AN AUTOMATED CONTROLLER/CALIBRATOR FOR LOW DIFFERENTIAL PRESSURE AROUND ATMOSPHERE

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Summary: In both the measurement and control aspects, there are few solutions for the calibration of low differential pressure instruments. Recent advances in oscillating quartz crystal pressure transducers, positive shut-off pressure control and primary standards have been applied to develop and calibrate a transfer standard for low differential pressure calibration. The new instrument covers the range of ± 15 kPa with turn down to ± 5 kPa and measurement uncertainty of ± 1 Pa (k=2). Operation is automated with pressure control precision inside ± 0.1 Pa. The new controller/calibrator is rugged enough to be transported and shipped without special precautions.

INTRODUCTION

There are many requirements for pressure measurement in ranges of less than 1 kPa to 15 kPa around atmosphere and a variety of transducers and transmitters exist to meet them. The calibration support of instruments in this range presents special challenges in the areas both of pressure measurement and control. First, transfer standards with adequate intrinsic performance (precision and stability) to provide the level of uncertainty needed are uncommon. If transfer standards of high enough performance are available, they in turn need to be calibrated. Reference pressure values with traceable uncertainty low enough to maintain adequate reference to test uncertainty ratios may not be available. Second, it is very difficult to set and stabilize pressure in a test system to the level needed to properly compare the transfer standard and device being calibrated. Environmental influences on the set pressure and the action of the pressure controlling device itself can create instability that contributes significant uncertainty to the comparison process.

A new pressure controller/calibrator has been developed to address the need for a low differential pressure transfer standard [Figure 1].

The instrument exploits recent developments in oscillating quartz crystal pressure transducers and primary standards to calibrate them. Existing pressure control technology is optimized for very low pressure operation to assure the necessary control precision and stability. Operation is automated allowing data averaging at each pressure point and making it easy to run multiple cycles to quantify test repeatability.

Fig. 1 *Low pressure controller/calibrator (top) with thermally isolated volume accessory (bottom)*

REFERENCE PRESSURE TRANSDUCER

The pressure transducer used in the low pressure controller/calibrator is a new model of the quartz crystal resonator type, a technology first introduced in the late 1970s [1, Figure 2]. The new model is conceptually identical to existing differential pressure models but has been modified to optimize performance over the low range of – 15 to + 15 kPa. The new model uses a more sensitive quartz crystal providing an order of magnitude higher resolution and sensitivity with proportional gains in hysteresis and repeatability. The sensitivity of zero to static pressure change is independent of full scale range, thus the new device is more sensitive to static pressure. The mechanical adjustment was fine tuned to minimize this sensitivity. In addition, a mathematical model was developed to eliminate the residual static pressure sensitivity both at zero pressure and under applied differential pressure. The transducer is completely characterized over the static pressure range of 80 to 110 kPa absolute.

In extensive testing the transducer has been found to be able to support triple ranging with a low range of ± 5 kPa, precision of ± 5 x 10^{-5} of span and typical span stability better than 1 x 10^{-4} of reading per year.

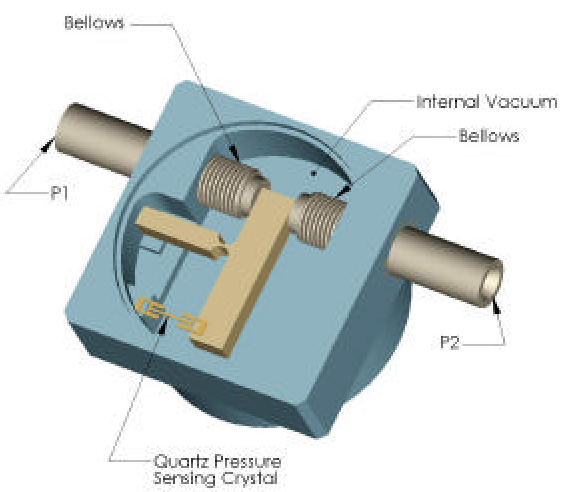

Fig. 2 *Oscillating quartz crystal transducer*

The transducer is automatically zeroed whenever the high and low sides are connected together to set zero differential. This eliminates the contribution of zero stability to measurement uncertainty. The transducer and the pressure controller are designed to operate with atmospheric pressure as the 'line' or 'static' pressure. The changes in static pressure caused by variations in atmospheric pressure that may be encountered in normal operating environments can have a significant influence on differential pressure response. The influence of static pressure is quantified during the transducer characterization. A preponderance of the static pressure effect is on zero offset and is eliminated by automated zeroing at zero differential pressure. The effect of static pressure on span is compensated for dynamically during operation. The pressure on the transducers low pressure side is measured by a barometer and used in a compensation algorithm. Using a barometer with uncertainty of ± 100 Pa to measure the static pressure results in an insignificant effect of static pressure on span. The use of the barometer is described in the Specific Low Differential Pressure Features section below.

MEASUREMENT UNCERTAINTY

The precision and stability of the quartz crystal resonator transducer give the potential for measurement uncertainty of ± 1 x 10^{-4} or better of each range, including the low range of ± 5 kPa. Two different methods have been used to calibrate the transducer. Both of these methods have the advantage of covering the very low differential range through zero without changes in setup or uncertainty. The first is based on the difference between an absolute pressure defined by an absolute piston gauge and a high precision barometer after taring the barometer against the piston gauge [2]. This method has an estimated uncertainty (k=2) of ± (0.3 Pa + 2 x 10^{-5}P). The second method is a new fundamental standard called a force balanced piston gauge which defines very low pressure directly against atmosphere [3]. This method has an estimated uncertainty (k=2) of ± (0.02 Pa + 3 x 10^{-5}P). The second method has the advantages of much lower uncertainty and fully automated operation but was not available before August, 2001. It has become the standard calibration method for the low pressure calibrator/controller. Both calibration methods with the uncertainties stated here are included in the scope of the DHI Phoenix, Arizona calibration laboratory's A2LA accreditation.

Combining the precision and estimated stability of the quartz crystal resonator transducer with the calibration methods available gives one year estimated measurement uncertainty (k=2) of better than ± 1 x 10^{-4} of span for the each of the three ranges, ± (5, 10 and 15 kPa). Figure 3 provides a plot of as left errors of a low pressure controller's three ranges relative to the force balanced piston gauge.

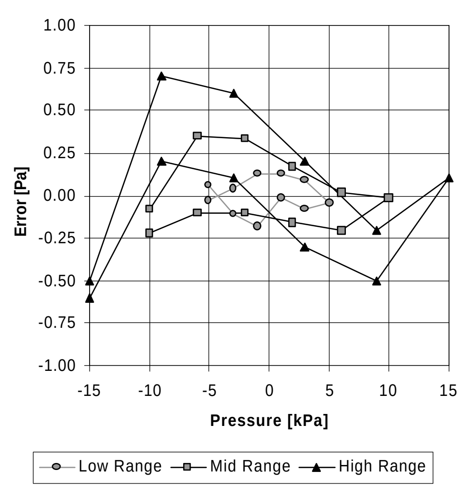

Fig. 3

Low pressure controller as left errors relative to FPG

PRESSURE CONTROL

The low pressure calibrator's pressure control system operates on the positive shut-off pressure control principle [4, Figure 4].

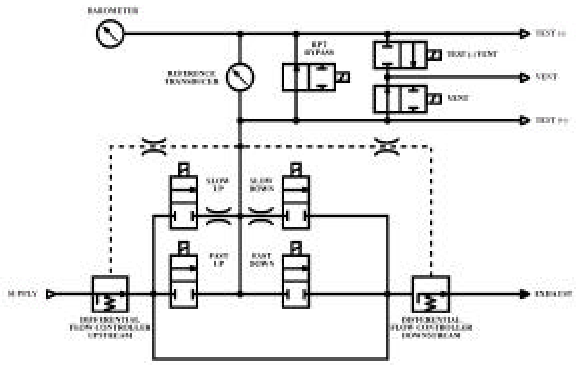

Fig. 4 *Low Pressure Controller Pneumatic Module*

Positive shut-off pressure control has been in use in pressure controllers, in ranges from about 35 kPa to 10 MPa, since the late 1980s. It is recognized for its very high precision, excellent turndown ratio and reliability in continuous service. Positive shut-off pressure control is based on the calculation of the amount of gas that must be added or removed from the test volume to change the set pressure by the desired amount. Additional calculation determines the control (inlet or exhaust) solenoid valve opening time required to flow the desired amount of gas. When the valve opening time is less than the valve's minimum reliable opening time, differential opening of the inlet and exhaust valves is used. Differential flow controllers assure a constant differential pressure across the control valves to simplify the relationship between valve opening time and gas flow.

To improve positive shut-off pressure control for very low pressure operation, several measures were taken. These include using valves with more repeatable response time, allowing smaller pressure steps to be accomplished predictably, and optimizing control coefficients for very low pressure. To improve control resolution and reduce the influence of ambient pressure and temperature changes, an accessory was developed that adds 840 cc thermally isolated volumes to both the high and low test legs. For best results, when operating the low pressure controller, both the high and low ports of the reference transducer are connected to corresponding high and low sides the device or system under test.

The pressure control system allows one controller with ranges of ± 15, 10 and 5 kPa to set pressure with control precision up to $\pm 1 \times 10^{-5}$ of the active span (i.e. ± 0.1 Pa in the ± 5 kPa range). The contribution of control precision to the uncertainty in the pressure controller's delivered pressure is therefore negligible. The typical time to set and stabilize a pressure is 30 seconds.

SPECIFIC LOW DIFFERENTIAL PRESSURE FEATURES

The low pressure controller has a number of special features developed to meet the requirements of low pressure control.

Relative to a very low differential pressure range, the instability of atmospheric pressure may make it impossible to set true zero differential by independently opening the two test legs to atmosphere. To assure that zero differential is achieved when it is desired, an internal bypass valve is included [Figure 4]. The valve is located as close as possible to the reference transducer to assure that it can be properly zeroed. It also assures zero differential across the device under test. Operation of the bypass valve is fully automated and coordinated with the controller "zero" and "vent" commands so its use is transparent to the operator.

As discussed above, to improve pressure control stability, both the high and low sides of the reference transducer should be connected to the system or device under test and isolated from atmospheric pressure. However, when the low side is isolated from atmosphere, the pressure in the low side may become undesirably different from atmospheric pressure. For example, if the devices under test are in an environmental chamber and the temperature is varied by a large amount, the pressure in the closed low side of the test could change significantly as the gas expands or contracts. To keep the low side pressure near atmospheric pressure, a separate low side vent valve is included to independently open the low side to atmosphere [Figure 4]. When the controller is executing fine pressure control at the pressure set point, the valve is closed, shutting off the low side from atmospheric pressure noise. Whenever the controller is slewing between points or setting zero differential, the low side vent valve is opened, equalizing the low side to atmospheric pressure.

Finally, a barometer is connected to the transducer's low pressure side to monitor the applied static pressure. The pressure read by the barometer is used in an algorithm that compensates the reference differential pressure transducer for static pressure.

APPLICATION OF THE CONTROLLER

The new low differential pressure controller/calibrator has been used in both the calibration laboratory and in production pressure transmitter characterization. Results of the calibration of a industrial differential pressure transmitter in the range of 0 to 5 kPa are shown in Figure 5.

Figure 5 plots the difference between the device under test and the pressure controller/calibrator for a repeated 20% increment ascending/descending sequence. Note that the system repeatability, including repeatability of the device under test, is within ± 0.4 Pa for all data points which is 4 x 10^{-5} of the range of the DUT and 2 x 10^{-5} of the controller range span.

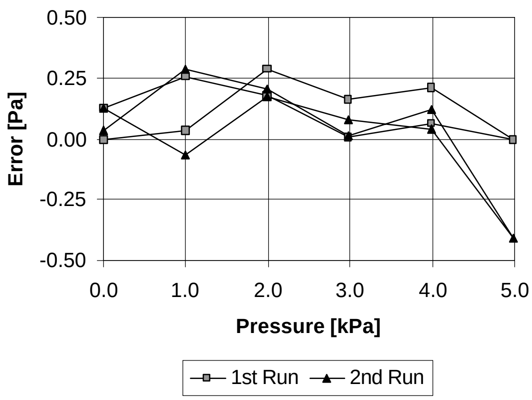

Fig. 5 *Pressure transmitter errors relative to the low pressure controller/calibrator*

CONCLUSION

The pressure controller/calibrator discussed in this paper, designated PPC2+ BG0002, provides high performance and relative insensitivity to ambient conditions in a rugged, easily transportable transfer standard. These capabilities in the range of differential pressure of a few kPa around atmosphere are welcome in both pressure calibration laboratories and production pressure device characterization facilities. It is expected that, as additional experience is gained over time using the new low pressure force balanced piston gauge to calibrate the transfer standard, its measurement uncertainty will be reduced.

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[4] United States Patent No. 5,142,483.