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Pressure gauge calibration applying 0-A-0 pressurization to a reference gauge

Hiroaki Kajikawa, Tokihiko Kobata

National Metrology Institute of Japan (NMIJ), National Institute of Advanced Industrial Science and Technology (AIST), Central 3, 1-1-1 Umezono, Tsukuba, Ibaraki, Japan

ABSTRACT
A calibration method is proposed to improve pressure calibration that uses a pressure gauge as the reference device. The reference gauge is pressurized by a 0-A-0 pressurization procedure, whereas the test gauge can be pressurized through various procedures. The calibration results with this method were consistent with those calibrated against a pressure balance. The method is expected to help develop low-cost pressure calibration systems that are more precise.

Section: RESEARCH PAPER

Keywords: calibration; pressure gauge; hysteresis

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Corresponding author: Hiroaki Kajikawa, e-mail: kajikawa.hiroaki@aist.go.jp

1. INTRODUCTION

Electromechanical pressure gauges are essential for pressure measurement and control in various industrial applications, and also for pressure calibration. Although pressure balances are the first choice as reference devices for pressure calibration because of their high resolution and long- and short-term stabilities, expertise is necessary to operate them correctly and efficiently. To make pressure calibrations easier, high-accuracy electromechanical pressure gauges are becoming more commonly used as reference devices.

When pressure gauges are used as the reference device, several characteristics should be evaluated in advance including repeatability, hysteresis, long-term shift, and environmental effects. We have been focusing on the time-dependent behavior of pressure gauges and the effect of pressurization on the outputs [1], [2]. The effects of the pressurization procedures on the calibration results have been quantitatively evaluated for stepwise pressurization (Figure 1(a)) [1], and for 0-A-0 pressurization (Figure 1(b)) [2].

Pressure gauges are typically calibrated by stepwise pressurization [3], [4]. When a pressure gauge is used as the reference device, the reference gauge is calibrated in advance against a pressure balance by stepwise pressurization, and then used for calibrating other gauges (Figure 2(a)). Although this

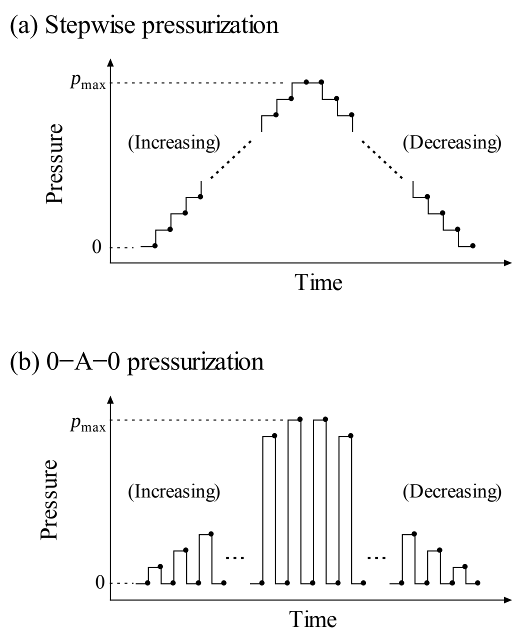

Figure 1. Pressurization procedure for pressure gauge calibration. (a) Stepwise pressurization, (b) 0-A-0 pressurization.

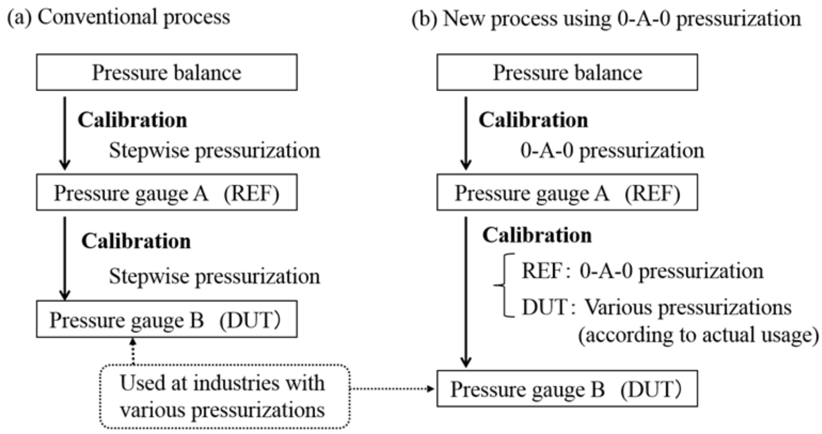

Figure 2. Dissemination process of the pressure standard using pressure gauges: (a) conventional process using stepwise pressurization, (b) new process using 0-A-0 pressurization for the reference pressure gauge.

conventional system is simple and useful, the reproducibility of the reference gauge may be insufficient in some cases because of the effects of pressurization procedures. First, even with a similar stepwise procedure, differences in the pressurization procedures, such as time intervals and the presence or absence of preliminary pressurization, can affect the reference gauge output and the calibration results of the test gauge. Second, the test gauges are used under various pressurization conditions in industrial sites, not always with stepwise pressurization. Some users want their gauges calibrated using a pressurization process corresponding to the actual conditions of use. One way to overcome the possible effects of the different procedures and to cope with user requirements is to prepare reference pressure gauges that have much higher accuracy and reproducibility or lower hysteresis than the test gauges. When higher-grade pressure gauges are not available or applicable, the hysteresis characteristics of the reference gauge need to be evaluated in detail to compensate for the effects of different pressurization procedures, increasing the workload of calibration laboratories.

In this study, a calibration method [5] is proposed for improving reproducibility and making calibration with reference pressure gauges more precise and useful. In this method, applying 0-A-0 pressurization to the reference pressure gauge eliminates the effect of the pressurization procedure on the reference gauge, and enables us to calibrate test pressure gauges precisely with various pressurization procedures. The advantages of using 0-A-0 pressurization in pressure gauge calibrations are summarized in Section 2. The crucial factors for obtaining reproducible results are also discussed, and then our calibration method using 0-A-0 pressurization is explained. Demonstration experiments are presented to confirm the effectiveness of the method. The experimental scheme and results are shown in Section 3, followed by a discussion of the advantages and applications of the new method in Section 4. The findings are summarized in Section 5.

2. NEW CALIBRATION METHOD

2.1. Dissemination process using 0-A-0 pressurization

Our method using electromechanical pressure gauges was developed to disseminate pressure standards with small uncertainty for use in industry. Figure 2 shows dissemination processes of the pressure standard to industrial users with the pressure gauges. Figure 2(a) shows a conventional process using stepwise pressurization. Figure 2(b) shows the new process using 0-A-0 pressurization. In both the processes, pressure gauge A is calibrated against a pressure balance in advance, and then used as the reference for calibration of pressure gauge B. There are two key points in the new process. First, 0-A-0 pressurization is used to calibrate the reference pressure gauges from the pressure balance. Second, different pressurization procedures are used for the reference and test pressure gauges in the next calibration of the test gauges. These points are explained in detail in the following subsections.

2.2. Advantages in 0-A-0 pressurization

An advantage in using 0-A-0 pressurization is the higher reproducibility of calibration results irrespective of pressurization history, for example, the order of calibration pressure, interval between the calibration cycles, waiting time at each calibration pressure, and the presence or absence of a preliminary pressurization [2].

Figure 3 shows calibration results for clamped thin-film pressure sensors (S-10, WIKA). The calibration results with the stepwise (Figure 1(a)) and 0-A-0 (Figure 1(b)) pressurization are shown for two pressure sensors using different materials for the sensing element, and the results for sensor A1 are shown in Figure 3(a) and those for A2 are shown in Figure 3(b). For both procedures, the maximum pressure in a calibration cycle was set at 100 MPa, 70 MPa, or 50 MPa. The relative deviation of the sensor's output from the standard pressure applied by a pressure balance is shown. The hysteresis, which is the difference between the results for the pressure increase and decrease, was much smaller with the 0-A-0 pressurization than with the stepwise pressurization. The results with 0-A-0 pressurization almost fell on a single calibration curve, although the data scattering was slightly larger at lower pressures. Even when the pressure point was changed in a random sequence instead of in sequential order, the calibration results also fell on the same calibration curve created in sequential order. Similar results were obtained for quartz Bourdon-type pressure transducers [2], for which the data scattering, defined as the relative standard deviation of three cycles' data, was several parts per million.

The offset correction using the measurement data at the atmospheric pressure just after the measurement at each target pressure is a key to achieving high reproducibility. In addition, the operations and time intervals between the measurements at the target pressure and at atmospheric pressure need to be fixed precisely. Using a fully automated calibration system in an

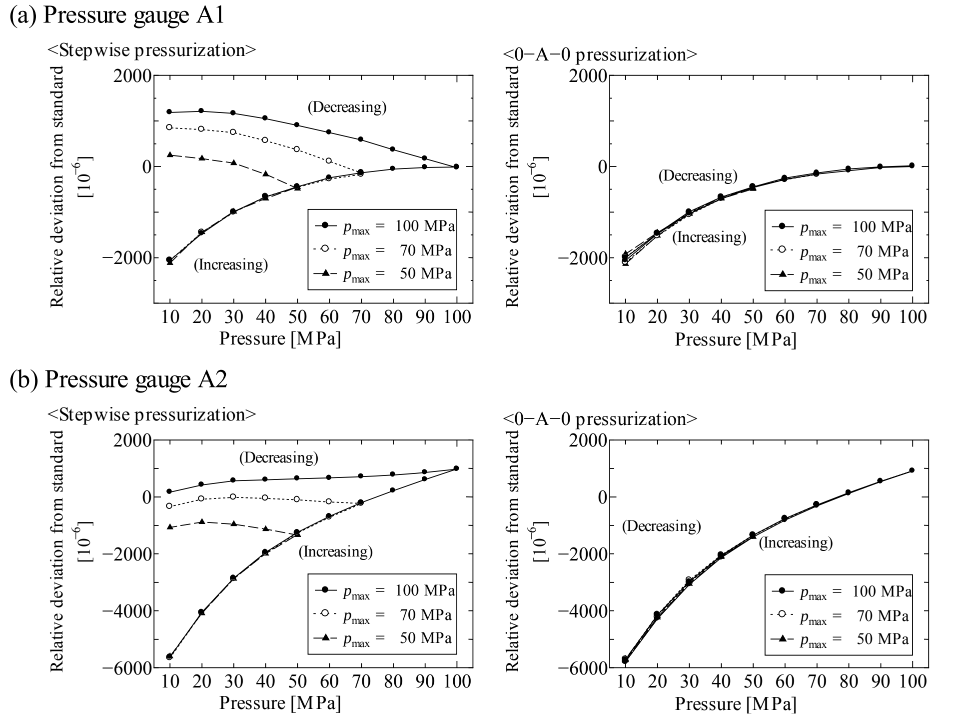

Figure 3. Calibration results for two clamped thin-film pressure sensors with maximum pressures of 50 MPa, 70 MPa, or 100 MPa. (a) Pressure gauge A1, (b) pressure gauge A2. Results for stepwise and 0-A-0 pressurization procedures are compared.

unattended environment reduced changes in ambient conditions and operations, and provided reproducible results for the respective pressurization procedures.

2.3. New calibration method applying 0-A-0 pressurization to reference gauge

To explain the new calibration method, we discuss a test gauge calibrated with the stepwise pressurization in this section. Figure 4 shows a schematic of the pressures applied to the reference and test pressure gauges. In the conventional method (Figure 4(a)), the same pressure is always applied to both the reference and test gauges. In the proposed method (Figure 4(b)), the two gauges are pressurized with different procedures; the test gauge is pressurized with the stepwise procedure, as in Figure 4(a), whereas the reference gauge is pressurized with the 0-A-0 procedure. The pressure lines for the two gauges are isolated from each other by closing the valves between the two gauges while the pressure is changed and adjusted to the target pressures, and then the gauges are connected by opening the valves when the measurement data are obtained at the target pressure.

The new calibration method can be implemented easily by using a pressure controller and by switching the opening and closing of the valves between the two gauges. Moreover, this method is applicable to various kinds of pressurization procedures for test gauges other than stepwise pressurization. The appropriate procedure can be selected according to the needs of users and the actual usage of test pressure gauges in industry.

3. DEMONSTRATION EXPERIMENTS

3.1. Demonstration experiments

Demonstration experiments were conducted to check that the correct calibration results were obtained with the new method. The test pressure gauge was a foil strain gauge (P3MB, HBM). The test gauge was calibrated with Method I or II, and then the calibration results were compared. In Method I, the test gauge was calibrated against a pressure balance. In Method II, the same test gauge was calibrated by using the new method. Two clamped thin-film sensors, the calibration results for which are shown in Figure 3, were used as the reference gauges. The two gauges were calibrated in advance against a pressure balance with the 0-A-0 pressurization (Figure 2(b)).

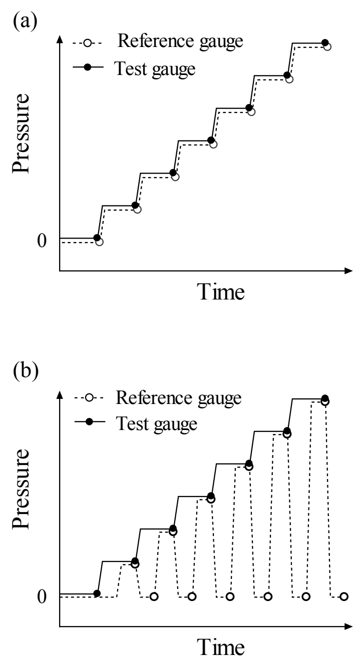

Figure 4. Pressurization procedures for reference and test gauges during calibration. (a) Conventional method, (b) proposed method. For both procedures, the test gauge is calibrated by stepwise pressurization. Timing of the measurements is shown by open circles for the reference gauge, and filled circles for the test gauge.

3.2. Stepwise calibration with different maximum pressures

In the first demonstration experiment, the test gauge was calibrated with the stepwise pressurization for maximum pressures p_{max} of 70 MPa and 100 MPa. We expected that the results for the pressure decrease would depend on the maximum pressure. The results for the test gauge with the two methods are compared in Figure 5. For the both conditions at the maximum pressure, the results for the two methods agree well, showing that the new calibration method and calibration system work appropriately and that the effects of the maximum calibration pressure on the test gauge were correctly evaluated without using pressure balance.

For the conventional pressure calibration using pressure gauges as the reference (Figure 2(a)), the reference gauge should be calibrated in advance with the two maximum pressures to obtain the correct calibration results. Otherwise, the results for the test gauge during the pressure decrease process would deviate from the correct values due to the reference gauge hysteresis. With the new method, it is not necessary to consider the effects of pressurization conditions, such as the change in the maximum pressure and direction of the pressure change, on the reference gauge.

3.3. Calibration with random pressure sequence

The proposed calibration method can also be applied to any pressurization procedure, unlike the conventional stepwise calibration procedure. Demonstration experiments were conducted with a random pressure sequence. Figure 6(a) shows the pressures applied to the test gauge during the experiment. Measurements were conducted at 10 pressures from 10 MPa to 100 MPa in steps of 10 MPa. The sequence of the measurement pressures was determined at random and 10 measurements were taken at each pressure, providing 100 measurements in total. In addition, the pressure was released to atmospheric pressure (zero gauge pressure) once every 20 measurements. The output of the test gauge at atmospheric pressure was used in the offset correction for the calibration results. The waiting time at each pressure point was 10 min.

Figure 6(b) shows the relative difference between the two sets of calibration results (Method II – Method I) in parts per million. The x-axis is the data number, and the y-axis shows the relative difference between the results. The differences were less than 0.02 % for all the measurement points. For most of the measurement points, the differences were within 0.01 %, although the differences were larger at lower pressures and for large pressure changes from the previous measurement.

The two reference pressure gauges showed hysteresis of 0.32 % and 0.58 % relative to the applied pressure at 10 MPa (Figure 3). This experiment showed that the proposed method obtained correct calibration results with much higher accuracy compared with the original hysteresis of the reference gauges, even when the test gauge was pressurized randomly.

4. DISSCUSSION AND APPLICATIONS

Controlling the time intervals of the reference gauge is a key to obtaining reproducible results, because the outputs of some gauges change rapidly with time after a pressure release to atmospheric pressure. The demonstration experiments were all performed with our custom-built and programmed automatic system. It may be difficult for calibration staff to conduct this kind of calibration continuously with rigidly fixed time intervals. Thus, for our method to be widely used for calibration and in industry, pressure calibration systems equipped with an automatic control system for pressure and valve operation should be developed.

The type of reference pressure gauge in this study is generally used in industry, but not for calibration because its hysteresis is more than 0.3 %. However, by using 0-A-0 pressurization, these gauges can be used as if their hysteresis were 0.01 %, much less than one-tenth of the original value. The method could help reduce the cost of reference pressure gauges, leading to precise, low-cost calibration devices for pressure gauges.

Our method can also be used for calibration with other types of pressure gauges as the reference. When a high-end

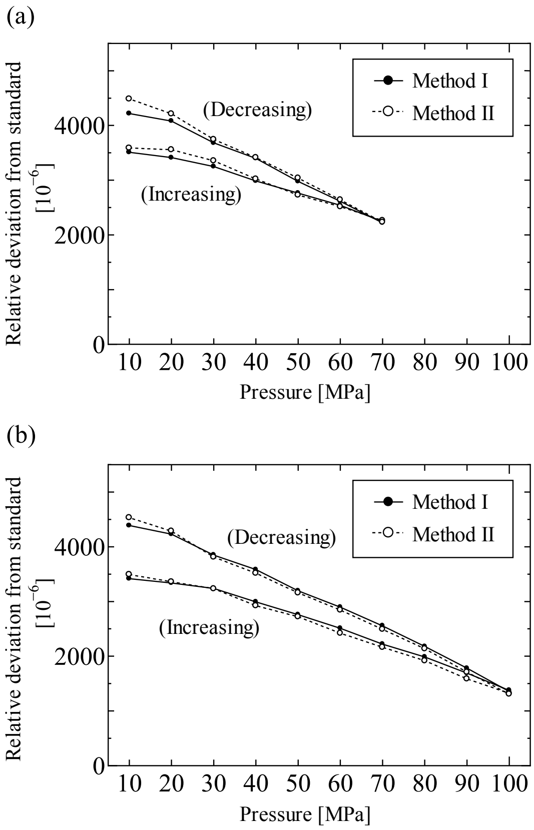

Figure 5. Calibration results for the demonstration experiment with stepwise pressurization for p_{max} of (a) 70 MPa and (b) 100 MPa.

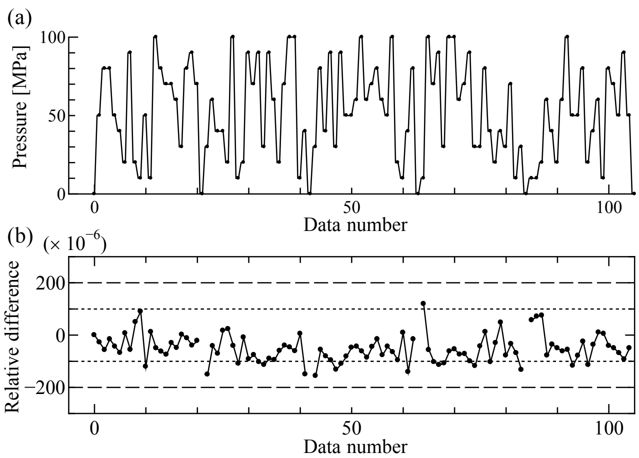

Figure 6. Demonstration experiment with random pressure sequence. (a) Sequence of measurement points, (b) difference between the results obtained with Methods I and II (Method II - Method I).

pressure gauge is used as the reference gauge with the new method, the magnitude of the pressurization effects on the results is at most several parts per million, which is comparable to the reproducibility of pressure balances.

In some cases, pressure gauges at industrial sites need to be calibrated or tested on-site. The lack of stable places for installation and factors such as wind and vibration make it difficult to use pressure balances as standards. In such cases, calibration with pressure gauges is more appropriate than with pressure balances because some pressure gauges are more robust to environmental conditions. Thus, our method offers a further advantage in improving the accuracy of on-site calibration.

In addition to further developments in the sensing elements of the pressure gauges by manufacturers, improving measurement procedures can enhance the performance of the pressure gauges and provide more effective and accurate calibration methods, leading to reliable pressure measurements at industrial sites.

5. CONCLUSIONS

We have described a new calibration method using pressure gauges as the reference that is more precise and useful. The reference gauge was pressurized by 0-A-0 pressurization, whereas the test gauge could be pressurized through various procedures according to the user's requirements and the measurement conditions of the test gauge at industrial sites. The 0-A-0 pressurization of the reference gauge greatly reduced the effect of the pressurization history on the output of the reference gauge, and produced highly reproducible outputs. In the demonstration experiments, the calibration results using the new method were consistent with those calibrated against a pressure balance. The new method should be widely applicable to any kind of reference pressure gauges and pressurization procedures applied to the test gauge. The method is expected to help develop low-cost calibration systems that are more precise.

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