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A fully automated calibration system for pressure balance

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Abstract

A new fully automated system for calibrating a pressure balance is described. The system consists of two automated pressure balances, a pressure controller, two air-operated constant volume valves, a precise pressure transducer, a device for measuring environmental condition, a computer and the program developed. In the system, one pressure balance is used as a standard and the other is calibrated and/or evaluated. To determine the equilibrium state between two pressure balances accurately, the cross-float measurement using the comparator method is performed. In this paper, the details of the system are described and the results obtained using the system are shown.

Keywords: pressure balance, calibration, cross-float, automated system

1. Introduction

A pressure balance is able to generate stable pressure and is often used as a pressure standard [1, 2]. A cross-float measurement using two pressure balances is widely used to calibrate a pressure balance and evaluate its characteristics. The unknown pressure generated by a test pressure balance can be calibrated by performing the cross-float measurement against a reference pressure balance whose pressure generated is already known.

A fully automated system for calibrating a pressure balance has been developed at the National Metrology Institute of Japan (NMIJ/AIST). The automated system can automatically calibrate the unknown pressure generated by a test pressure balance. All the procedures needed for performing the calibration, such as handling the large weights, pressurizing the calibration system, and determining the equilibrium state between two pressure balances, can be automatically performed by the system without depending the expertise and experience by an operator.

1.1 Pressure Balance and Cross-float Measurement

Figure 1 shows the schematic drawing of a pressure balance of simple type. Its main components are a piston-cylinder assembly and weights. The cylinder is installed in the mounting post of the pressure balance. The force generated under the weight whose mass has been measured precisely is exerted on the piston. When the pressure is applied to float the piston under load up to the equilibrium level, the pressure P generated with the pressure balance at the reference level is defined by:

$$P = \frac{M \cdot g \cdot (1 - \rho_a / \rho_m) + \gamma \cdot C}{A(0, t_r) \cdot (1 + \lambda \cdot P) \cdot [1 + \alpha_{s} (t - t_r)]} + (\rho_f - \rho_a) \cdot g \cdot h \quad (1)$$

where M is the total mass of the piston and weight, g is the local gravitational acceleration, ρ_a is the air density, ρ_m is the average density of the piston and weights, γ is the surface tension of the pressure medium, C is the length of the circumference of the piston, $A(0, t_r)$ is the effective area under a pressure of 0 Pa at the reference temperature t_r °C, λ is the pressure distortion coefficient, α_s is the sum of the linear thermal expansion coefficients of piston and cylinder. The effective area at the standard condition $A(0, t_r)$ is determined from geometrical measurements of the diameter, the roundness and cylindricity of the piston and cylinder or from the results of comparative calibration with a superior standard. The second term in the right side of equation (1) is added to correct the head difference, where ρ_f is the density of the pressure medium, and h is the vertical distance between the end surface of the piston and the reference level. Normally the piston is rotated by a motor or hand to avoid a mechanical contact between the piston and the cylinder.

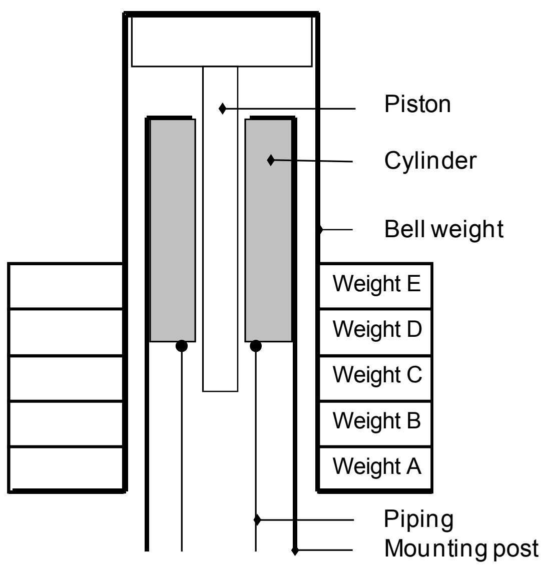

Figure 1: Schematic drawing of simple-type pressure balance

Figure 2 is the schematic drawing of a conventional cross-float measurement. In the measurement, minute pieces of mass are loaded or unloaded one after another onto the pressure balances on either side until complete pressure equilibrium is achieved between the two pressure balances. Several methods have been proposed to date for judging equilibrium or equality between two pressure balances [2].

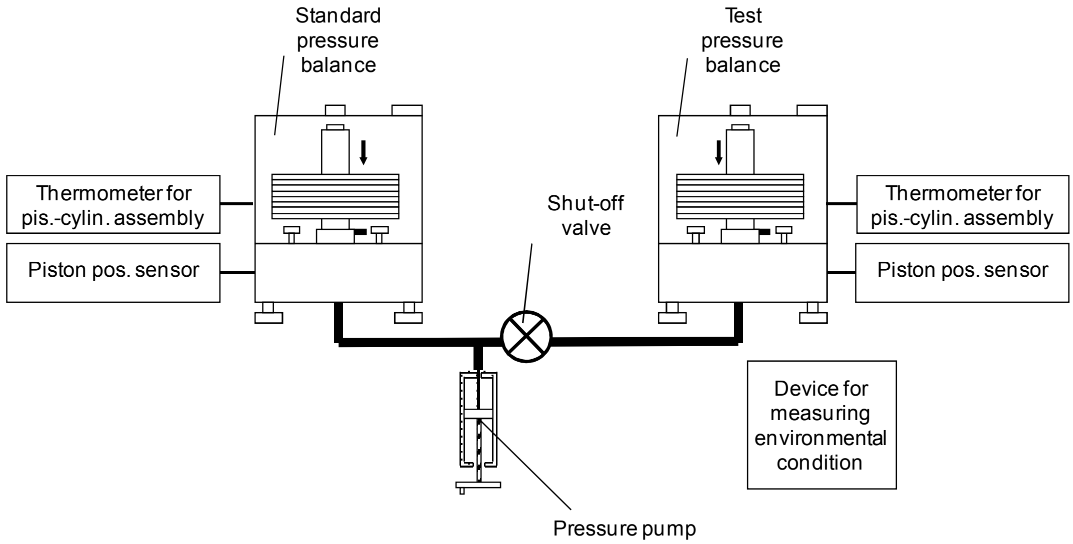

Figure 2: Schematic drawing of conventional setup for cross-float measurement between two pressure balances

1.2 Development of Fully Automated Calibration System

Figure 3 shows the schematic of the automated system for calibrating a pressure balance. The automated system consists of two automated pressure balances, a pressure controller, a precise pressure transducer, two air-operated constant volume valves (CVVs), the device for measuring environmental condition, a computer with a connecting interface used for communicating with other equipments and the program developed. Each automated pressure balance equipped with a thermometer for measuring the temperature of piston-cylinder assembly, sensors for measuring the floating piston position and the rotational speed of the piston, a motor for rotating the piston, and an automatic weight handler which is used to load or unload the larger weights for the pressure balance. Any automated pressure balance can be used in the system. The precise pressure controller is used to change the system pressure and is capable of adjusting the floating position of either piston precisely by a fine control. The precise pressure transducer is used to measure the system pressure in the system accurately. Each CVV can be opened or closed without changing the internal volume of its duct. Therefore the floating position of either piston can be kept during the operation of CVVs, which enables a fine adjustment of the piston position. The device for measuring environmental condition is used to measure the ambient temperature, the relative humidity, and the atmospheric pressure at the calibration room. The data measured by the device is used for making the air buoyancy correction of the weights used. All the equipments in the system are connected to the computer and can be operated from the computer. All the measured data is acquired by the computer through the connecting interface. The program developed for performing the automated pressure calibration is installed in the computer. After setting the necessary parameters in the program, the calibration process is executed by running the program. All the operations needed for the calibration are performed automatically according to the program.

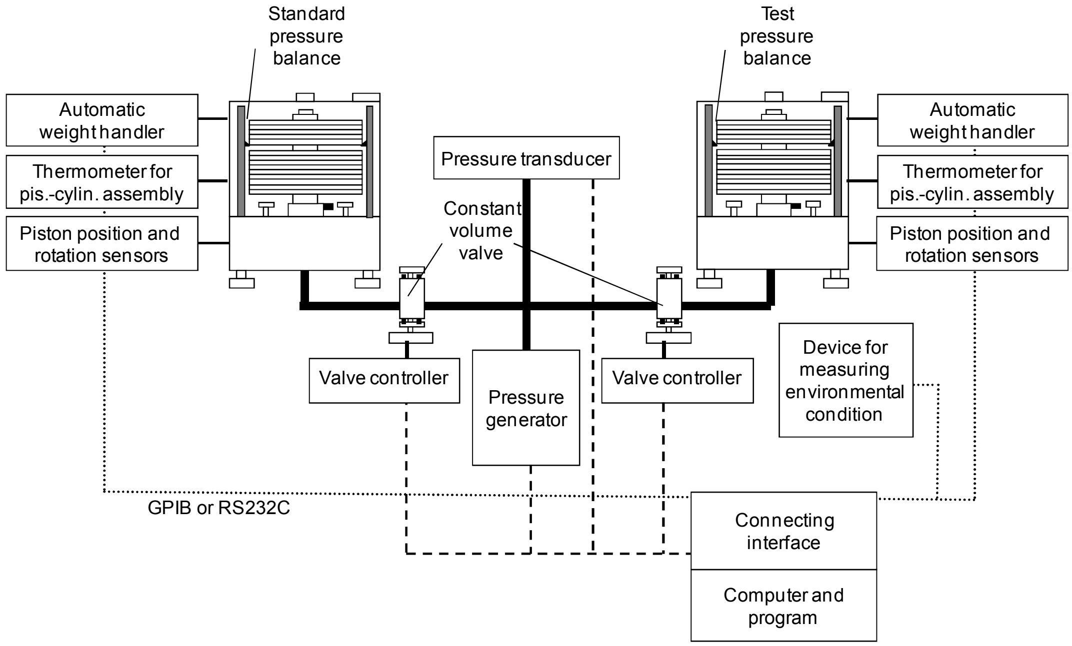

Figure 3: Schematic of automated system for calibrating pressure balance

1.3 Calibration Procedure

The calibration system can perform a cross-float measurement between two pressure balances automatically by the comparator method [3]. The method is based on substitution comparison and uses a high-precision pressure transducer as a comparator, which is used to measure each of the pressures generated by two pressure balances in turn while switching CVVs. Measuring the pressures generated by the two pressure balances separately makes it possible to evaluate the stability of the pressures separately. This method has the advantage that the equilibrium status can be estimated even if pressure equilibrium has not been achieved completely between the two pressure balances [3].

The typical calibration procedure by the automated system is described in the following. First, the necessary weights for the initial target pressure are loaded on either pressure balance by the automatic weight handler. Next, after opening both CVVs, the pressure controller pressurizes the system pressure up to the target pressure by monitoring the reading of the precise pressure transducer. When the system pressure reaches to the target pressure, the system waits for a period of time for pressure stabilization. After the waiting time, the following operations are performed. (a) The CVV at the standard side is opened and the CVV at the test side is closed, then the floating piston position of the reference pressure balance is adjusted within the target position range by using the pressure controller. With this state the pressure generated by the reference pressure balance is applied to the pressure transducer. After waiting for pressure stabilization, the reading of the pressure transducer, I_r, is recorded. Also the temperature of the piston-cylinder assembly, the piston position and the rotational speed of the piston of the reference pressure balance, and the environmental condition are measured and recorded in the computer. (b) By switching the two CVVs, the floating piston position of the test pressure balance is adjusted by using the pressure controller. With this state, the pressure generated by the test pressure balance is applied to the pressure transducer. After waiting for pressure stabilization, the reading of the pressure transducer, I_t, is recorded. Also similar measurements mentioned in (a) are performed. Thereafter, the procedures (a) and (b) described above is repeated more than 3 times by switching the valves and the pressure generated by either pressure balance was alternately measured by the transducer.

From the readings of the transducer obtained during the measurements, the differential pressure between two pressure balances, ΔP, can be evaluated by the next equation.

$$\Delta P = \left(I_{ta} - I_{ra}\right)/ f \qquad (2)$$

where I_{ta} and I_{ra} are the averages of I_t and I_r obtained from the repeated measurements, respectively. f is the scaling factor of the pressure transducer used and can be evaluated by using the data taken during the measurements, which is obtained from the relationship between the known pressure by the reference pressure balance and the reading of the pressure transducer. The accurate determination of the differential pressure by the comparator method including the evaluation of scaling factor has been reported [3].

From the differential pressure ΔP and the known pressure generated by reference pressure balance, P_r, the pressure generated by the test pressure balance, P_t, can be calculated by the next equation.

$$P_t = P_r + \Delta P \qquad (3)$$

here P_r is obtained by calculating equation (1).

When the cross-float measurement at the target pressure is completed, either piston is returned to the rest position by using the pressure controller and by switching the two CVVs. After that, the two CVVs are opened to make the system pressure uniform. The above is the measurement and operation procedure at one target pressure. Thereafter, the procedure is repeated at the necessary target pressures according to the program.

After all the measurements are completed at all the target pressures, the automated system returns the system pressure to the atmospheric pressure. The weight combinations of both pressure balances are set to the initial combinations by using the automatic weight handlers.

2 Calibration Results

Figure 4 shows the calibration results by the automated system. In this calibration, the nominal target pressure was varied from 10 MPa to 100 MPa and then from 100 MPa to 10 MPa in steps of 10 MPa. The cross-float measurement was performed at each target pressure. Figure 4 (a) shows the system pressure as a function of elapsed time. The plotted points indicate the averaged pressures measured by the transducer during each cross-float measurement. As shown in the figure, the processing time for each target pressure was almost constant. Figure 4 (b) shows the average temperatures of both piston-cylinder assemblies. As shown in the figure, both average temperatures were stable within ± 0.1 ℃ during the whole calibration process. Since the automated system carries out the calibration automatically without an operator, the system does not suffer the heat from a human body. Figure 4 (c) shows the average floating positions of both pistons during each cross-float measurement. Although the full stroke of both pistons used is about ± 5 mm, the floating positions of both pistons should be adjusted to keep them within the target position ranges as close as possible for a precise cross-float measurement. As shown in the figure, the average floating positions of both pistons could be kept within ± 0.2 mm by the automated system. Figure 4 (d) shows the relative deviation of the test pressure calibrated from the nominal target pressure, $(P_t - P_{nom})/P_{nom}$. With the automated system, the pressure generated by the test pressure balance is automatically calculated at each target pressure. Therefore, the pressure calibrated is available one after another even during the calibration process.

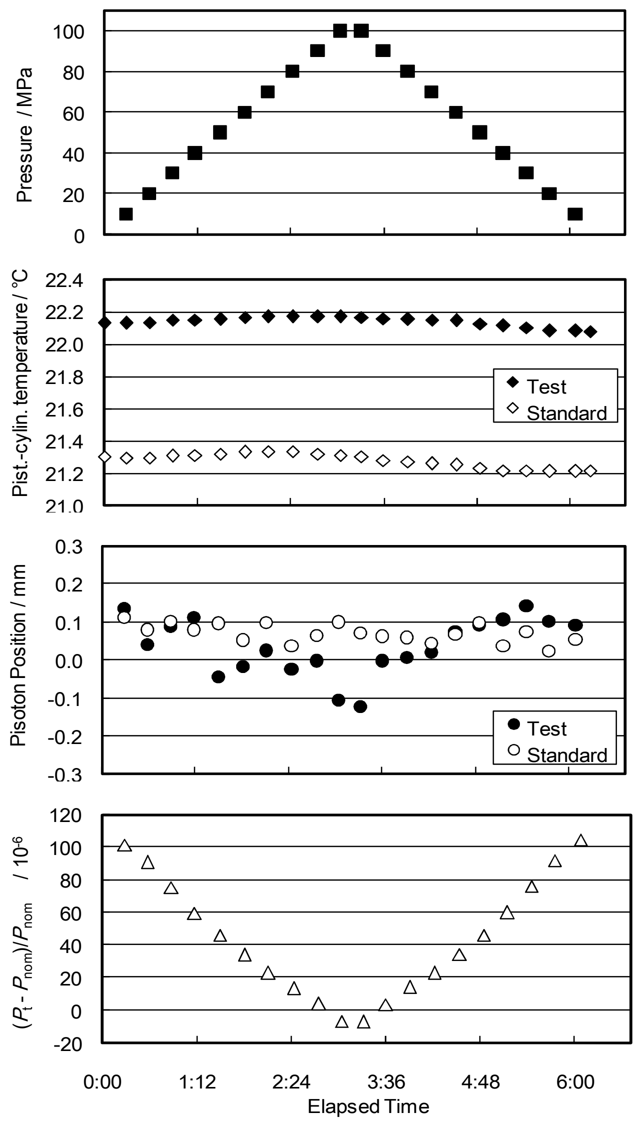

Figure 4: Calibration results by the automated system. 1st column: pressure generated, 2nd column: temperatures of both piston-cylinder assemblies, 3rd column: floating positions of both pistons, 4th column: relative deviation of pressure generated by test pressure balance from nominal target pressure.

2.1 Characterization of Piston-cylinder

The automated system can also be used to characterize the metrological property of a piston-cylinder assembly. For example, the effect by the piston position on the generated pressure can be evaluated. Figure 5 shows the result of the effect evaluated by using the automated system. The evaluation procedure is described here. First, at 10 MPa, the cross-float measurement was repeated 5 times by changing the piston position of the test pressure balance from -1.0 mm to +1.0 mm in steps of 0.5 mm, while that of the reference one was kept at around 0.0 mm. The measurements at one target pressure were repeated by changing the system pressure from 10 MPa to 100 MPa in steps of 10 MPa. Figure 5 (a) shows the system pressure as a function of elapsed time. Figure 5 (b) shows the piston positions of both pressure balances. As shown in the figure, it is confirmed that the piston position of the reference pressure balance was kept at around 0.0 mm and that of the test one was changed in 5 steps at each target pressure. Figure 5 (c) shows the relative variation of the pressure generated by the test pressure balance. For convenience, the differential pressure obtained in the case that the piston position of the test pressure balance is around 0.0 mm is set to zero at each target pressure. As shown in the figure, the pressure generated by the test pressure balance depends on the floating position of its piston. Similarly, the effect by the rotational speed of the piston on the generated pressure can be evaluated by the automated system.

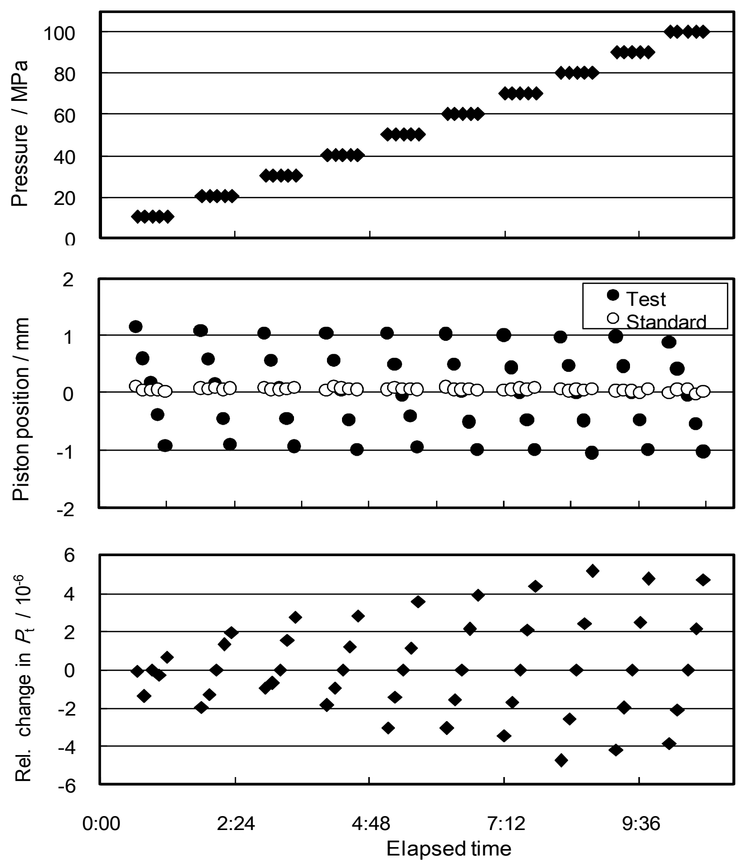

Figure 5: Characterization results by the automated system. 1st column: pressure generated, 2nd column: floating positions of both pistons, 3rd column: relative variation of pressure generated by test pressure balance.

3 Conclusions

The principle of a fully automated system for calibrating a pressure balance is described. So far the automated system has been realized in hydraulic pressure range at NMIJ/AIST. However, the principle can be applied to various kinds of calibrations of a pressure balance. The automated system can also be used to characterize the metrological properties of a piston-cylinder assembly. For example, the effect by the piston position on the generated pressure was evaluated by using the automated system.

References

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