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Effect of the kind of gas medium on calibration values of high gas pressure transducers

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ABSTRACT

In an international comparison of high gas pressure standards up to 100 MPa, we have found that the calibration values of quartz Bourdon-type pressure transducers are affected by the kind of gas medium. In this study, focusing on the structure of the sensing element of the transducer and the density of the gas medium, we examined whether calibration values are affected by the weight of the pressure medium inside the sensing element or by the setting condition of the transducer. To evaluate the effect in detail, two horizontally mounted transducers were calibrated at different rotation angles. Changes in calibration values were expressed as a sinusoidal function of rotation angle. The rotation angles at which the calibration values were not affected by the kind of gas medium were identified. When the transducer was set at the identified rotation angle, the calibration values obtained by using nitrogen agreed well with those obtained by using helium.

1. Introduction

The National Metrology Institute of Japan (NMIJ), AIST has developed a high gas pressure standard for pressures up to 100 MPa using a liquid-lubricated pressure balance [1]. Nitrogen is used as the usual pressure medium. In 2014, NMIJ conducted an international comparison of high gas pressure standards up to 100 MPa using two quartz Bourdon-type pressure transducers [2,3] as a transfer standard. In this international comparison, which was identified as APMP.M.P-S6 [4], NMIJ used nitrogen and one participating institute used helium. Therefore, the effects of the kind of gas medium on the calibration values of the transfer standard were evaluated at NMIJ beforehand. Specifically, calibrations of the transfer standard were performed with nitrogen and with helium. We found that the calibration values of the quartz Bourdon-type pressure transducers are affected by the kind of gas medium. The trend and size of the effect depend on the individual transducers. The differences in the calibration values between nitrogen and helium could not be neglected in the comparison because the difference was comparable to the claimed uncertainties of the participants. In the comparison, the values calibrated by using helium were corrected for gas media effects, and finally the results of the comparison showed good agreement. However, the reason for the effect was not given in detail in the comparison report.

The effect of the kind of gas medium on the calibration values of pressure transducers is important because pressure transducers are used for various applications and measure the pressure of various gas media. Here, we investigated the reason for the effect of the kind of gas medium on the calibration values with a focus on the structure of the sensing element and the gas density. To examine the effect in detail, two quartz Bourdon-type pressure transducers with a maximum pressure of 100 MPa were calibrated simultaneously. The cylindrical pressure transducers were mounted horizontally and calibrated at different rotation angles around the central axis. The relationship between the calibration values and rotation angles was evaluated. It was found that there were rotation angles at which the calibration values were not affected by the kind of gas medium. Finally, the transducers were calibrated at the one of the identified rotation angles both with nitrogen and with helium.

2. Effect of the weight of gas medium on calibration values

The reason for the effect of the kind of gas medium on the calibration values was examined with a focus on the structure of the sensing element and the gas density.

The sensing element of a quartz Bourdon-type pressure transducer mainly consists of a Bourdon tube and a quartz crystal oscillator [2,3]. In the sensing element, the quartz crystal oscillator

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is attached across the root and tip of the Bourdon tube as shown in Fig. 1. A pressure applied to the Bourdon tube generates an uncoiling force that applies tension to the quartz crystal. The change in frequency of the quartz crystal oscillator as a function of tension is a measure of the applied pressure. The accuracy of these pressure transducers is about 0.01% of full scale. The quartz Bourdon-type pressure transducer is one of the highest-precision pressure gauges in the high gas pressure range. Because the pressure medium does not directly contact the quartz crystal in the pressure transducer, it was thought that there would be no effect from the kind of pressure medium, and the effect mentioned above had not been reported previously.

In this study, we postulate that the calibration results are affected by the weight of the pressure medium inside the Bourdon tube. The weight of the pressure medium can cause additional or compensatory deformation of the Bourdon tube, thereby affecting the oscillating frequency and hence the pressure indication. In this case, the indication of the transducer can be expressed as the sum of two contributions: the force acting on the Bourdon tube purely from the applied pressure and an additional (or compensatory) gravitational force from the weight of the pressure medium inside the Bourdon tube. It is also thought that the second term depends on both the density of the pressure medium and the relation between the directions of the gravitational force and the deformation of the Bourdon tube. Since the gas density largely differs depending on the kind of gas, the indications of the quartz Bourdon-type pressure transducers can be significantly affected by the kind of gas medium.

When the pressure transducer is mounted horizontally, as shown in Fig. 1, the root tube of the Bourdon tube inside the transducer is also set horizontally. The relation between the directions of gravitational force and the deformation of the Bourdon tube is changed by rotating the transducer around its central axis. Then, the second term can be expressed using a sinusoidal curve against the rotation angle. Based on the above considerations, when the pressure transducer is mounted horizontally, the indication of the pressure transducer set at the rotation angle θ, $I_{p,\theta}$, is expressed by the following equation:

$$I_{p,\theta} = I_{p,\theta_0} + \Delta I_p \times \sin(\theta - \theta_0). \quad (1)$$

Here, the first term I_{p,θ_0} represents the contribution purely from the applied pressure, and ΔI_p represents the maximum effect of the weight of the pressure medium inside the Bourdon tube. The

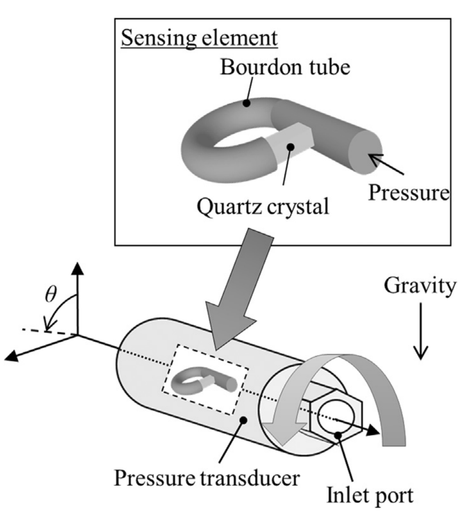

Fig. 1. The sensing element of a horizontally mounted quartz Bourdon-type pressure transducer is rotated around its central axis.

parameter θ_0 is the angle at which the indication $I_{p,\theta}$ is not affected by the weight of the pressure medium, where $I_{p,\theta}$ becomes equal to I_{p,θ_0}. When the transducer is set at rotation angle θ_0, the indication of the transducer is expected to be independent of the pressure medium.

In the next section, the above assumption is experimentally confirmed by evaluating the relationship between the calibration values and the rotation angles of the quartz Bourdon-type pressure transducers.

3. Experiment

3.1. Calibration method

The pressure transducers are calibrated in a high gas pressure calibration system. A liquid-lubricated gas pressure balance [5] is used as standard device. Because the clearance of the liquid-lubricated piston-cylinder is filled with liquid, the generated pressure of the liquid-lubricated pressure balance should not be affected by the gas medium.

The calibration is conducted by comparing the applied pressure from the liquid-lubricated pressure balance with the indication of the pressure transducer. The target pressure was changed from 0 MPa to 100 MPa in steps of 10 MPa. Stepwise calibration cycles included only ascending processes. At each target pressure, the indication of the pressure transducer was sampled 18 times at 10 s intervals after waiting 7 min following establishment of a steady pressure.

The difference between the pressure applied by the standard and the indication of the pressure transducer after offset correction at nominal gauge pressure p, R_p, is calculated as

$$R_p = (I_p - S_p) - (I_0 - S_0). \quad (2)$$

Here, S_p is the pressure applied by the standard. The mean value of R_p in three ascending processes is used as the calibration value. The reference level of each pressure transducer is the level at the center of the inlet port.

3.2. Calibrations at different rotation angles

Two quartz Bourdon-type pressure transducers A and B (Paroscientific, Inc., Model 9000–15 K, pressure range 100 MPa) [6], which are cylindrical and easy to rotate, were calibrated simultaneously. The pressure transducers were mounted horizontally as shown in Fig. 1, and calibrated at four rotation angles: 0°, 90°, 180°, and 270° from the initial setting condition. The pressure medium was nitrogen.

The calibration value at rotation angle θ, $R_{p,\theta}$, is expressed by the following equation from Eqs. (1) and (2).

$$R_{p,\theta} = R_{p,\theta_0} + (\Delta I_p - \Delta I_0) \times \sin(\theta - \theta_0). \quad (3)$$

Here, $R_{p,\theta_0} = (I_{p,\theta_0} - S_p) - (I_{0,\theta_0} - S_0)$. R_{p,θ_0} is the calibration value when the rotation angle is θ_0.

The gas density [7] changes greatly with pressure. The density at 10 MPa is about 100 times larger than that at atmospheric pressure. In this study, the target pressure was more than 10 MPa. ΔI_0 was less than one one-hundredth of ΔI_p and was negligibly small. So, Eq. (3) is changed to

$$R_{p,\theta} = R_{p,\theta_0} + \Delta I_p \times \sin(\theta - \theta_0). \quad (4)$$

Fig. 2 shows the calibration results at the four rotation angles. The vertical axis shows the calibration value, $R_{p,\theta}$. Error bars indicate the standard deviation of $R_{p,\theta}$ obtained from three ascending processes. $R_{p,\theta}$ clearly depended on the rotation angle.