity, and resonant frequency, were stored in a personal computer. Each temperature dependence of the output from the Q-gauge was measured within the temperature range of 15–50 °C, which is a normal working temperature range for the Q-gauge, at constant RH.

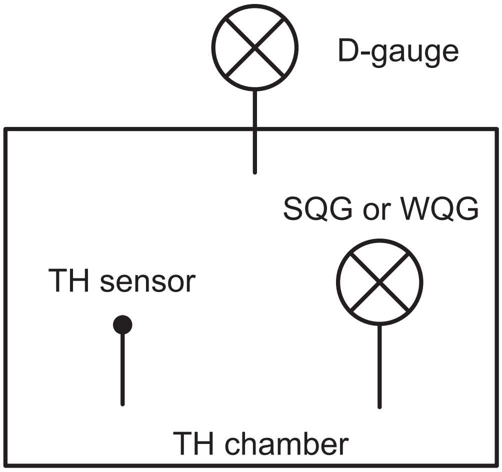

Fig. 1. Experimental system used in this study.

3. Results

3.1. *Single quartz pressure friction gauge (SQG)*

3.1.1. *Temperature dependence of PQO from SQG*

Temperature dependences of the baseline of the pressure-calibrated output (PQO) from the SQG at each constant RH from 0 to 100% RH are shown in Fig. 2. The PQO was obtained through dividing the Q-gauge output by the absolute total pressure measured by the D-gauge. The PQO changed with temperature in the temperature range of 15–50 °C for all values of constant RH. The changes in PQO were relatively small for temperatures below 35 °C, but PQO drastically decreased above 35 °C except for several PQO measured at relatively low RH. Results in Fig. 2 should be affected by temperature dependence of PQO from SQG. In particular, the result for 0%RH on PQO is probably attributed to the temperature dependence of PQO from SQG, which has maximum at around 45 °C.

A decrease in the PQO recorded from the SQG at higher RH is reasonable because the viscosity and molecular weight of the source of RH, H_2O (12.6 μ Pa s, 18.0 g/mol), are smaller than those of air (17.1 μ Pa s, 29.0 g/mol), as mentioned in the introduction [18]. In addition, PQO decreases with temperature in Fig. 2, which is probably because the saturated vapour pressure in air increases with temperature, indicating that the density of H_2O in air increases with temperature [32]. On the other hand, at lower RH, PQO from the SQG tends to increase with temperature based on temperature dependence of PQO from SQG.

The difference in PQO between maximum and minimum for a given RH is, for example, 0.054 at 100% RH. The changes in PQO have been correlated to the leaked hydrogen concentration; previous works showed that 0.01 of change in PQO approximately corresponds to 1 vol% hydrogen concentration when hydrogen is leaked into the air [8]. The change in PQO from the SQG at constant 100% RH corresponds to 5.4 vol%, which is greater than the lower explosive level (LEL) of hydrogen in air. Because the lower detection limit necessary for hydrogen sensing is generally below 1/4 of the LEL of hydrogen, the fluctuations due to temperature in PQO from the SQG over the range 15–50 °C at 100% RH may result in errors in hydrogen sensing. Therefore, it is necessary to temperature-calibrate PQO from the SQG to stabilize the baseline for outdoor use.

Finally, results in Fig. 2 can be explained by the temperature dependence of PQO from SQG and density of H_2O in air.

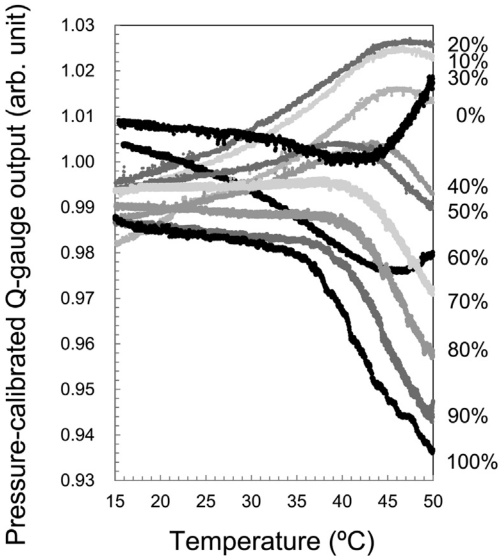

Fig. 2. Temperature dependence of pressure-calibrated Q-gauge output from single quartz friction pressure gauge (SQG) for various relative humidities.

Please cite this article in press as: Suzuki A, et al., Temperature calibration of quartz oscillator for outdoor hydrogen sensing, Vacuum (2015), http://dx.doi.org/10.1016/j.vacuum.2015.03.020